University of Antwerp

What role for rail in urban freight distribution?

A dissertation submitted

by

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What role for rail in urban freight distribution?

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Abstract

Many national and international institutions encourage the use of environment-friendly transport modes. Subsequently, local authorities take increasing measures to prevent negative transport-related externalities in urban areas. Hence, logistics service providers consider alternative ways to deliver goods in urban areas. Which alternative mode is appropriate depends on multiple factors, including the available transport infrastructure, the freight volume, the time of the transport, the measures taken by the authorities and the presence of congestion.

This doctoral thesis focuses on urban freight distribution by rail and the conditions for a successful implementation. The potential success is studied from a financial, economic and a socio-economic perspective for a dedicated freight vehicle, a freight wagon attached to a passenger vehicle and the transport of freight alongside passengers. The government's viewpoint is adopted. A generic tool is created, by developing a tailor-made social cost-benefit framework and investigating the rail freight product in depth. The generic framework is applied to a case study for the use of a tram in the city of Antwerp.

The main lessons to be learned are twofold. Firstly, the good environmental performance of rail and the presence of congestion on the road network favours the shift from road to rail transport. The interference with passenger traffic, resistance from different stakeholders, initial investment needed and commitment of different stakeholders are disadvantageous for rail transport. Secondly, attaching a freight wagon to a passenger vehicle shows, ceteris paribus new innovations, more potential than using a dedicated freight vehicle. This is related to the lower rail operational costs. The transport of freight alongside passengers also reveals some potential, but this is only an option for small quantities of goods.

This doctoral dissertation adds to the existing body of knowledge in several ways. Firstly, the research makes an original contribution to scholarly theory. A unique characteristic of this research is the fact that the framework is developed for an urban rail freight context, and the viewpoint of the government is adopted. The key strength is the development of a generic tool which can easily be applied to different worldwide cases. Secondly, the developed tool provides policy makers the boundaries for an adapted policy towards for example subsidies. The results of this research show the benefits to society of a modal shift from road to rail. Thirdly, the framework helps private actors to understand under which conditions shifting from road to rail can become interesting for them.

Nederlandstalig abstract

Veel nationale en internationale instellingen moedigen het gebruik van milieuvriendelijke transportmodi aan. Lokale overheden nemen bovendien steeds meer maatregelen om negatieve transportgerelateerde externaliteiten in stedelijke gebieden te voorkomen. Bijgevolg zoeken logistieke dienstverleners naar alternatieve manieren om goederen te leveren in stedelijke gebieden. Welke alternatieve transportmodus geschikt is, hangt af van verschillende factoren, zoals de beschikbare transportinfrastructuur, het goederenvolume, de timing van het transport, de maatregelen genomen door de autoriteiten, en de aanwezigheid van congestie.

Dit doctoraatsonderzoek focust op stedelijke distributie door spoorvervoer, en de voorwaarden voor een succesvolle implementatie ervan. Het potentieel succes is onderzocht vanuit een financieel, economisch en socio-economisch perspectief en dit voor een vrachtvoertuig, een vrachtwagon die aan een reizigersvoertuig is vastgemaakt en het transport van goederen in een reizigersvoertuig. Het overheidsperspectief werd aangenomen. Een generiek instrument is gecreëerd, door een op maat gemaakt maatschappelijk kosten-batenkader te ontwikkelen en het spoorvrachtproduct in detail te onderzoeken. Het generieke model is toegepast op een gevalstudie voor het gebruik van een tram in de stad Antwerpen.

De belangrijkste lessen uit dit onderzoek zijn tweevoudig. Ten eerste vormen de goede milieuprestatie van spoorvervoer en de aanwezigheid van congestie op het wegennet gunstige condities om over te schakelen van weg- naar spoorvervoer. De interactie met het reizigersvervoer, weerstand van verschillende belanghebbenden, vereiste initiële investeringen, en de betrokkenheid van verschillende belanghebbenden zijn daarentegen in het nadeel van spoorvervoer. Ten tweede toont het vasthechten van een goederenwagon aan een reizigersvoertuig, ceteris paribus nieuwe innovaties, meer potentieel dan het gebruik van een vrachtvoertuig. Dit is gerelateerd aan de lagere operationele spoorkosten. Het transport van goederen in een reizigersvoertuig toont ook potentieel, maar dit is enkel een optie voor kleine hoeveelheden.

Deze doctoraatsthesis draagt op verschillende vlakken bij aan de reeds bestaande kennis. Ten eerste levert dit onderzoek een originele bijdrage aan de wetenschappelijke literatuur. Een unieke eigenschap van dit onderzoek is het feit dat het kader ontwikkeld is voor een stedelijke spoorvrachtcontext, en dat het perspectief van de overheid werd aangenomen. De belangrijkste troef is de ontwikkeling van een generiek instrument dat gemakkelijk kan worden toegepast op verschillende wereldwijde gevalstudies. Ten tweede biedt het ontwikkelde instrument een vork aan voor beleidsmakers om een aangepast beleid te voeren richting bijvoorbeeld subsidies. De resultaten van dit onderzoek tonen de baten aan voor de maatschappij van een modale verschuiving van weg- naar spoorvervoer. Ten derde helpt dit kader private spelers om te begrijpen onder welke omstandigheden een verschuiving van weg- naar spoorvervoer interessant begint te worden voor hen.

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Abbreviations

ADEME	Agence De l'Environnement et de la Maîtrise de l'Energie
APUR	Atelier Parisien d'Urbanisme
B2B	Business-to-Business
B2C	Business-to-Consumer
BART	Bay Area Rapid Transit
BAU	Business-As-Usual
BCR	Benefit-Cost Ratio
CAPM	Capital Asset Pricing Model
CH_4	Methane
CL	Crowd Logistics
$CO_{(2)}$	Carbon (di)Oxide
CNR	Comité National Routier
CPI	Consumer Price Index
CS	Consumer Surplus
DB	Deutsche Bahn
DC	Distribution Centre
DM	Deutsche Mark
DRIEA	Direction Régionale et Interdépartementale de l'Equipement et de l'Aménagement d'Ile-de-France
DVB	Dresdner VerkehrsBetriebe
EBITDA	Earnings Before Interest Taxes, Depreciation and Amortisation
EBT	Earnings Before Taxes
EC	EuroCity
ECB	European Central Bank
ENPV	Economic Net Present Value
ERR	Economic internal Rate of Return
ERZ	Entsorgung und Recycling Zurich
ETA	Estimated Time of Arrival
EU	European Union
FaaS	Freight as a Service
FFC	Fresh Food Centre
FNPV	Financial Net Present Value
FOT	Freight On Transit
FOT-EX	Freight On Transit on Existing public transport services
FOT-NEW	Freight On Transit on New freight trips
FRR	Financial internal Rate of Return
FTE	Full Time Equivalent
GC	Generalised Cost
GDP	Gross Domestic Product
GLEC	Global Logistics Emissions Council
GVB	Gemeentelijke VervoerBedrijf
H&S	Handling and Storage point
HC	HydroCarbon

IAU	Institut d’Aménagement et d’Urbanisme
IC	InterCity
ICE	InterCity-Express
ISO	International Organisation for Standardisation
IT	Information Technology
ITU	Intermodal Transport Unit
IRR	Internal Rate of Return
JIT	Just In Time
LCA	Life Cycle Assessment
LGV	Light Goods Vehicle
LRV	Light Rail Vehicle
MaaS	Mobility as a Service
MPC	Marginal Private Cost
MSC	Marginal Social Cost
MUDC	Multimodal Urban Distribution Centre
N_2O	Nitrous Oxide
NACE	Nomenclature statistique des Activités économiques dans la Communauté Européenne
NB	Net Benefits
NBB	National Bank of Belgium
NGV	Natural Gas Vehicle
NMVOS	Non-Methane Volatile Organic Compounds
NO(x)	Nitric Oxide
NPV	Net Present Value
O/D(O)	Origin-Destination(-Origin)
Pb	Lead
PCC	Presidents’ Conference Committee
PI	Physical Internet
PM	Particulate Matter
POP	Population
PPI	Purchasing Power Index
ppm	Parts per million
PPP	Public-Private Partnership
P+R	Park and Ride
PVTCR	Present Value To Capital Ratio
RATP	Régie Autonome des Transports Parisiens
RER	Réseau Express Régional
(S)CBA	(Social) Cost-Benefit Analysis
SF_6	Sulfur hexafluoride
SNCF	Société Nationale des Chemins de fer Français
SNPV	Social Net Present Value
SO_2	Sulfur (di)Oxide
SRR	Social internal Rate of Return
SULP	Sustainable Urban Logistics Plan
SWOT	Strengths, Weaknesses, Opportunities & Threats

TP	Transit Platform
UCC	Urban Consolidation Centre
UITP	Union Internationale des Transport Publics
UK	United Kingdom
ULF	Ultra-Low Floor
US(A)	United States (of America)
VAT	Value Added Tax
VBZ	VerkehrsBetriebe Zurich
VITO	Vlaamse Instelling voor Technologisch Onderzoek
VOC	Volatile Organic Compounds
VoT	Value of Time

1. Introduction

Many different types of goods are transported to and delivered in cities, involving several sectors and multiple types of goods flows. The logistics of small retail shops in cities is for example characterised by a large number of delivery locations with very limited cargo. This results in many vehicle movements generated by vans and city trailers, often with a low load factor (Quak & de Koster, 2008). The transport and delivery of goods results in private and external costs, such as congestion and air pollution. Congestion reduces the reliability of deliveries and implies that more and more vans are put into service to preserve an acceptable reliability, in many cases with a lower load factor (Allen, Browne, & Cherrett, 2012). As a consequence, emissions are increasing and the cost per stop, being both a private and a public cost, increases. These issues related to urban freight distribution are likely to increase in the future.

This chapter provides the rationale for investigating the role of rail for urban freight distribution (Section 1.1), the research objective and research questions (Section 1.2), the scope of the research (Section 1.3), the methodology used (Section 1.4), and the outline of the thesis (Section 1.5).

1.1 Rationale and background

The rationale for investigating the role of rail for urban freight distribution comes from the challenges that urban freight distribution is facing, changing policies related to urban freight distribution and the fact that urban rail infrastructure is available in many urban areas, but often not fully used by passengers.

1.1.1 Trends and urban freight distribution challenges

Urban freight distribution is affected by several trends, such as growing population and urbanisation, and growing freight transport (European Commission, 2018b; United Nations, 2018c). The world population amounted to 7.7 billion people in mid-2019, while the medium-variant forecasts predict a world population of 8.5 billion people by 2030, 9.7 billion people by 2050 and 10.9 billion people by 2100 (United Nations, Department of Economic and Social Affairs, Population Division, 2019). Specifically for Belgium, the population is expected to grow from 11,376,070 inhabitants in 2018 to 11,887,072 inhabitants in 2030 and 13,226,178 by 2070 (Federaal Planbureau, 2019).

Concerning urbanisation, 55% of the people worldwide are living in urban areas in 2018, whereas this share is expected to grow to 68% by 2050. In Belgium, 98.0% of the population lives in an urban area in 2019. By 2050, this share is forecasted to grow to 98.9% (United Nations, 2018a). The growing population and urbanisation result in more passenger movements and this amongst others in urban areas. Moreover, the derived demand for freight transport is growing (Meersman et al., 2015). Total freight transport in Belgium by lorry for instance is expected to grow from 467 million tonnes in 2015 to 543 million tonnes in 2040 (Daubresse, Hoornaert, & Laine, 2019).

Congestion and air pollution in city centres are unwanted consequences of the growing passenger and freight transport. Specifically for Belgium, the European Commission (2019) highlights the fact that growing transport volumes are putting pressure on the existing transport infrastructure. Belgium is one of the most congested countries within Europe. Moreover, the country has with around 55 road fatalities per million inhabitants a higher road fatality rate than the average of the EU-28 Member States in 2017.

In sum, growing population, urbanisation and freight transport leading to unwanted externalities such as congestion, make it more and more challenging to reach urban premises by road transport.

1.1.2 Urban freight distribution policy

The transport and logistics sector contributes to the worldwide CO_2-emissions. Hence, many European governments are trying to implement policies to prevent negative impacts of freight transport in and around cities (Davydenko, Ehrler, de Ree, Lewis, & Tavasszy, 2014). In this context, many national and international institutions, such as the European Commission (2011, 2018b) and the United Nations (2018b), encourage the use of environment-friendly transport modes.

The European Commission (2011) encourages national governments in its Transport White Paper to introduce policies to optimise freight transport in and around cities. More specifically, the European Commission (2019) recommends its Member States to invest in alternative modes of transport. For Belgium in particular it is recommended to do this especially around amongst others Antwerp. The modal split for land freight transport in Belgium in 2016 is as follows: 71.9% road transport, 15.1% inland navigation, 10.6% railways and 2.4% pipelines. Compared to the EU-28 share of rail transport of 16.6%, Belgium lags behind (European Commission, 2018a). Ruesch (2001) also indicates the need for the development of innovative rail freight distribution concepts and Behrends (2012a) too suggests to use more environmentally friendly transport modes such as rail transport.

At local and national level, more and more measures are taken by authorities challenging road transport (Cruz & Montenon, 2016; Gevaers, 2013; Letnik, Marksel, Luppino, Bardi, & Božičnik, 2018). Examples are the introduction of road pricing and low emission zones, to prevent negative transport-related externalities in urban areas (Cavallaro, Giaretta, & Nocera, 2018; Chang, Tseng, Hsieh, Hsu, & Lu, 2018; Maes, Sys, & Vanelslander, 2011b). The introduction of these progressive measures restricting road transport possibilities can even lead to more vehicle movements (Quak & de Koster, 2008).

On the other hand, an increasing sustainability awareness exists amongst different urban freight stakeholders. Specific initiatives taken are deliveries during off-peak hours (José Holguín-Veras, Wang, Browne, Hodge, & Wojtowicz, 2014), using urban distribution centres (Browne, Allen, & Leonardi, 2011; van Duin, Slabbekoorn, Tavasszy, & Quak, 2018) and using other modes of transport, for example electric vehicles (van Duin, Tavasszy, & Quak, 2013), inland waterways (Mommens, Lebeau, & Macharis, 2014) and railways (Arvidsson & Browne, 2013).

1.1.3 Available urban rail infrastructure

Many urban areas in the world possess rail infrastructure. However, this infrastructure is anno 2019 often only used for passenger transport. This used to be different in the past. Until the first half of the twentieth century, goods were daily transported in Belgium by tram (Annys et al., 1994). In 1885, liquor was transported by the Vicinal Railways in Antwerp. In general, the Vicinal Railways had an unloading platform in the centre of a village or city. Retailers that wanted to transport goods, could rent a tram wagon from the Vicinal Railways. The retailer loaded the wagons, which were then transported by the operator. Several types of goods were transported, including for instance milk, living stock and glass windows (Henrard, 1985).

Before 1900, almost no dedicated freight trams were used. Some freight wagons were instead added between the locomotive and passenger wagons. After 1900, dedicated freight trams were implemented (Henrard, 1985). In Tienen, sugar beets were transported by tram from the land to the refinery (Centrum Agrarische Geschiedenis, 2016). Construction materials for large transport infrastructure projects were also transported by the Vicinal Railways. Between 1908 and 1913, 39% of the income of the Belgian operator was related to freight transport (Henrard, 1985). During World War I and World War II, the railways were used to supply several areas from potatoes, vegetables, coal, meat, cheese, butter and other food products (De Lijn, 2019b; Henrard, 1985). However, during World War I, more than 1,000 km of tracks were destroyed (Infrabel, 2019b) and during World War II, more tracks had to be broken out (De Lijn, 2019b). Since 1930, the use of the Vicinal Railways for freight transport decreased gradually due to the increasing popularity of lorries (Henrard, 1985).

Given the changed environmental conditions anno 2019, including increasing congestion and air pollution issues, it is worthwhile to investigate whether rail transport can again play a role in urban freight distribution. As passenger demand varies during the day, the spare capacity of the urban passenger transport network in off-peak moments could be used to transport freight (Pimentel & Alvelos, 2018). In this context, Chiron-Augereau (2009) examines the potential role of a public transport operator in Paris for urban freight distribution. Ozturk & Patrick (2018) develop a decision support framework for optimised freight transport by urban rail.

Making use of the spare capacity of the urban rail infrastructure and using existing public transport trips to transport freight fits within recent open network ideas such as Crowd Logistics (CL) [1], Freight as a Service (FaaS) and Phyiscal Internet (PI). Crowd Logistics is "*a sharing mobility service and implies delivering goods using the crowd*" (Gatta, Marcucci, Nigro, & Serafini, 2019, p. 1). Freight as a Service is analogous to Mobility as a Service (MaaS) and includes the sharing of resources in order to reduce costs, improve the utilisation rates of available resources (ABI research, 2016), and facilitate a modal shift towards public transport (Smith, Sochor, & Karlsson, 2018). Physical Internet is a concept in which goods are transported in modular freight boxes through interconnected logistics networks (Chargui, Bekrar, Reghioui, & Trentesaux, 2019).

1.2 Research objective and research questions

The growing population and urbanisation, as well as growing freight transport make it more challenging to reach urban areas by road. Moreover, the awareness of the need for more sustainable transport is growing and many urban areas possess rail infrastructure which is not always used at full capacity for passenger transport. In this context, the objective of this doctoral thesis is to investigate what the role of rail transport can be for urban freight distribution. This objective is translated in three research questions:

RQ1: What are the main success and failure factors of urban rail freight?
RQ2: What is the potential of urban rail freight from a financial and economic viewpoint?
RQ3: What is the potential of urban rail freight from a socio-economic viewpoint?

These three research questions are examined throughout this doctoral dissertation.

1.3 Scope

The potential role of rail for urban freight distribution is investigated in this research. Urban freight distribution is defined here as the transport of goods to, from and within urban areas by or for commercial or public entities. An urban area is considered a (nearly) continuous compact area, with a certain minimal population density, of which a large proportion consists of commercial activities such as retail activities. An urban area in this research can as well be a small area with a high concentration

[1] Other terms used for Crowd Logistics are cargo hitching, collaborative logistics, crowdshipping or crowdsourced delivery (Buldeo Rai, Verlinde, Merckx, & Macharis, 2017).

of shops, as a large area with a lower concentration and this area does not necessarily equal the legal city boundaries. Rail transport is defined here as the use of trams or trains. Moreover, a distinction is made between the use of a dedicated freight vehicle, a freight wagon attached to a passenger vehicle, and the transport of parcels alongside passengers.

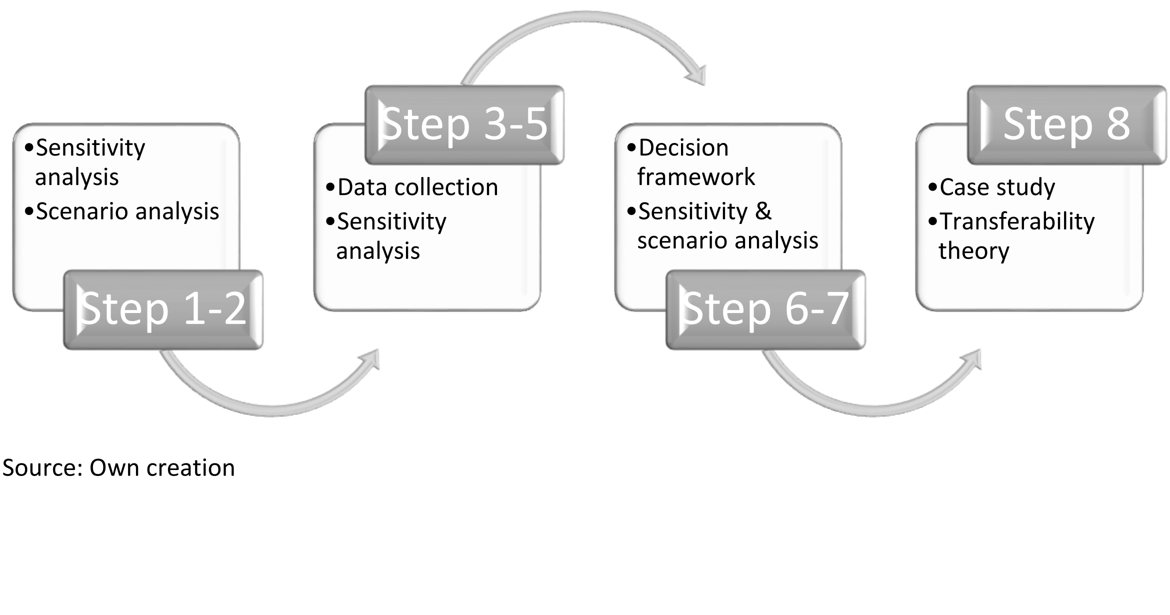
A literature review over the period 1995-2018 is carried out, covering the worldwide body of knowledge. The model developed in this dissertation has a generic design, meaning that it can be applied to different urban areas, different types of rail transport and different case studies within the same environment. An application of the model for the urban freight distribution of a retailer in Antwerp is presented.

The analysis is done from the viewpoint of a project leader, which is in this research the government. The viability of a rail-based urban freight project is examined from a financial, economic and socio-economic point of view. In the financial analysis, the return on capital is calculated. The economic analysis determines the return on investment. Ultimately, the socio-economic analysis examines the effect of the rail-based project on the society as a whole.

1.4 Methodology

A social cost-benefit framework is developed specifically for this research. In order to do so, the rail freight product is analysed in depth with respect to the time costs and out-of-pocket costs, and a generic model is tailor made by reframing the cost-benefit methodology for this research. Figure 1 shows the eight steps of the SCBA-framework, which consists of eight steps. For each step, it is indicated in Figure 1 which additional methods are used to complete the step. In the first step, the reference case and the set of project cases are identified. In the second step, it is decided whose costs and benefits have to be taken into account, i.e. the viewpoint of the analysis is defined. Sensitivity and scenario analyses are applied to these two steps. In step 3, the impacts of the project case are specified and in step 4, they are quantified and monetised. In step 5, the costs and benefits are discounted to present values. In order to fulfil steps 3-5, data are collected and sensitivity analyses are performed. In step 6, each project case is evaluated and in step 7, uncertainty and risk are dealt with. This is done based on a decision framework and sensitivity and scenario analyses. Ultimately, in step 8, recommendations are made based on the application of the framework to a case study and the transferability of the model and the main findings are discussed.

Figure 1 – Methods applied next to the social cost-benefit framework

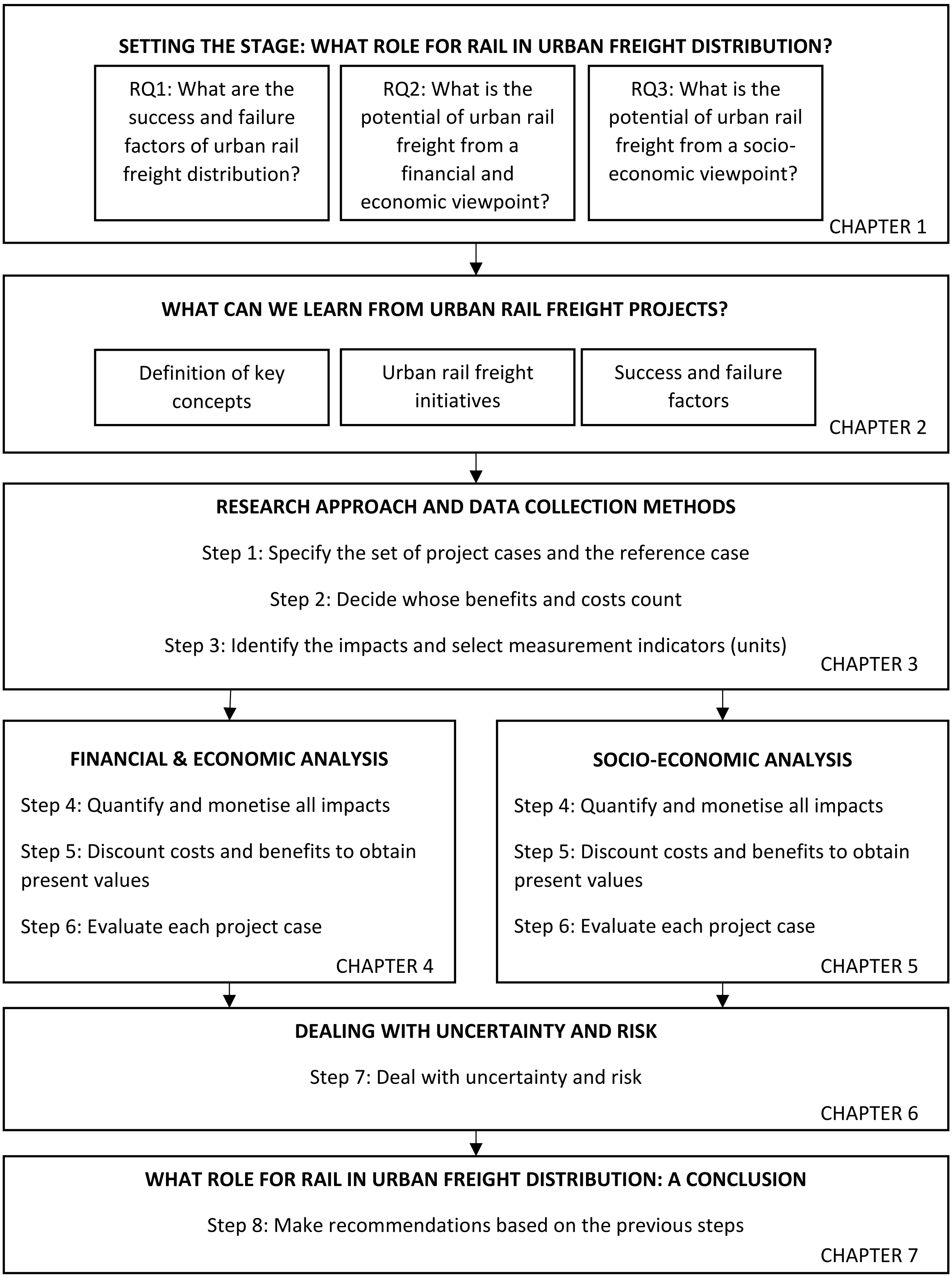


Source: Own creation

1.5 Outline of the thesis

This thesis is structured as shown in Figure 2. In the **current chapter**, the background for this research is explained, the objective of the research is made clear and the research questions are defined. Moreover, the research scope is set and the methodology used is presented.

Figure 2 – Outline of the thesis



Source: Own creation

In **Chapter 2**, experiences with urban rail freight projects are reviewed. Before discussing different urban rail freight projects, the key concepts used in this research are defined. Next, several existing and past urban rail freight initiatives are reviewed, from which success and failure factors of using rail transport for urban freight distribution are identified. This literature review gives a first response to research question 1.

In **Chapter 3**, the research approach and data collection methods are elaborated on. The social cost-benefit framework that is developed for this research is discussed in detail. Moreover, the necessary background information to conduct sensitivity and scenario analyses is provided and the different methods used to collect data are explained. Ultimately, the case study environment in which the social cost-benefit framework is applied is introduced. In particular, this chapter focuses on steps 1-3 of the social cost-benefit framework.

Chapter 4 offers the financial and economic analysis of urban rail freight by focussing on steps 4-6 of the social cost-benefit framework. The financial and economic costs of using rail for urban freight distribution are identified, as well as the benefits. Subsequently, an urban rail freight case study for a retailer owning three shops in Antwerp is conducted. The use of a dedicated freight tram, a freight wagon attached to a passenger tram, and the transport of parcels alongside passengers is appraised. The insights from this chapter provide the first part of the answer to research question 2.

In **Chapter 5**, the analysis is extended by adopting the socio-economic viewpoint. The effects of the project on its users and impactees are added. External cost savings play a major role in this perspective. The same case study as in Chapter 4 is used in order to evaluate the use of a dedicated freight tram, a freight wagon attached to a passenger tram and the transport of parcels alongside passengers from a socio-economic perspective. This chapter assists in responding to research question 3.

Uncertainty and risk that originate from different assumptions made when developing and applying the framework are dealt with in **Chapter 6**. This corresponds to step 7 of the social cost-benefit framework. Sensitivity and scenario analyses are developed and carried out in order to give a more extended and more robust reply to the three research questions proposed.

Ultimately, **Chapter 7** provides the conclusion of this research. The main findings are summarised, and it is explained how they can be generalised. Moreover, the transferability of the social cost-benefit framework to other case studies, other urban areas and other rail types is explained. The developed tool is generic and can be applied to any urban rail-freight project. The contribution of the research to scholarly theory, policy and practice is highlighted and ultimately, some interesting avenues for further research are indicated.

The list of abbreviations used in this thesis is provided on page xviii-xx, and all appendices are added at the end of this dissertation.

2. What can we learn from urban rail freight projects?

Urban rail freight transport is not a new concept, but already exists for a while. Examples dating from the nineteenth and twentieth century in amongst others Belgium show that trams were used to carry food products, but also living stock, and construction materials. Due to the increasing popularity of the car and lorry, and because many tracks were destroyed during World War I and World War II, urban freight transport by tram gradually lost attraction in Belgium (Annys et al., 1994; Henrard, 1985). Since the late 1990s and the first years of the twenty-first century, new rail-based urban freight projects are popping up all over the world. Anno 2019, some of them are still operational, while others failed.

This chapter provides insights in experiences with urban rail freight projects. Firstly, the key concepts of the present research are defined in Section 2.1 in order to make it clear what exactly is examined in this doctoral thesis. Secondly, urban rail freight projects are explained in Section 2.2. This section provides an overview of the available academic literature on this topic, which is extended by information from non-academic sources. Thirdly, the main success and failure factors of using rail for urban freight distribution are derived in Section 2.3. Section 2.4 provides the conclusion of this chapter.

2.1 Definition of key concepts

In order to examine the role of rail in urban freight distribution, it is necessary to clarify the key concepts of this research, being urban freight distribution and rail.

2.1.1 Urban freight distribution

Urban freight distribution seems a clear-cut term. However, in the literature, different terminologies are used, each with their own scope, ranging from city or urban logistics, over city or urban (freight) distribution, to urban freight or goods transport, and urban freight or goods movement. The terminology used by different authors does not always comprise the same activities. Alessandrini et al. (2012) for example use the term "urban freight distribution" to talk about bringing goods towards the city centre, whereas Regué & Bristow (2013) use "urban goods distribution" to describe the transport of goods within a city centre. Another observation is that some authors, such as Genta et al. (2006), Gorçun (2014), Strale (2014), Cleophas (2018) and Ozturk & Patrick (2018), use different terms for the same concepts. Moreover, no clear evolution over time can be noticed. All terms are used in older papers (starting from 1995) as well as in more recent papers (until 2018). Appendix 1 provides an overview of the different terms for delivering goods in urban areas using rail transport. The term "urban freight distribution" is chosen in this research, because it covers both train (Alessandrini et al., 2012) and tram (Arvidsson & Browne, 2013) transport towards the city centre and within the city centre (Regué & Bristow, 2013). Moreover the term "urban" is more often used than "city" (see Appendix 1).

Besides multiple terms, different definitions of urban freight distribution are available in the literature. Ogden (1992) defines urban goods movement as "*the movement of things (as distinct from people) to, from, within, and through urban areas*". Taniguchi et al. (1999) define urban freight distribution as "*the process for totally optimizing the logistics and transport activities by transport companies in urban areas while considering the traffic environment, the traffic congestion and energy consumption within the framework of a market economy*". De Munck & Vannieuwenhuysse (2008) describe urban freight distribution as follows: "*Urban freight distribution encompasses all freight transport with origin or destination in the city, both from or to entrepreneurs and public institutions in the city as the inhabitant-*

consumer. Besides transport, other logistics activities are important, such as loading, unloading, consolidating and value added activities". Dablanc (2009) defines urban freight distribution as "*a segment of freight transport which takes place in an urban environment*. … *[It] is the transport of goods by or for commercial entities (as opposed to households) taking place in an urban area and serving this area*". In the strategic plan for freight transport in Brussels, "*urban freight distribution comprises the logistics activities and the transport of goods for supplying companies, institutions and other consumers in an urban environment. It encompasses all deliveries to and from cities … as well as the transport of goods produced by Brussels companies.*" (Regering van het Brussels Hoofdstedelijk Gewest, 2012).

Based on Ogden (1992) and Dablanc (2009), urban freight distribution is defined here as the transport of goods to, from and within urban areas by or for commercial or public entities. In contrast to Ogden (1992), transit traffic is only taken into account in this research as an external factor influencing urban freight distribution. The difference with respect to the definition provided by Dablanc (2009) is the more explicit mentioning that goods can be transported within and away from urban areas. This corresponds to the classification of journey types made by Allen et al. (2012): to the urban area from elsewhere, from the urban area to elsewhere and completely within the urban area.

Taniguchi (2001) identifies three main factors defining urban freight distribution: the stakeholders, the spatial factor and the economic, energetic, environmental, financial and social impacts. The latter are measured in the following chapters. The main stakeholders involved in urban freight distribution as well as the spatial factor, i.e. the urban area and the freight corridors, are discussed more in depth in the following subsections.

2.1.1.1 Stakeholders

Urban freight distribution involves different stakeholders. Behrends (2012a) indicates that many actors with a large amount of interactions and different interests exist within urban areas. Moreover, Regué & Bristow (2013) state that different stakeholders are influenced by different costs and benefits of a certain measure. Therefore, it is necessary to have an overview of the stakeholders involved in urban freight distribution.

The main stakeholders concerning urban freight distribution are identified by Taniguchi (2001) as the carriers, the community, the government and the shippers. Quak (2008) sees three important players in this segment, being governmental actors, professionals and impactees. Behrends (2012a) uses the same categorisation of stakeholders as Taniguchi (2001), dividing them in shippers and receivers of goods, transport operators, inhabitants and authorities. These actors are characterised by a large amount of interactions and different interests. Wolpert & Reuter (2012) identify the same stakeholders as Taniguchi (2001), being carriers, public authorities, receivers, residents and shippers. Cleophas et al. (2018) divide the stakeholders in businesses, citizens, logistics service providers and the public sector.

In this research, the shippers and receivers, logistics operators, impactees and public actors are identified as the main stakeholders. The shipper and/or receiver of the goods on the one hand and the transport operator on the other hand can be a different actor. Consequently, these stakeholders experience different costs and benefits when shifting from road to rail and hence, they are seen as two separate categories in this thesis. The term "impactees" is preferred over "inhabitants", since also people who do not live in the urban area can be affected by urban freight distribution. The main actors are now described in more detail.

2.1.1.1.1 Shippers and receivers

Shippers and receivers are important private actors involved in urban freight distribution. The shippers are in this research the suppliers, who want their goods to be delivered at their customers. In other words, the shippers are at the origin of the goods that are transported. The receivers are the customers, located in an urban area at the destination of the transported goods, who get the goods sent by the shippers. The shipper or the receiver pays for the transport of the goods from one actor to the other one (Dablanc, 2007; Quak, 2008).

2.1.1.1.2 Logistics operators

Logistics operators are the second private actor involved in urban freight distribution. The term "logistics operators" is chosen here instead of "transport operators" to make it clear that logistics service providers also belong to this category. Logistics operators offer transport and logistics services that are demanded by shippers and receivers of goods (Behrends, 2012a). The transport services can be performed by different transport modes, in this research being road or rail transport, as well as cargo bikes for the potential road post-haulage after the rail leg. Manufacturers of vehicles also belong to this category.

2.1.1.1.3 Impactees

Impactees are all inhabitants of cities, all people who work there, and users of the city. The latter is a group of stakeholders that makes use of some urban facilities, such as bars, museums, shopping malls, etc. These stakeholders are affected by transport operations, in the sense that these have an impact on the liveability in the city (Behrends, 2012a; Quak, 2008).

2.1.1.1.4 Public actors

Tsolakis & Naudé (2008) state that initiatives in urban freight distribution allow for the involvement of the public sector. These authors argue that the (local) government is one of the main stakeholders in urban freight distribution. Quak (2008) identifies the European Commission, national governments, city authorities and road and traffic authorities as public actors. One of the objectives of local authorities is to minimise the negative external effects of transport in order to conserve a good liveability in the city (Behrends, 2012a). Therefore, they are involved in urban freight distribution. Another public actor is the manager of the rail infrastructure. ERRAC (2012) found that in 2009, around 60% of the infrastructure of light rail in Europe is owned by public authorities, whereas this is only around 30% with respect to the rolling stock.

2.1.1.2 Urban area

Urban areas are important for freight distribution. Christaller (1933)[2] shows that cities are interesting places for suppliers because of the high population density. Loopmans et al. (2011) agree with this, since the increase of population density is a measure for the growth of facilities. However, some comments have to be added here. Firstly, suppliers can also gain advantages by establishing themselves at remote locations in view of having a monopoly for a certain area. Secondly, the central place location is for a company not the only choice factor for a certain area (Saey, 1990). Krugman (1993) states that companies tend to position their subsidiaries at places where the accessibility to the market is adequate. On the other hand, the accessibility to the market is higher at places where more

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[2] This study is included, since it is the reference work with respect to location theory. However, the central place theory is more recently discussed and adapted by authors such as Hesse (2010) and Taylor, Hoyler & Verbruggen (2010).

firms are located. This loop is one of the drivers behind urban centres. Hesse (2008) also pointed out the crucial role of cities for the exchange of goods. In later research (Hesse, 2013), this author added that cities have always been connected to trade and are thus by definition central places and gateways to transfer goods and services to the hinterland. Allen et al. (2012) add that goods are often transported towards an urban area and from there to maximum a few final destinations.

In the following paragraphs, the terminology and definition of an urban area is described, followed by an analysis of the characteristics of urban areas. Ultimately, an urban area is defined in a Flemish context.

2.1.1.2.1 Terminology & definition

In order to avoid confusion, the first step when defining urban areas is to agree on the terminology used to refer to them. Different terminologies are used in the literature to describe urban areas. Appendix 2 gives an overview of these different terms used by authors. The studies are ranked chronologically and all tackle issues in an urban context. Different terms are used by different authors, ranging from city and city-region over metropolitan area/centre and metropolis over town to urban area/centre/place/space/zone and urbanised area. Most authors do not provide in their studies a clear definition of what they mean by a specific term. In general, most authors use the term "city" and "urban area".

Cladera et al. (2009, p. 2842) define a metropolis as a "*city of cities*", including all centres and sub-centres. A metropolitan area is then according to these authors an area "*comprising urban sub-systems, characterised by greater or lesser degrees of monocentrism, polycentrism or dispersion*". Tsai (2005) describes first the urban form, after which the author moves on by using the terms metropolitan form, without explaining the difference between these terms or the choice for one of them. Only in the conclusion of her research she mentions the need for a definition of a metropolitan area.

In general, a metropolitan area is assumed to enclose a metropolitan centre or metropolis, or a city (Dessemontet, Kaufmann, & Jemelin, 2010; Krugman, 1993; Parr, 2007; Pflieger & Rozenblat, 2010; Tsai, 2005). When referred to a metropolis or city, the authors mean in most cases the city as the legal, county-based entity, without stating that explicitly. A metropolis is also sensed to be larger than a city. Parr (2007) states that in his research no distinction is made between a "town" and a "city". Riguelle et al. (2007) use the province around the cities as the border of the urban area. The reasoning behind this is that the borders of provinces do not change in the short run. A broader term for an urban area is proposed by Parr (2005) and is called "city-region". The author defines a city-region as "*a territory within which the city and the area surrounding it are engaged in a complex and interrelated set of economic and social interactions*".

In some cases it may be more appropriate to use another definition for an urban area than the legal, county-based one. Galster et al. (2001) suggest the idea to develop a redefinition taking into account density and contiguity criteria. Tsai (2005) suggests that urban areas can comprise rural areas and adds to this that the natural landscape may need to be included in the definition in case the purpose of the analysis is to measure the effect of the metropolitan form on for example travel behaviour. Similar to this statement, the natural landscape may also affect the transport patterns of goods in urban areas. Thus, this criterion should be included in the definition that is developed for this research. Scott (2008) defines a city as "*the dense spatial concentration of human activity*". Brueckner (2011, p. 1) sees a city as a place where jobs are concentrated and thus also includes residences. Cant & Verhetsel (2013) highlight that shopping centres outside the city centres can be seen as commercial cores in another city centre. This insight provides some interesting opportunities for using rail for urban freight distribution in urban areas where shopping centres are located outside the city centre, such as Antwerp.

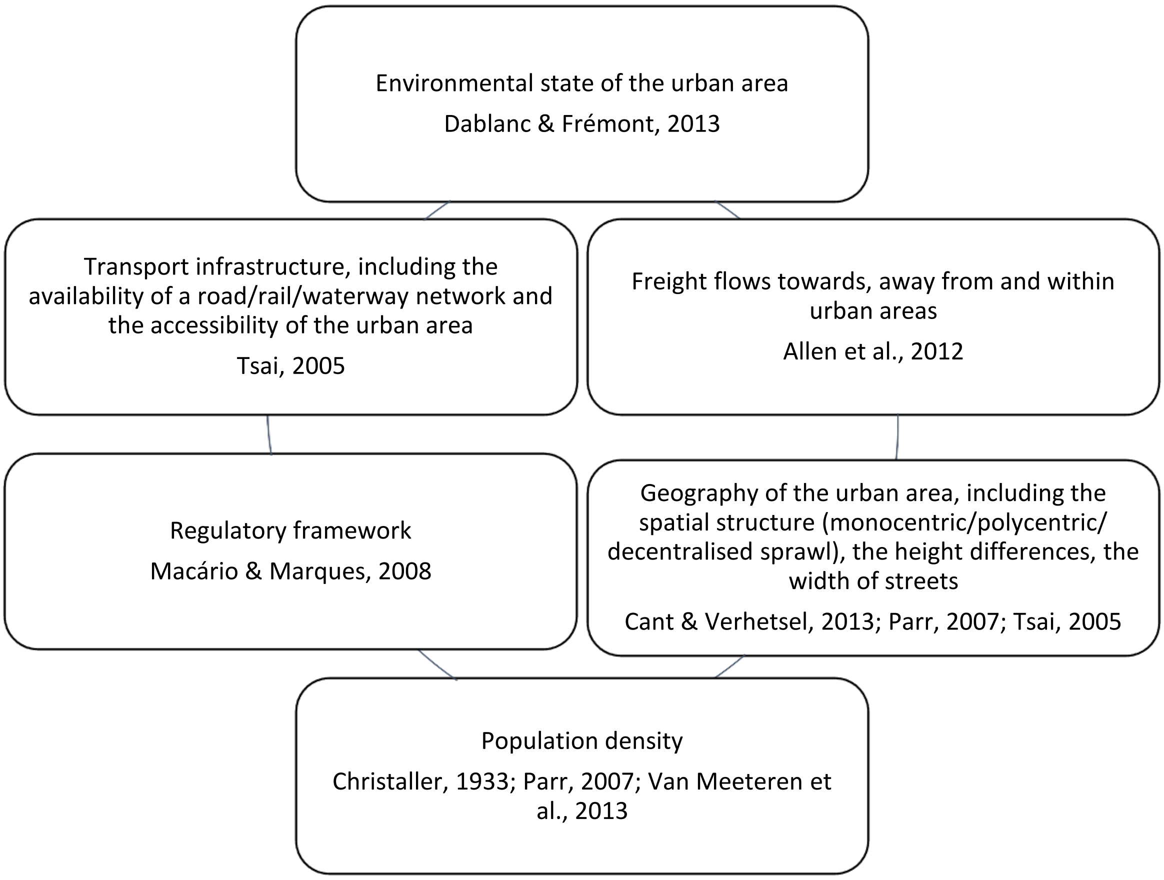
Instead of taking a city or an urban area as measure unit, a “functional economic area” can be used. This area is defined by Berry et al. (1968) as “*all those counties within a labour market, for which the proportion of resident workers commuting to a given central county exceeds the proportion commuting to alternative central counties*”. Following this concept, Hall & Hay (1980) use the term “functional urban region”. The area considered in this concept is thus at region and not at city level. This suggests that when defining the urban area in Flanders, one of the possible options is to consider Flanders as a whole as one functional urban region.

As Clark (1982) states, cities of the same size may have totally different economic functions and vice versa. Parr (2007) confirms that a general definition of a city that can be used for all purposes does not exist. The author stresses that a proper definition should be chosen according to the specific problem that is examined. In the current research, the definition of an urban area provided by Van Meeteren et al. (2013), is adapted and becomes “an urban area is *a (nearly) continuous compact area, with a certain minimal population density, of which a large proportion consists of commercial activities such as retail activities*”. An urban area in this research can as well be a small area with a high concentration of shops, as a large area with a lower concentration and this area does not necessarily equal the legal city boundaries. The term “urban area” is chosen, because this is one of the terms that is used the most in the literature relevant for this research (see Appendix 2), and it avoids confusion with the legal meaning of the term “city”.

2.1.1.2.2 Characteristics of an urban area

After defining the term “urban area”, an overview of the characteristics of an urban area can be made. Urban areas are distinct from each other with respect to several features, as discussed in the previous paragraphs. Figure 3 shows the characteristics derived from and applied to cities in which rail was used or is still being used for urban freight distribution. These characteristics are divided in six categories: environmental state, freight flows, geography, population density, regulatory framework and transport infrastructure. Dablanc & Frémont (2013) highlight the importance of the environmental state of the urban area. This includes amongst others air pollution and congestion. Allen et al. (2012) mention the freight flows towards, away from and within urban areas as the second important characteristic describing an urban area. The geography of the urban area includes the spatial structure, such as is the urban area monocentric, polycentric or is there decentralised sprawl, as well as the height differences present and the width of the streets (Cant & Verhetsel, 2013; Parr, 2007; Tsai, 2005). The population density also characterises an urban area (Christaller, 1933; Parr, 2007; Van Meeteren et al., 2013). The regulatory framework, including measures such as time windows, lorry restrictions and low emission zones, is highlighted by Macário & Marques (2008). Ultimately, the transport infrastructure is a critical variable. The availability of a road, rail and waterway network and the accessibility of the urban area are to be considered here (Tsai, 2005).

Figure 3 – Urban area characteristics



Source: Own creation

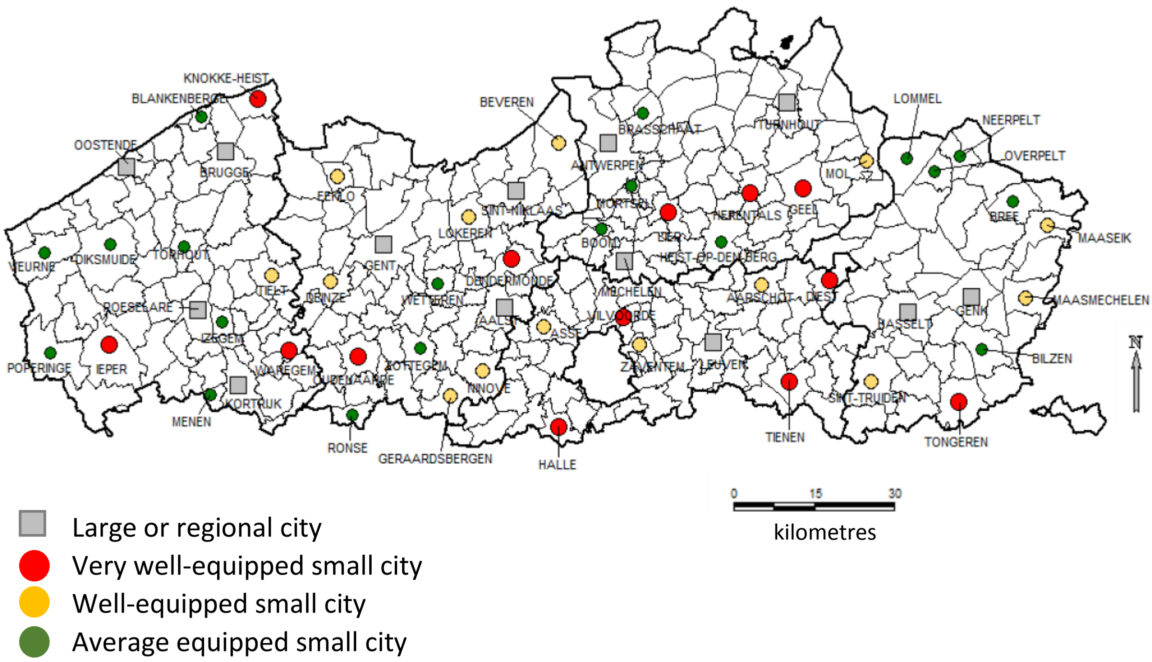
All the characteristics shown in Figure 3 are taken into account in the model that is developed in the following chapters to examine the potential of rail for urban freight distribution. By including these characteristics, the developed model is made generic and hence, is applicable to multiple urban areas. Applying the theory of Quandt & Baumol (1966), in which different transport modes are compared based on their abstract characteristics, urban areas are here defined by means of some characteristics.

2.1.1.2.3 Urban area in a Flemish context

When applying the definition of an urban area to Flanders, the geographical scale of an urban area can vary between a group of retail activities, a legal Flemish city, a region in which several cities are located or Flanders as a whole.

Figure 4 gives an overview of the different city types in Flanders (13,552 km²). It shows that Flanders is a dense area of cities and hence, it could be considered as one urban area. Four types of urban areas are distinguished in Figure 4: large or regional city, very well-equipped small city, well-equipped small city and average equipped small city. Loopmans et al. (2011) classify Ghent and Antwerp as "large city". The cities of Leuven, Bruges, Hasselt, Kortrijk, Mechelen, Ostend, Aalst, Sint-Niklaas, Roeselare, Turnhout and Genk are classified as "regional cities", although the authors state that within this group of regional cities large differences exist with respect to the different functions offered. The other places are considered to be either "small cities" or municipalities. The difference between these two categories is for example the cross-border service. The ten small cities that are the best equipped concerning the different functions taken into account by Loopmans et al. (2011)[3] are Ieper, Dendermonde, Geel, Lier, Halle, Tongeren, Knokke-Heist, Diest, Oudenaarde, Tienen, Waregem, Vilvoorde and Herentals.

Figure 4 – Hierarchy of Flemish cities

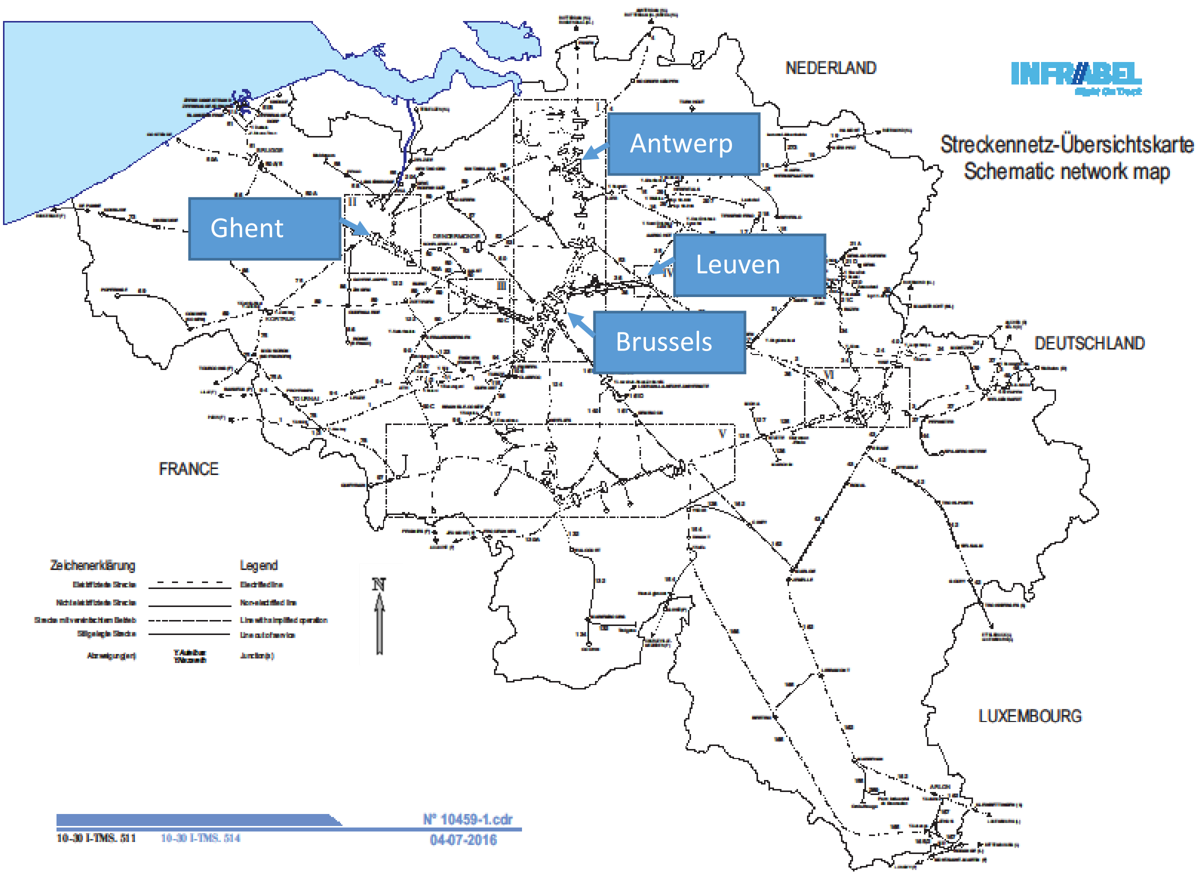


Source: Loopmans et al. (2011, p. 145)

Two additions to Figure 4 have to be made. Firstly, the term “city” corresponds to what Loopmans et al. (2011) see as a “city” and not to the legal definition of a city. Secondly, Figure 4 excludes Brussels, i.e. the white spot on the map, since it does not belong to Flanders from a political point of view. However, Brussels is a main node in the Belgian rail network, strongly connected to the Flemish rail network (see Figure 5). This rail network is mainly concentrated between Antwerp, Brussels, Leuven and Ghent. Thus, when considering Flanders as a whole as one urban area, the Brussels Region has to be added to the urban area when examining the role of rail transport.

[3] These functions are medical, societal and social care, sport, recreation and horeca, services with an office window function, government functions, culture, education, traffic function and retail function.

Figure 5 – Network map of the railway lines in Belgium



Source: Infrabel (2019a)

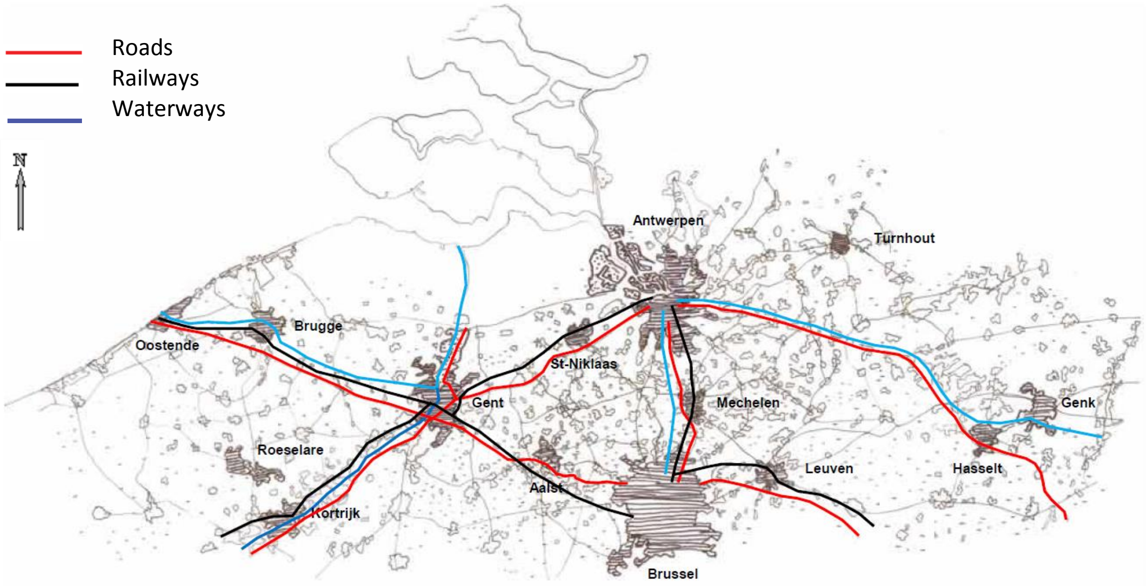
Besides considering Flanders as a whole as one urban area, a specific part of Flanders can be chosen. Depuydt & Van Daele (2012) state that a large number of places in Flanders have a potential for polycentric clustering. The area of Flanders looks polycentric from a morphological, functional and infrastructural point of view. There is an urban structure, consisting of multiple cores, in which functions are spread and infrastructure is fine-grained. From an infrastructural point of view, Flanders is a potential polycentric area that is characterised by multiple transport networks such as roads, railways and waterways. The fine-grained nature of these transport networks, especially of the road and rail network, leads to the fact that Flanders is evolving more in the direction of an urban area than a polycentric area as such (see Figure 6). Therefore, these authors see Flanders as a structure that is more complex than just polycentric and thus something in between an urban area and a polycentric structure. Van Meeteren et al. (2013) argue that Flanders can be seen as a rather polycentric area.

Based on the morphology, Depuydt & Van Daele (2012) distinguish three zones in Flanders, respectively called West-Flanders, Flemish-Brabant & Antwerp, and Limburg[4]. In the zone West-Flanders, the main centres are located at a distance of 40-50 km from each other, small centres at 5

[4] Flanders has anno 2019 five provinces: West-Flanders, East-Flanders, Antwerp, Flemish-Brabant and Limburg. In the distinction suggested by Depuydt & Van Daele (2012), the area called "West-Flanders" covers the province of West-Flanders and a part of the province of East-Flanders, the area "Flemish-Brabant & Antwerp" covers the remaining part of the province of East-Flanders, part of the province of Antwerp and part of the province of Flemish-Brabant, and the area "Limburg" covers the remaining parts of the provinces Antwerp and Flemish-Brabant, as well as the whole province of Limburg.

km. The zone Flemish-Brabant & Antwerp comprises main centres that are located at only 25 km distance from each other, including Ghent, Antwerp, Mechelen, Leuven and Brussels, while the smallest centres are at 2-3 km distance. The zone Limburg only includes two main centres, being Hasselt and Genk. These two cities are located at a distance of 60 km from Brussels, while they are only 30 km removed from Maastricht, a city in the Netherlands.

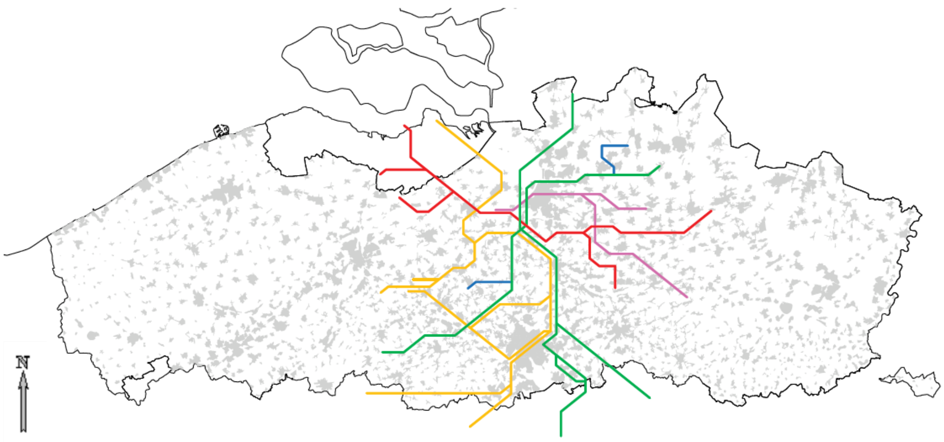
Figure 6 – Linear concentrations along main infrastructure bundles in Flanders



Source: Depuydt & Van Daele (2012)

In this context, Depuydt & Van Daele (2012) pasted the RER (Réseau Express Régional) network of Paris on the map of Flanders. The result of this exercise is shown in Figure 7. The Paris' RER network covers about one third of the Flemish area and hence, a city such as Paris may have some similar characteristics as the central part of Flanders. This central part corresponds roughly to the Flemish Diamond, which is the area between Antwerp, Leuven, Brussels and Ghent and is considered the economic centre of Flanders. Given the fact that also the rail network is the densest in this area, the Flemish diamond has potential to be the most appropriate urban area in Flanders to examine the potential of rail in urban freight distribution.

Figure 7 – The RER network of Paris on the map of Flanders



Source: Depuydt & Van Daele (2012)

At a lower geographical level, a distinction of several urban areas can be made within Flanders. Loopmans et al. (2011, pp. 46–50, 107–109) mapped different functions of the Flemish municipalities. One of these functions is the traffic function, measured by indicators such as railway stations and public transport buses. Depending on the number of railway lines and bus lines, as well as the frequency of the train and bus service, the traffic function of the Flemish municipalities is determined. In 2010, the city of Antwerp had the highest score for this function, followed by Leuven, Ghent, Bruges and Mechelen. An important remark here is that only passenger traffic is included in the traffic function of the municipalities.

Another function analysed by Loopmans et al. (2011, pp. 51–57, 110–125) is the retail function of a municipality. In order to include different sectors in the analysis, a distinction is made based on the NACE-code. Depending on the number of sectors represented in each municipality, the number of shops and the number of different sectors present in each municipality, a total score was calculated. With respect to this function too, Antwerp is the biggest city, followed by Ghent, Bruges, Mechelen and Knokke-Heist.

Van Criekingen et al. (2007) add that a certain area is mono- or polycentric depending on the spatial boundaries that are chosen. The population density in Flemish cities shows a monocentric pattern; the population density increases towards the centre of the city. In cities such as Antwerp, the structure of the city centre is also visible because of the transport infrastructure, i.e. the ring road around the city centre (Van Meeteren et al., 2013).

Cant & Verhetsel (2013) investigated the shop structure of the Antwerp districts. The urban district of Antwerp appears to have a very large and varied commercial core that has attraction till outside the district borders. Besides, the shop density within the district is very high and retail activities are relatively homogeneously spread. Other Antwerp districts are Zandvliet-Berendrecht, Hoboken, Ekeren, Berchem, Wilrijk, Deurne, Borgerhout and Merksem. These districts have a different shop density due to several factors such as the presence of green areas and the capricious borders of the districts. The authors neglect the presence of the port in the Antwerp district, because inclusion would distort the average dimension.

Cant & Verhetsel (2013) use three clusters of retailers developed by the Policy Centre Entrepreneurship and Regional Economics: a large urban cluster, a centre cluster in a small municipality and a street concentration. An example of a large urban cluster is the centre of Antwerp, more specifically for example along the Keyserlei, Meir and the historical centre of the city.

In brief, an urban area in Flanders can be defined as Flanders as a whole, the Flemish diamond, separate cities, or a concentration of shops in a certain area. The second element of urban freight distribution that has to be clarified next to an urban area is the freight flows.

2.1.1.3 Freight flows

Transport flows towards, from and within cities have different characteristics. Allen et al. (2012) state that trips within urban areas are likely to contain more low-volume freight than trips towards urban areas. Furthermore, trips away from urban areas include more empty trips and lower load factors than trips towards urban areas. Many urban areas are net importers of goods. The same authors studied 14 urban areas within the UK and found that only two of them, Bristol and Southampton, are net exporters. Important to note is the fact that these two cities are port cities. Another observation is that flows within urban areas have a shorter distance than the flows to and from urban areas.

Not only is the difference between intra-and inter-urban freight flows important. Existing examples of rail in urban freight distribution show that different types of goods can be transported in this context. Depending on these freight types, the transport conditions and requirements are different. Some goods have temperature restrictions, some goods are transported in low volumes to small shops, while other goods are transported in high volumes to large shops. Depending on the type of goods, the rail transport has to be organised in a different way (Comi et al., 2014). Therefore, different subdivisions of goods are given in the next paragraphs: catchment area and threshold value, supply chain type and weight-driven versus volume-driven freight.

2.1.1.3.1 Catchment area and threshold value

Porta et al. (2012) make a distinction between primary and secondary activities in an urban area. Primary activities have "*a larger-than-local market or catchment area, they are typically highly skilled, larger or more specialised economic activities such as wholesale, industry and those not related to the public or not mainly serving the end-users and their location choice is more likely to be driven by a formal top-down decision-making process*" (Porta et al., 2012, pp. 1477–1479). Secondary activities have "*a local market or catchment area and they are typically retail and services that respond to the ordinary needs of a general public on a daily or regular basis*" (Porta et al., 2012, p. 1479).

Similar to this reasoning, a ranking of goods can be made based on the threshold value, or the minimum turnover needed to be profitable (Christaller, 1933). Goods and services with a high threshold value are typically expensive and infrequently purchased items. Lower on the ranking, goods and services with a lower value appear, which are more frequently used. Ultimately, at the bottom of the ranking low value products can be found that are consumed on a daily basis (Clark, 1982). Tannier et al. (2012) distinguish among two types of shops and services, depending on the potential user frequency. Daily-frequented shops or service centres are bakers, butchers, newsagents, schools and supermarkets/hypermarkets. Weekly-frequented shops or service centres are cafés, doctors, hypermarkets/supermarkets/minimarkets, pharmacists and post offices.

Table 1 gives some examples of goods ranked by threshold value. High threshold value products are only available in the largest urban areas of a region, while low threshold value products are also available in small urban areas.

Table 1 – Goods typology based on the threshold value

Threshold value	Examples
High	Housing products, television
Medium	Pharmaceutical products, hobby products
Low	Groceries, food, catering industry

Source: Own creation based on Clark (1982), Tannier et al. (2011) and Wood and Roberts (2011)

Dablanc and Frémont (2013) state that retailers have a weekly delivery frequency of 4-8 times per FTE employee. Small independent retailers and hotels and restaurants have a weekly frequency delivery of 5-15 times. Chain retailers and shopping centres have less frequent deliveries per m² and their deliveries are more consolidated and transported in vehicles with a higher load factor.

2.1.1.3.2 Supply chain type

Routhier et al. (2001) estimate based on their simulation model FRETURB that 150-200 types of supply chains exist in the city of Paris. This figure corresponds to the number of economic sectors. Dablanc and Frémont (2013) state that these supply chains differ from each other with respect to the operating times, operators and vehicles used. Gevaers (2013) also distinguishes among different supply chains, based on a typology made by Boyer et al. (2005) and Figliozzi (2007). The latter author distinguishes among three types of supply chains: low value and less time-sensitive products, low value and high time-sensitive products and high value and high time-sensitive products. Gevaers (2013) states that different logistics approaches are needed for different product types, i.e. a typology of last-mile subflows is needed corresponding with different freight types.

More specifically, a distinction can be made between fast and slow moving goods. Fast moving goods are too expensive to be stored decentrally. Consequently, they are often transported directly to their final destination without intermediate stop. Distribution centres are therefore often used for cross-docking purposes, not for storage. On the other hand, slow moving goods are transported to distribution centres near the final destination of the goods, in which they are stored together with goods from other companies (Tsolakis & Naudé, 2008).

Furthermore, time-sensitive freight can be divided into courier and express freight. According to Sirikijpanichkul and Ferreira (2006, p. 3), courier freight consists of "*door-to-door and fixed schedule delivery services mainly in inner city areas*" and includes important documents, office support and technical services. Express freight is associated with "*a time-definite delivery of freights – usually on the basis of the overnight priority, same day, next day, and international services – which involves a process of pick-up, consolidation, deconsolidation and delivery to final destination*". Examples of express freight are fashion products, just in time products, perishable goods, priority items and retail products.

Strale (2014) examines the supply chain of retail activities and follows the distinction between independent retailers, supermarkets and chain stores, proposed by Fernie & Sparks (2009). Independent retailers make often use of wholesalers and are often spread over the urban area. This makes consolidation of goods of different independent retailers challenging. With respect to supermarkets and chain stores, the last-mile occurs centralised from distribution centres. Hence, freight flows are bundled more with respect to these two types of retail activities, leading to a higher potential for a modal shift from road to rail. The e-commerce supply chain is also based on the use of a distribution centre. However, consolidation for the last mile rarely happens, leading to smaller transport flows compared to supermarket and chain stores flows. Ultimately, freight flows of tertiary activities are examined. These consist of a mix of express deliveries and office equipment. Table 2 displays these different urban freight supply chains and their characteristics. The potential of using rail for urban freight distribution is the most present for chain stores and supermarkets, since their supply chain already goes through distribution centres, and rather long distances between suburbs and the urban area are covered.

Next to retail supply chains, Strale (2014) investigates the potential of using rail for two other types of supply chains, being express mail and waste. Shippers of express mail are in Belgium in particular located near Brussels Airport and the type of goods they receive is parcels. However, there is anno 2019 no tram line between Brussels Airport and the city centre of Brussels[5]. With respect to waste, the main advantage mentioned by Strale (2014) is the fact that the transport by rail could be executed

[5] The Flemish Government plans new tram lines in and around Brussels starting from 2020 (Vlaamse Overheid, 2019b)

during the night and hence, would not disturb the passenger transport. However, this would need the development of silent equipment and rail vehicles.

Table 2 – Urban freight supply chains

Characteristics	Urban freight supply chains				
	Independent retailer	Chain store	Supermarket	Tertiary activities	E-commerce
Intermediary	Via wholesaler	Via distribution centres	Via distribution centres	Via global integrators	Via distribution centres/ stores in case of big actors, pick-up points
Last mile	Inside the urban area	Long distances	Between suburbs and cities	Between major transport nodes such as airports or highways and cities	Delivery rounds
Consolidation	In general not	Yes	Yes	Sometimes	Sometimes
Transport mode	Private car or small van	Lorries	Lorries	Vans, bikes, electric vehicles	Depends on provider and circuit choice, sometimes final customer
Delivery time	During shop opening hours	Flexible, but in general during shop opening hours	Flexible	Flexible	Flexible

Source: Own creation based on Strale (2014)

2.1.1.3.3 Weight-driven versus volume-driven freight

Tsolakis and Naudé (2008) developed a typology of freight, consisting of bulk and non-bulk goods. Bulk goods comprise primary goods such as coals, mining and ores, and agriculture and forestry, such as grain and timber. These bulk goods are considered non-urban, while the non-bulk goods are assumed to be urban flows.

Within the non-bulk goods, one can distinguish urban heavy freight and urban light freight, in which heavy freight can be considered to be weight-driven and light-freight to be volume-driven. The urban heavy freight consists of industry supplies, infrastructure construction materials, residential building materials and household removals, waste removal and recycling and wholesale and retail supplies. The urban light freight includes household waste removal, mail, office and residential maintenance, office supplies, service delivery trips and small-scale retail deliveries. Most light freight activities take place in an urban context and are thus urban flows. Some of the main characteristics of urban light freight are its time-sensitive nature, which is even increasing over time, the use of light commercial vehicles and the small volumes to be transported (Tsolakis & Naudé, 2008). Urban light freight is a growing segment (Janjevic, Kaminsky, & Ballé Ndiaye, 2013) which contributes to a large amount of total urban freight, expressed in number of deliveries and vehicle trips. In Liège, a city in the southern part of Belgium, three quarters of all deliveries in the city centre are parcels and 79% of all deliveries in the city is transported by means of light commercial vehicles in 2004 (Debauche, 2007).

Light commercial vehicles are defined by Tsolakis and Naudé (2008, p. 5) as "*motor vehicles constructed for the carriage of goods and which are less than or equal to 3.5 tonnes*". This definition includes cab-chassis, goods carrying vans, panel vans and utilities. When Janjevic et al. (2013) describe the classification of vehicles made by Debauche (2007), they count private cars, vans and estate cars as light commercial vehicles.

For this study, the classification of Tsolakis and Naudé (2008) is especially useful and leads to the assumption that mainly non-bulk weight-driven as well as volume-driven freight qualifies for a potential use of rail transport in an urban context. This reasoning comes from the fact that both examples of transport of weight-driven freight (e.g. Dresden, Paris) and volume-driven freight (e.g. Zürich, Rome) by rail exist. In general, B2B flows are considered, since B2C flows are too fine-grained for rail transport (Comi et al., 2014).

Different freight types transported by rail are displayed in Table 3. The freight categories in the first column are proposed by Janjevic et al. (2013). The second and third column respectively show the freight that is or was transported by rail and the related urban area. Janjevic et al. (2013) use the concept of urban light freight that was defined by Tsolakis & Naudé (2008, p. 5) as "*a myriad of trips of smaller loads such as smaller scale retail deliveries, household waste removal, offices and residential maintenance, packages (e.g. courier services), mail, office supplies, or service delivery trips (e.g. plumbing and electrical services)"*. The difference with heavy freight is that the latter includes the supply of industry, wholesale and retail products, as well as the removal of waste and construction materials and recycling. Waste and reverse logistics are not included in the overview of Janjevic et al. (2013). However, waste is considered in the cases of Amsterdam, Barcelona, Kawasaki, Vienna and Zurich.

When goods are bundled in a distribution centre in the urban area, this operation is more appropriate for urban light freight. This type of bundling is called micro-consolidation (Janjevic et al., 2013). Janjevic et al. (2013) developed a typology of micro-consolidation projects and make a distinction between six types: the vehicle reception point, the goods reception point, the urban logistics boxes, the micro-consolidation centres, the handling points to lighter vehicles and the mobile logistical facility.

At vehicle reception points, an area is created for loading and unloading operations for receivers nearby. Goods reception points are locations where transport providers drop the goods at a common reception point. Urban logistics boxes serve as delivery points at which the receiver does not need to be present for delivering the goods. Micro-consolidation centres are similar to urban consolidation centres, but they are located closer to the final delivery point and make use of vehicles with a limited range, such as cargo bikes or electrical trolleys. At handling points to lighter vehicles, goods are bundled and transferred to lighter vehicles. A mobile logistical facility is a mobile depot that comprises consolidated goods and contains the vehicles for the transport to the final receiver (Janjevic et al., 2013).

Table 3 – Freight types transported by rail

Freight category	Example	Case
Courier services	Air cargo FedEx	BART, San Francisco
	Commercial parcels	CityCargo, Amsterdam & Kyoto-Arashima
	Lunch boxes	Dabbawalas, Mumbai
	Time-critical shipments	ic:kuriers, Germany
Electrical & telecommunication equipment	Household products	Monoprix, Paris
Express services	Documents, urgent spare parts	ic:kuriers, Germany
Home deliveries	n/a	n/a
Machinery	Automotive parts	CarGo Tram, Dresden
	Construction materials	Plymouth, UK
Medical	Hospital products	GüterBim, Vienna
		Italy
Motor vehicles spares	n/a	n/a
Office supply & equipment	Paper	MUDC, Rome
Post services	n/a	n/a
Residence & business maintenance	Housing & hobby products	Monoprix, Paris
	Spare parts	GüterBim, Vienna
Service delivery trips	n/a	n/a
Small scale retail (food)	Fish	MUDC, Rome
		Plymouth, UK
	Fruits and vegetables	Italy
	Heineken beer	CityCargo, Amsterdam
	Mineral water	MUDC, Rome
	Retail products	Freight Tram, Barcelona
		GüterBim, Vienna
		Tramfret, Paris/St-Etienne
	Soft drinks	Monoprix, Paris
		MUDC, Rome
Small scale retail (non-food)	Clothing	CityCargo, Amsterdam
	Cosmetics	Monoprix, Paris
	Mix of non-food	MUDC, Rome
	Textile	Monoprix, Paris

Source: Own creation based on the freight categories of Alessandrini et al. (2012), Arvidsson & Browne (2013), Cleophas et al. (2018), Delaître & De Barbeyrac (2012), Dinwoodie (2006), Filippi & Campagna (2014), Genta et al. (2006), Issenman et al. (2010), Janjevic et al. (2013), Marinov et al. (2013), Ozturk & Patrick (2018), Percot (2014), Regué & Bristow (2013), Sivakumaran et al. (2010), time:matters (2019), Zych (2014)

2.1.1.4 Intermediate conclusion

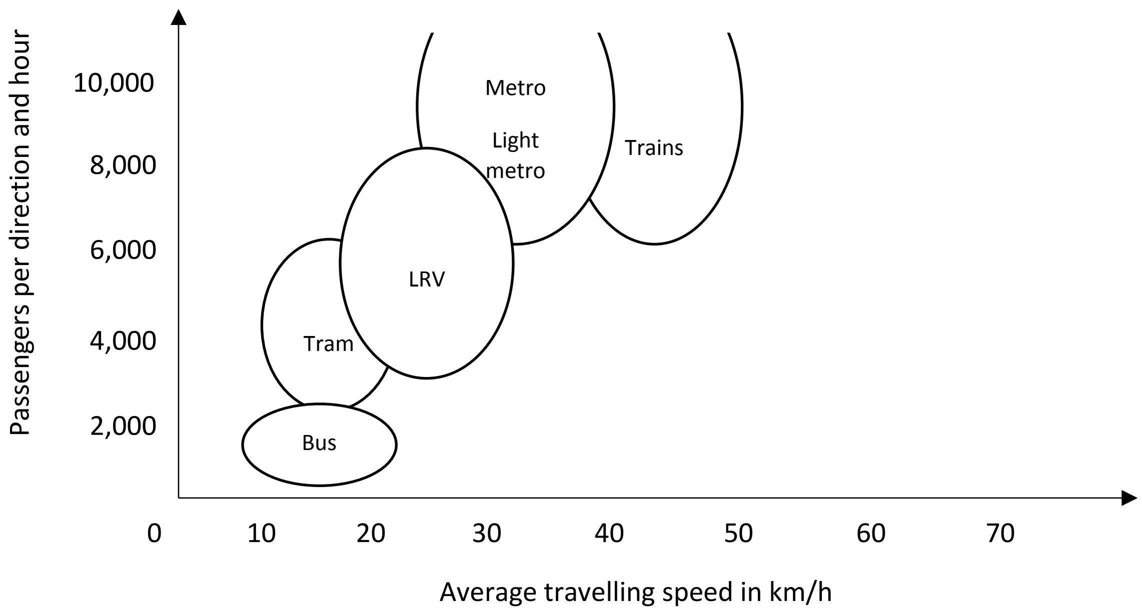
Urban freight distribution is in this research defined as the transport of goods to, from and within urban areas by or for commercial or public entities. An urban area is considered a (nearly) continuous compact area, with a certain minimal population density, of which a large proportion consists of commercial activities such as retail activities. An urban area in this research can as well be a small area with a high concentration of shops, as a large area with a lower concentration and this area does not necessarily equal the legal city boundaries. More specifically for Flanders, four types of urban areas are distinguished among: Flanders as a whole, the Flemish Diamond, a city such as the city of Antwerp, and a concentration of shops, such as the area around Groenplaats and Meir in the city of Antwerp. The characteristics that determine an urban area are sixfold: environmental state, freight flows, geography, population density, regulatory framework and transport infrastructure. With respect to the types of freight that can be transported by rail, most potential is identified for chain stores and supermarkets. Hence, B2B retail activities are the focus of the following chapters, although the model developed in this research can also be applied to other types of freight flows (for example construction materials and B2C e-commerce parcels).

2.1.2 Rail

The second key concept that needs to be clarified is rail transport. In general, rail comprises heavy rail, light rail, trams and metros (Gorçun, 2014; Kikuta, Ito, Tomiyama, Yamamoto, & Yamada, 2012; Motraghi & Marinov, 2012). When talking about rail transport in an urban context, heavy rail is not taken into account by most authors. Alessandrini et al. (2012) divide rail-based alternatives in an urban context into the use of rail for the urban penetration leg, the use of tramways and the use of underground infrastructure. Arvidsson & Browne (2013) divide rail transport in cargo trams, light rail and underground freight.

Devriendt (2017b) explains the typology of rail vehicles that is used by Bombardier. Figure 8 shows how buses, trams, light rail vehicles (LRV), light metros, metros and trains differ from each other with respect to the number of passengers that can be transported per direction and per hour on the vertical axis and the average travelling speed on the horizontal axis. The difference between trams, light rail vehicles, metros and trains can be explained from this perspective.

Figure 8 – Typology of rail vehicles of Bombardier



Source: Own creation based on Devriendt (2017b)

In this research, in which the use of rail freight is examined in an urban context, it is useful to consider light rail, tramways and underground rail transport. Moreover, some innovative rail systems can be added to this classification. As mentioned for the characteristics of an urban area, different abstract rail systems can be defined based on their characteristics, following Quandt & Baumol (1966).

2.1.2.1 Light rail

When transporting goods towards and away from urban areas, light rail can be used. In this case, the freight is bundled in a multimodal consolidation centre, which is located outside the urban area. The freight is transported between this multimodal consolidation centre and an urban consolidation centre by means of a shuttle train. Subsequently, the freight is brought to the final customer, for example by using low-pollution vehicles (Alessandrini et al., 2012).

Priemus and Konings (2001, p. 188) define light rail as "*a rail associated transport system that can be positioned in the triangle between train, tram and metro*". Light rail is a type of rail transport, which allows covering distances of 10-40 km between an urban centre and the area around it. One of the main features of light rail vehicles is the interoperability with different track sizes. Thus, the vehicles can both drive on tramways and heavy railways. Smiler (2013) states that light rail vehicles are almost always electrically-powered. The difference with trams is that light rail vehicles are generally "*more modern (post 1970), rapid transit-type systems which use larger articulated vehicles and feature stops which are slightly further apart and more (or even total) separated from street traffic*". Devriendt (2017b) argues that light rail vehicles operate mainly on segregated tracks and are characterised by stops that are located at more than 400 meter from each other. A typology of light rail can be made based on the scale and interoperability (see Table 4).

Table 4 – Light rail typology

	Combination of own infrastructure and shared use of railway net	(Practically) exclusive use of the railway net
Urban regional main connections	Randstad Rail model	Randstadspoor model (mixing with other trains)
Regional connections around medium big cities	Karlsruhe model	Dürener model (no mixing)

Source: Priemus & Konings (2001)

In the Randstad Rail model, the vehicles use both the existing railway network and tramways and they connect the city centre to important commuter areas. This service is characterised by high frequencies. The Randstadspoor model means that the vehicles only use the railway network, on which they are mixed with other trains and they connect the city centre to important commuter areas. This service is featured by frequencies of four to six times per hour (Priemus & Konings, 2001).

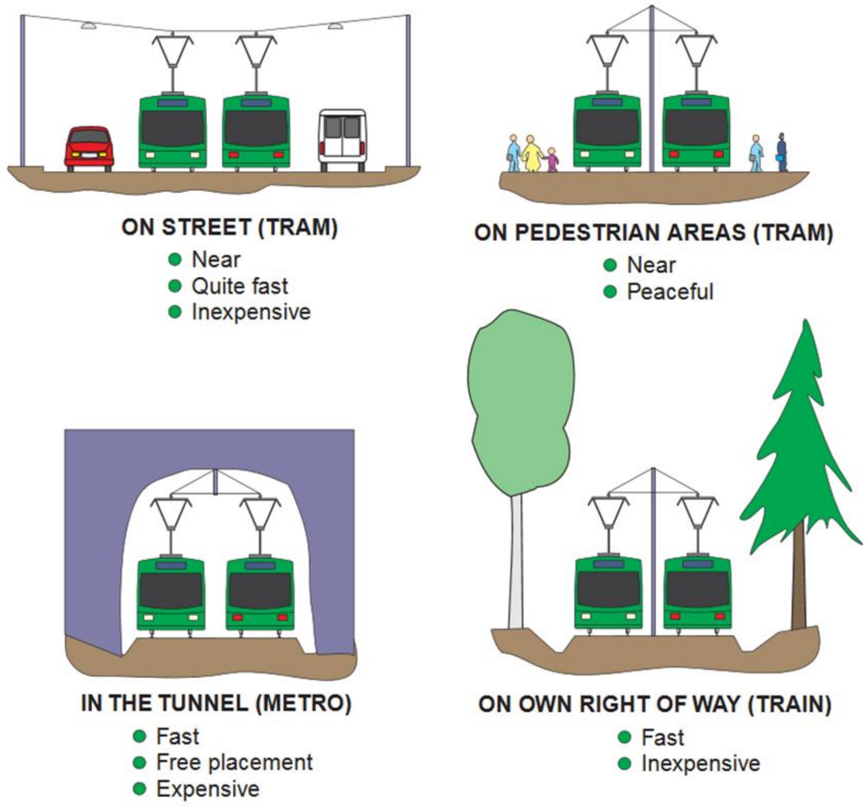
The Karlsruhe model makes use of both the railway network and existing or new tramways. On the railway network, the light rail vehicles are mixed with other trains, while on the city network, there is a mix with trams. Besides, residential areas are connected to regional city centres. This service is provided with a frequency of maximum four times per hour. The Dürener model uses exclusive railway infrastructure, connecting residential areas and regional city centres. The frequency of this service amounts to one to four times per hour (Priemus & Konings, 2001).

Arvidsson & Browne (2013) argue that the light rail industry is focused on passenger transport and this confirms the ideas of the light rail typology of Priemus & Konings (2001). However, in this research, light rail is considered a transport mode to also carry freight.

UITP defines light rail as "*a public transport system permanently guided at least by one rail, operated in urban, suburban and regional environment with self-propelled vehicles and operated segregated or not segregated from general road and pedestrian traffic*" (ERRAC, 2012, p. 18). Following this definition, all types ranging from a tram, which is not segregated, to a metro, which is fully segregated, are defined as light rail. Strale (2014) analyses the use of light rail for freight distribution in Brussels, but means the use of the tramways and underground tramways, called "pre-metro", more specifically. ORR (2019) defines light rail as "*an urban rail transportation system that uses electric-powered rail cars along exclusive rights-of-way at ground level, on aerial structures, in tunnels or occasionally in streets*". The main difference with heavy rail is that lighter equipment is used and speeds are lower.

Alku (2002) identifies four different types of light rail: on-street trams, trams in pedestrian areas, metros and trains. This classification is displayed in Figure 9. On-street trams and trams in pedestrian areas operate as conventional trams. Compared to especially a metro system, the construction of a tram system is cheap. The main advantage of trains is that they have their own right of way and are therefore a fast transport mode. The maximum speed of a light rail system is 80-100 km/h.

Figure 9 – Four types of light rail



Source: Alku (2002)

2.1.2.2 Tramways

As mentioned by Arvidsson & Browne (2013), different terms for trams do exist. Smiler (2013) describes trams as "*frequently smaller vehicles operating on older or 'historic' installations which have been open since before the 1970s*". Devriendt (2017b) states that trams are integrated in the urban traffic and that the maximum distance between two consecutive stops is about 400 meter. ORR (2019) defines a tram as *"a railway on which streetcars or trolleys run […] (and) is typically built at street level, sharing roads with traffic, but may include private rights of way especially in newer light rail systems".*

The definitions show that no unambiguous definition exists and that most definitions are passenger-oriented. When talking about a 'tram' here, an electric vehicle is meant that can carry passengers and/or freight and which uses dedicated metal tracks in the street and moves within a limited geographical area. Within this definition, it is possible that the tram drives for a part of the covered distance underground, which is called in Belgium "pre-metro", but it is not underground rail transport as such.

2.1.2.3 Underground rail transport

Visser (2003) provides a classification of different types of underground rail transport. A distinction is made between capsule pipeline systems and freight transport using underground tunnels. The difference between these two types can be explained by means of the pipeline diameter, the vehicle shape and the way the vehicle is guided. Underground freight transport through tunnels is by this author assumed to be automated. In other words, the transport occurs unhindered, on a dedicated underground freight infrastructure. The economic benefits of such a system include short lead times, 24/7 services and low operational costs. The socio-economic benefits are the reduction of accidents, emissions, congestion, noise and visual pollution and a more intense use of the available urban space. However, these benefits have to be traded off against the underground infrastructure that has to be constructed. This often leads to high investment costs, the need for cooperation between different stakeholders and a lot of time.

Taniguchi et al. (2001b) suggest that underground transportation can play a role in sustainable urban freight distribution and this from an environmental, congestion and spatial point of view. In particular, companies that have high volume suppliers and customers can benefit from this technique. In a case study for Tokyo, Taniguchi et al. (2001a) explain the plan for an underground rail freight system. Different transport methods can be used, such as containers, conveyor belts, dual-mode lorry, piggyback and tubes. The piggyback technique means "*the movement of loaded lorry trailers on railroad flatcars*" (Merriam-Webster, 2013). The dual-mode lorry technique comprises lorries that operate as normal lorries on the road network and that drive on special railways in the underground system. Within the underground system, the lorries drive automatically based on electricity provided by the rails, while on the road drivers operate the vehicles that are equipped with batteries. The speed within the system amounts to 45 km/h (Taniguchi et al., 2001a).

UITP defines metropolitan railways as "*urban, electric transport systems with high capacity and a high frequency of service*" (ERRAC, 2012, p. 4). Moreover, metros are characterised by the fact that they operate independently from other types of traffic. As a result, they operate in the underground, or on dedicated metro lines on surface level that are physically fully separated from other traffic types. Furthermore, metros have a high carrying capacity of sometimes more than 30,000 passengers per hour per direction and a higher commercial speed than for instance light rail. Disadvantages are the high investment costs compared to light rail systems. The distance between consecutive stations is more than 1 kilometre (ERRAC, 2012). At Bombardier, stops at (light) metro lines are considered to be more than 400m away from each other (Devriendt, 2017b).

Bous (2001) investigated the use of underground freight transport further. This author concludes that substantial investments are needed, while the returns are rather small. Another crucial issue mentioned is that private actors cannot easily be attracted to step in the project. Visser (2003) states that underground freight transport has some potential, but that it offers long-term possibilities and it is a not a solution for the short run. Quak (2008) argues that the high construction costs and unknown risks of underground transport make it difficult to implement. Mortimer (2008) states that the conflicts between passenger and freight activities that are present on a light rail network are even intensified in the underground. Issenman et al. (2010) add to this issues related to accessibility, available surfaces and the interaction with passenger flows as the main problems of underground urban rail freight distribution. Freight elevators are needed, which are expensive and not always technically feasible. Strale (2014) states that underground transport complicates retail deliveries, since the underground rail lines and the retail premises on the ground level have to be linked to each other. Because of these issues, underground transport is not included in the remainder of the current research.

2.1.2.4 Innovative rail systems

Next to these three types of rail transport, some innovative rail systems have been developed in the 21st century. The first innovation that is interesting to mention here is rubber-tired trams, also known as guided light transit vehicles. This technology emerged in the early 2000s. These vehicles use a mix of rail and road technologies. The rubber tires allow the vehicles to drive on roads, whereas the guiding rails, pantograph and electric engine allow the vehicle to operate as a tram. The vehicles take power from overhead wires via their pantograph, and they are guided by a guiding rail in the road surface (Devriendt, 2017a; King, Vecia, & Thompson, 2015).

Three benefits of rubber-tired trams exist. Firstly, these vehicles have an improved traction and hence, can climb higher slopes than conventional trams. This is especially useful in hilly cities. Secondly, less tram infrastructure is needed to cover a certain distance. The vehicle has a diesel auxiliary engine, allowing it to drive independently off track for a certain distance. Thirdly, the space needed between parallel lines is smaller than for buses, since no human steering error can take place (King et al., 2015).

Some cities such as Caen, Clermont-Ferrand, Nancy and Paris in France, L'Aquila and Mestre in Italy, and Shanghai and Tianjin in China, have been experimenting with rubber-tired trams or metros. Figure 10 shows an example of a rubber-tired tram (left) that was running in Caen, as well as a guiding rail (right). In 2016, it was decided to abandon the rubber-tired trams by 2019 due to problems related to performance and reliability, such as derailments of the guiding wheels and breakdowns (WordPress, 2016). The higher derailment risk, as well as increasing road maintenance costs, the lower energy efficiency compared to conventional tramways and the higher installation costs than conventional tramways are a few issues (King et al., 2015). This type of vehicle causes damage to the road and the maximum axle load of the vehicle when driving on the road is a limiting factor (Deduytsche, 2017a). Moreover, the traction unit and rail wagon have to possess both small wheels to be guided along the tracks, and large wheels for the road transport. Due to these operational and technical problems, Bombardier, one of the two worldwide producers of rubber-tired trams, decided to stop developing the vehicles (Devriendt, 2017a).

Figure 10 – Rubber-tired tram running in Caen (left) and guiding rail (right)

Source: WordPress (2016) (left) and King et al. (2015) (right)

A tram-bus is one specific type of rubber-tired tram. A tram-bus of 18m length and with full electric traction has a price tag of around €700,000 (value for 2018). The life span of the tram-bus is however only 14 to 15 years. The main advantage of a tram-bus is that this type of vehicle can leave the tracks and therefore, is more flexible than a tram (Deduytsche, 2017b).

The second innovation that is briefly mentioned here, is a tram that can execute part of its route by using energy from a battery instead of a catenary. Such a tram possesses a battery that is charged at the tram stop by means of an electric contact point. The battery typically has a radius of one to two kilometres, depending on the slopes, the number of times the tram has to stop and the drag force. A battery has a life span of ten years on average (Devriendt, 2017a).

It is possible to use this system of operating without catenary for the loading and unloading part on an additional siding. Like this, no catenary has to be constructed on the siding, reducing the infrastructure cost. For this concept, one to three tonnes of batteries is needed to provide the tram with enough energy (Devriendt, 2017a).

2.1.2.5 Rail transport by type of loading unit

Cleophas et al. (2018) and Cochrane et al. (2017) make an additional distinction of using trams or trains. These authors identify three types of rail transport:

- Operating dedicated freight vehicles in between public transport vehicles on the passenger lines;
- Attaching freight wagons to public transport vehicles;
- Transporting goods alongside passengers on public transport vehicles.

Cochrane et al. (2017) came up with the term “Freight on transit” (FOT) to describe the transport of freight making use of public transport vehicles or the public transport infrastructure. Next, these authors use the distinction FOT-EX and FOT-NEW, which is respectively freight on existing public transport services and new freight trips on existing public transport infrastructure. The term of FOT is adopted by Ozturk & Patrick (2018), who develop a decision support framework for the optimal urban freight distribution by rail. Cleophas et al. (2018) use the distinction shared infrastructure and shared vehicle, which is equal to the FOT-NEW and FOT-EX developed by Cochrane et al. (2017) respectively.

Given the objective of this research, i.e. to investigate the economic and socio-economic costs and benefits of using rail for urban freight distribution, this distinction is not followed here. The reason is that attaching a freight wagon to a public transport vehicle and transporting goods alongside passengers are both characterised by different cost and benefit components. However, the distinction between operating a dedicated freight vehicle, attaching a freight wagon to a passenger vehicle, and transporting goods alongside passengers on public transport vehicles, is adopted in this research.

2.1.2.6 Research decision

Three main types of rail transport are discussed, being light rail, tramways and underground transport. Given the issues mentioned with respect to underground transport, the remainder of this research focusses on the use of light rail, referred to as “trains” in the rest of this study, and tramways. Moreover, a distinction is made between the use of a dedicated freight vehicle, a freight wagon attached to a passenger vehicle, and the transport of parcels alongside passengers.

2.2 Urban rail freight initiatives

Firstly, an overview of the existing literature on using rail for urban freight distribution is given in Section 2.2.1. Next, the characteristics of the main urban rail freight initiatives are examined in Section 2.2.2. To summarise, the existing initiatives are divided per type of tram and light rail transport used in Section 2.2.3.

2.2.1 Overview of the existing literature

The use of rail for urban freight distribution has been treated by different authors. Table 5 displays different initiatives of using rail for urban freight distribution in several study areas, without comparing the projects and cities with each other. The studies are conducted between 1995 and 2018. Table 5 is built according to the structure of the rail typology proposed in Section 2.1.2, with the themes modal shift and rail freight station as two additional themes here in order to provide a more complete overview of the existing literature. Existing research on underground rail transport is still discussed here for the same reason. The different studies are ranked chronologically per theme. Firstly, studies focusing on a modal shift from road to rail are mentioned. Secondly, light rail initiatives are listed, followed by tram and underground projects. Ultimately, papers focusing on rail freight stations are added.

The first observation of Table 5 is that several authors examined urban freight distribution by means of rail transport between 2001 and 2018 and that different types of rail transport are investigated in these projects. Although Dorner (2001) argues that the implementation of rail transport in an urban context is difficult, Dinwoodie (2006) and Ruesch (2001) state that there is a potential for rail freight in urban areas. Hence, it is a topic that needs some further research. Moreover, as WSP (2008) states that emissions are reduced when using rail instead of road transport, the introduction of rail in urban freight distribution is potentially a sustainable solution and thus fits within the objectives of this research.

Secondly, the largest part of the studies is applied to European cities. It is clear that for Belgium, only the study of Strale (2014) is available, who discusses the potential of using tramways for freight in Brussels from a geographical perspective[6]. Hence, for Flanders, no projects on rail in an urban freight distribution context do exist yet. Thus, an investigation of this topic with the focus on the Flemish region is an interesting complement to the existing body of knowledge.

Thirdly, the methodologies used in the different studies are provided in the third column of Table 5. Several authors start their research with a data collection by means of interviews, surveys, traffic counts or workshops. Table 5 shows that cost-benefit analysis is a common methodology, as well as case studies. Chapter 3 goes deeper into the methodology chosen for this research. The different rail-based initiatives displayed in Table 5 related to the modal shift, light rail, tramways, underground transport and freight stations are now briefly discussed.

2.2.1.1 Modal shift

Eleven studies are displayed in Table 5 with respect to a modal shift from road to rail in an urban context. Foyer (2001) discusses the issue of a just in time strategy in an urban rail freight context. More specifically, the author describes the features of JIT[7] and indicates where rail can play a role in this story. Besides, some technological solutions such as a self loading/unloading container carrier, and a bimodal freight multiple unit, are highlighted. The conclusion of this research is that rail transport is shifting away from high-value markets.

[6] In the period 2015-2020, a feasibility study for the use of rail in an urban context will be carried out in Brussels (Regering van het Brussels Hoofdstedelijk Gewest, 2012).

[7] JIT stands for 'just in time' and means that goods cannot arrive too early, but also not too late (Blauwens, De Baere, & Van de Voorde, 2016, p. 138)

Table 5 – Overview of existing literature on urban rail freight[8]

Theme	Author(s) (year)	Applied research method(s)	Study area
Modal shift	Foyer (2001)	Literature	/
	Ruesch (2001)	Case study, integrated three-pillar concept	Düsseldorf
	Robinson & Mortimer (2004a, 2004b)	Case study	Amsterdam, Düsseldorf, Paris, Vienna, Zurich
	WSP (2008)	Interviews, workshops, case study, SWOT analysis	Gothenburg
	Behrends (2012a)	Framework for sustainable urban freight transport developed by Sjöstedt (1996)	/
	Motraghi (2013)	Case study	Amsterdam, Dresden, Newcastle, Paris, Zurich
	Macário (2014)	Policy evaluation framework	/
	Nuzzolo & Comi (2014)	Binomial logit model	Rome
	Woodburn (2014)	Literature	Londo
	Cleophas et al. (2018)	Literature study	Amsterdam, Dresden, Paris, Vienna, Zurich, Vienna
Light rail	Dorner (2001)	Case study, private cost and environmental effects analysis	Berlin and Vienna
	Dinwoodie (2006)	Disaggregate spreadsheet cost simulations, semi-structured interviews	Plymouth
	Nuzzolo et al. (2007)	Case study, cost analysis, interviews, O/D matrices, surveys, traffic counts	Sorrentina Peninsula
	Issenman et al. (2010)	Case study	Monoprix in Paris, Amsterdam
	Sivakumaran et al. (2010)	Economic feasibility study, scenarios	San Francisco Bay Area
	Maes & Vanelslander (2011)	Case study, interview	Monoprix in Paris
	Alessandrini et al. (2012)	Case study, monitoring of vehicles, scenarios, social and private cost analysis	Distribution of fish by rail in Rome
	Delaître & De Barbeyrac (2012)	Case study, scenarios, feasibility study	Monoprix in Paris
	Marinov et al. (2013)	Case study	Monoprix in Paris
	Diziain et al. (2014)	Case study	Kawasaki, Kyoto, Monoprix & Chapelle International in Paris
	Filippi & Campagna (2014)	Case study, vehicle monitoring	Rome
	Cochrane et al. (2017)	Delphi method, case study, scenarios	Greater Toronto and Hamilton Area
	Behiri et al. (2018)	Integer programming	Monoprix & Chapelle International in Paris
	Ozturk & Patrick (2018)	Integer programming	Monoprix & TramFret in Paris

[8] The appearance of several sources of 2001 is explained by the fact that it are, with the exception of Taniguchi et al. (2001a, 2001b), all presentations at the BESTUFS I workshop.

Theme	Author(s) (year)	Applied research method(s)	Study area
Tramways	Kortschak (1995)	Case study	Vienna
	Rien & Roggenkamp (1995)	Case study	Kassel
	Neuhold (2005)	Case study	Zurich
	Genta et al. (2006)	Case study	Cosenza
	Mortimer (2008)	Case study	Amsterdam, Vienna
	Arvidsson (2010)	Case study	Dresden, Vienna, Zurich, Amsterdam
	Issenman et al. (2010)	Case study	Monoprix in Paris, Amsterdam
	Kortschak (2010)	Case study	Dresden, Vienna, Zurich
	Arvidsson & Browne (2013)	Case study, interviews	Amsterdam, Gothenburg
	Marinov et al. (2013)	Case study	Amsterdam, Dresden, Zurich
	Regué & Bristow (2013)	Case study, cost-benefit analysis, scenarios, face-to-face establishment survey, observational vehicle count	Barcelona
	Gonzalez-Feliu (2014, 2016)	Case study, cost-benefit analysis, interviews	Paris, St-Etienne
	Gorçun (2014)	Cost-benefit analysis, case study, scenarios	Istanbul
	Strale (2014)	Case study	Brussels
	Zych (2014)	Case study	Warsaw
	Behiri et al. (2018)	Integer programming	Dresden
	Ozturk & Patrick (2018)	Integer programming	Monoprix & TramFret in Paris
Underground rail transport	Bous (2001)	Logistic scope long term, possibilities metro system, potential transport markets, environmental conditions, phased implementation approach	Amsterdam
	Taniguchi et al. (2001b)	Simulation modelling	/
	Taniguchi et al. (2001a)	Cost-benefit analysis	Tokyo
	Visser (2003) & Dorner (2001)	Case study	London, the Netherlands
	Kikuta et al. (2012)	Case study, questionnaire	Sapporo
	Marinov et al. (2013)	Case study	Newcastle-upon-Tyne
	Behiri et al. (2018)	Integer programming	New York
Rail freight station	Dönnhöfer & Eisele (2001)	Case study	Nuremberg
	Ebrardt (2001)	Experience, projects	Lille-Paris railway, Toulouse, Strasbourg
	Ruesch (2001)	Case study, integrated three-pillar concept	Düsseldorf

Source: Own creation

Ruesch (2001) describes a project in the neighbourhood of Düsseldorf that has the objective to evoke a modal shift from road to rail transport. The different framework conditions tackled in this research are the freight volumes and demand in the Nordrhein-Westfalen region, the freight volumes and demand in Düsseldorf, the logistics needs and concepts of private sidings owners, the infrastructure, the rail operation, the organisation and cooperation and the land use and policy. Based on these aspects, the main problems of rail freight in urban areas are highlighted. The author defines the different aspects considering both the favourable and unfavourable conditions for rail freight. Concerning the infrastructure, a dedicated rail freight network[9] is created with a high number of freight stations and private sidings. The method used in this research is an integrated three-pillar concept, in which the three pillars are services, operation/infrastructure and organisation/ cooperation. One of the side conditions is that the existing infrastructure is used as much as possible. Some main ideas in the project are direct trains from Düsseldorf to the seaports of Antwerp, Bremerhaven, Hamburg, Rotterdam and Zeebruges, direct trains to other high-volume economic regions, guaranteed early delivery and late collection, set up of intra-urban transport connections and logistics valued added services. The conclusions of the research are that rail freight has a potential in urban areas and it can contribute to a modal shift away from road transport. Besides, the improvement potential is present in the three pillars, as a result of which integrated approaches comprising the three areas are useful.

Robinson & Mortimer (2004a, 2004b) provide an overview of different urban rail freight projects, including light rail, trams and underground rail. The conclusion of these authors is that rail transport can help in reducing road congestion, but some hurdles need to be overcome. Rail services need to be improved in terms of for instance frequency, organisation, and infrastructure. Moreover, these authors suggest rail to move away from conventional train technologies and organisation. Rail infrastructure managers for example could gain more from rail freight than from passenger services.

WSP (2008) too analysed intermodal city distribution and concludes that the use of rail transport instead of road transport reduces emissions. The authors published a report on intermodal city distribution. Interviews with transport operators and officials are carried out in order to have an overview of their opinions. The output of this analysis was input for workshops that lead to a case study of the transport between three main hospitals in Gothenburg. These authors conclude that emissions are reduced when rail transport is used to replace a certain share of the road transport.

Behrends (2012a) investigates the opportunities and threats for a modal shift from intermodal road to rail transport in an urban context. The method used comprises literature analysis and use of the framework for sustainable urban freight transport, developed by Sjöstedt (1996). The main conclusions are that the urban context can have a negative impact on the growth of rail freight transport, although it also offers opportunities. Cooperation of actors is one of the variables that appears to be crucial in this context. Behrends (2012a) identifies three areas in which improvements can enhance the competitiveness of rail freight: land-use and transport planning that is adapted to rail, urban cooperation of shippers and receivers and urban cooperation of transport operators.

Motraghi (2013) elaborates on several rail research projects, among which the use of rail for urban freight distribution. Case studies described by this author include CarGo Tram in Dresden, Cargo and E-Tram in Zurich, City Cargo in Amsterdam, Monoprix in Paris, TruckTrain in the UK and Newcastle Metro. Macário (2014) discusses a policy evaluation framework that can be used when rail transport is introduced in urban freight distribution. Nuzzolo & Comi (2014) investigate how the demand for urban rail freight can be modelled. These authors develop a binomial logit model. Woodburn (2014)

[9] Some rail lines are only used for freight transport, not for passenger transport.

discusses the potential of using rail for urban freight distribution in the city of London. This author describes a pilot study that took place on 31 October 2012 in London. In the context of the European project LaMiLo, retail products for Sainsbury's were delivered by underground rail. After this trial, this initiative was not continued. Cleophas et al. (2018) discuss sharing infrastructure and vehicles for urban rail freight distribution. These authors mention the examples of CityCargo in Amsterdam, CarGo Tram in Dresden, Monoprix and TramFret in Paris, GüterBim in Vienna and Cargo Tram and E-Tram in Zurich.

2.2.1.2 Light rail

With respect to light rail, 14 studies are presented in Table 5. Dorner (2001) gives an overview of some concepts of rail based city distribution. Firstly, he highlights the technical and logistics requirements and solutions of rail transport. Secondly, he presents two case studies, more specifically Berlin and Vienna. The conclusion of his study is that the implementation of rail transport in an urban context is difficult.

In Berlin, the City Terminal Concept was introduced in 2004. Five terminals were spread over the city of Berlin and these terminals had following functions: local retail warehouse serving outlets, single operation base of a single freight carrier, and transhipment for distributing local outlets. Furthermore, the city terminals formed a system of combined units with the three peripheral freight centres of freight carriers. An urban freight distribution shuttle was transporting goods between the city terminals and peripheral freight centres. Long haul trains drove directly to both the city terminals and the freight centres. Logistics standard boxes were used on the trains, so that the same boxes could be used both on the long haul trains and the shuttle trains. The shuttle trains operated on a fixed schedule and existed in two models: accompanied shuttles, i.e. lorries and drivers, and unaccompanied shuttles, i.e. containers and logistics boxes. The cost-benefit evaluation of this concept included that there were only time savings for the accompanied shuttle trains and cost savings for the unaccompanied shuttle trains, when terminal costs are excluded. Furthermore, the shuttle trains lead to fewer environmental emissions and less vehicle-kilometres. However, the whole concept appeared to be unrealistic due to the costs and time factors (Dorner, 2001; PRONET, 2007).

In Vienna, the CarGoTram concept was introduced in 2004. Three city terminals were established within the city of Vienna. Long haul transport was done by rail transport, city transport by small sized vehicles and a cargo tram line. Logistics boxes were used in order to speed up transhipment. Furthermore, the city of Vienna had plans to transport waste by the CarGo Tram, having a potential volume of 500,000 tons of waste (Dorner, 2001; PRONET, 2007).

Dinwoodie (2006) examines the potential of rail freight in an urban and port context. The research is built around a case study in Plymouth on local freight movements and local corporate reactions to more sustainable rail freight developments proposed in new plans. The analysis is based on cost simulations and semi-structured interviews. The stakeholders interviewed for this research are owners of local wharves, a fish processing company, a rail freight facility and a rail operator. The main conclusion of the research is that there is a market potential for rail freight in Plymouth with dedicated transport of China clay on a long distance and potentially also with cement, based on the existence of economies of scale. The author indicates that future work would be to identify the type and frequency of intra-city freight movements. Furthermore, he highlights the importance of examining the origin and destination of movements, the transport modes used, the costs, the forecasts for serving new markets and the potential of rail to serve these new markets.

In the 90s, licensed freight operators in Great Britain could obtain a rail freight grant, distributed by the Strategic Rail Authority. The purpose of the grant was to stimulate operators to enter the British rail freight network. For example, track access grants were assigned in order to fund track access agreements, consisting of i.a. fixed network access fees and variable fees depending on the utilisation of the network. These grants are calculated based on net savings in sensitive lorry miles and in 2003 they amounted to £0.53[10] on urban roads (Dinwoodie, 2006). To calculate the amount of the grant, different parameters such as tonnage of several flows, rail access fees, revenue, cost of transport, capital, administration and handling for both road and rail transport are considered. Then, the grant compensates for the negative net present value of the rail transport after discounting (Strategic Rail Authority, 2003).

In the UK, there have been some initiatives in integrating small flows into full trainloads. More specifically, the projects Speedlink, TransRail and Enterprise systems failed in integrating separate loads. Besides, freight facilities grants were dispensed to compensate for the capital infrastructure costs. The reasoning behind these grants is that freight should be transported by rail in case this is beneficial for the society. In order to facilitate this, the grants provide sufficient capital facilities to rail freight operators. In cases where the rail transport would be economically feasible without grants, where no road transport alternative is existing and where there are too little ecological benefits, the grants are suppressed (Dinwoodie, 2006).

Nuzzolo et al. (2007) study the use of rail for urban freight distribution for Sorrentina Peninsula in Italy. These authors estimate the potential freight demand by means of lorry driver interviews, retailer surveys and traffic counts. Based on O/D-matrices, these authors arrive at a potential freight demand of 110 tonnes per day. Moreover, these authors evaluate the technical feasibility of the project and analyse the costs for the operators. A cost reduction of €10 per tonne would be obtained by the operators when shifting from road to rail in this specific case study.

Issenman et al. (2010) describe the case studies of Monoprix in Paris and City Cargo in Amsterdam. Next, these authors examine the issues related to accessibility, available surface and interaction with passenger transport when metro stations in Paris would be used for urban freight distribution.

Sivakumaran et al. (2010) examine the use of the passenger rail network in the San Francisco Bay Area for the transport of air cargo of FedEx. The passenger rail network is operated by BART (Bay Area Rapid Transit) and in 2010, 70% of the network capacity was unused. Therefore, these authors conducted a feasibility study to know whether the unused capacity can be used for freight transport purposes. As a conclusion of their research, the authors see potential for mixed-goods services on this passenger rail network.

Maes & Vanelslander (2011), Delaître & De Barbeyrac (2012), Marinov et al. (2013), Diziain et al. (2014), Behiri et al. (2018) and Ozturk & Patrick (2018) describe the case study of Monoprix in Paris. Monoprix is a French supermarket chain, which made use of rail transport between 2007 and 2016. Figure 11 shows the route covered by the train shuttle. The goods were transported by rail over a distance of 40 kilometres between two distribution centres in Combs-la-Ville (point B) and Lieusaint (point A) on the one hand and the bimodal cross-docking platform “Halle de Bercy” (point C) at the edge of the city of Paris on the other hand. For the last-mile transport, natural gas lorries were used in order to supply 94 stores. In total, 210,000 pallets or 120,000 tonnes of goods were annually transported by train (Monoprix, 2007a).

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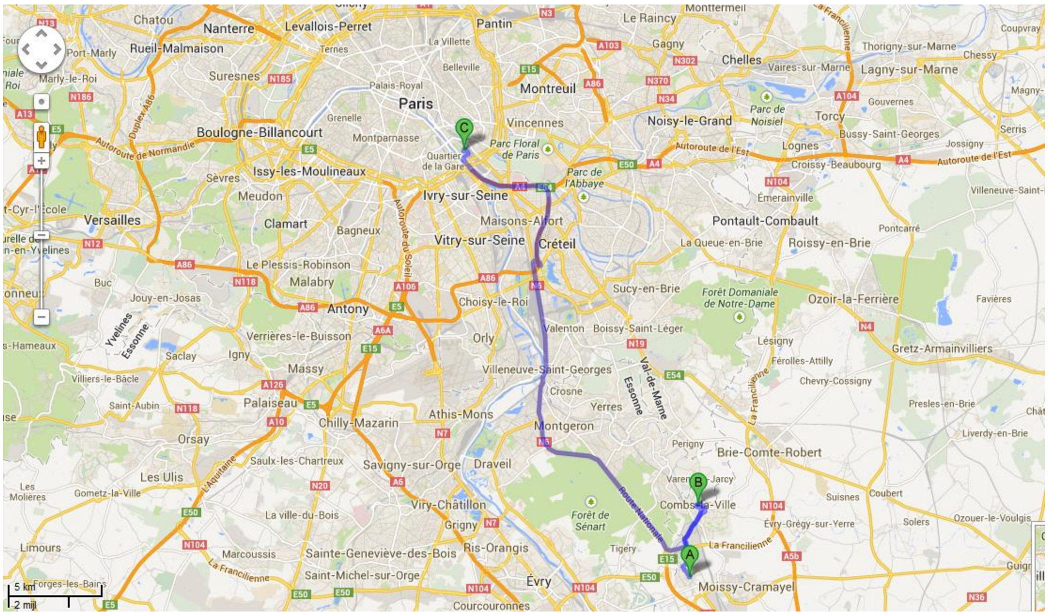
[10] In prices of 2018, this would be £0.82, or €0.94.

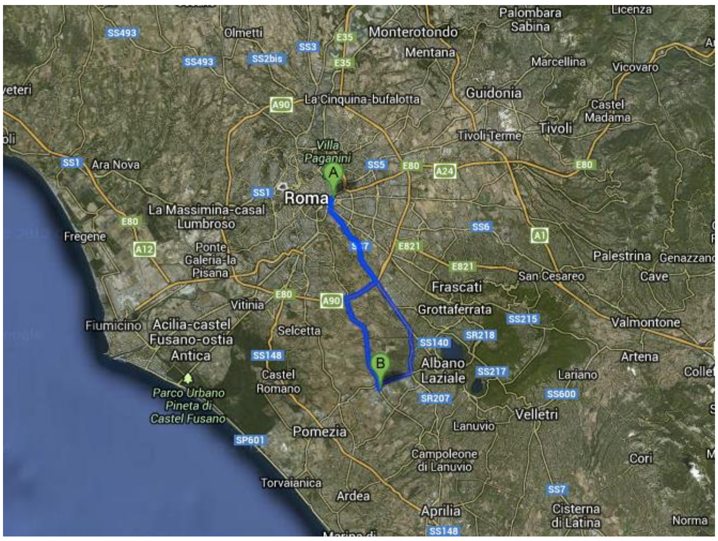
Figure 11 – Rail freight shuttle train of Monoprix (2007-2016)



Source: Own creation based on Google Maps

Alessandrini et al. (2012) examine how rail can be used to make urban freight distribution more sustainable. These authors conduct a case study on the transport of fish via a multimodal urban distribution centre in the city of Rome. The route covered by the rail shuttle is displayed in Figure 12. The train transports the fresh fish between the logistics platform of the Fresh Food Center in Pomezia Santa Palomba (point B) and the multimodal urban distribution centre in Scalo San Lorenzo (point A) over a distance of 30 kilometres. The authors conclude that the actual costs of the train and the transfer operations are depending on different variables, such as distance, transfer efficiency and transported quantity. Besides, the authors state that obtaining economies of scale is possible. This study still lacks calculations on externalities such as congestion and road accidents and does not incorporate future potential measures such as road pricing. The latter is one of the measures the European Commission proposes in its Transport White Paper as a possible solution to decrease the use of conventional vehicles (European Commission, 2011).

Figure 12 – Rail shuttle in Rome



Source: Own creation based on Google Maps

Diziain et al. (2014) discuss several rail- and waterway-based initiatives in Japan and in France. The initiatives in Japan are the transport of waste by rail in Kawasaki City since 1995, and the transport of parcels between Kyoto and Arashiyama since 2011. Different types of waste are transported by the railways in Kawasaki, including residential waste, incinerated ashes, cans and bottles. Specific containers were developed for this transport. The distance covered by rail is 23 km. The transport of parcels between Kyoto and Arashiyama, occurs over a distance of ten kilometre. One or two couriers of the courier company Yamato accompany the parcels in the train. Regular passenger wagons are used and the train runs once a day before the peak-hour starts. For the last-mile transport, electric bikes are used.

Diziain et al. (2014) and Behiri et al. (2018) discuss the initiative of Chapelle International, in Paris. This is a so-called logistics hotel of 45,000 m², consisting of amongst others office buildings, sport accommodation, a data centre and a railway terminal. Goods will be transported by rail from the north of France to the city centre of Paris. Chapelle International was supposed to open in 2018 (SNCF, 2019).

Filippi & Campagna (2014) describe a light rail solution for the city of Rome. Trains coming from the freight village of Civitavecchia stop at six different multimodal urban distribution centres in the centre of Rome and continue their trip then to the freight village of Orte. The pallets are transported to the retailers in the urban area by means of electric or methane vehicles. The transported goods include cement, fruit juice and preserved food, mineral water, non-food products and paper.

Cochrane et al. (2017) identify five challenges concerning the use of rail transport for urban freight distribution in the Greater Toronto and Hamilton Area in Canada. Firstly, high capital investment is needed when using rail. Secondly, free capacity has to be available for freight purposes on the public rail network. Thirdly, the cooperation of different stakeholders is needed. Fourthly, different stakeholders are resistant to change their current business models. Fifthly, the last-mile leg from the rail vehicle to the customer has to be coordinated. These authors conduct a Delphi study and arrived at different possible strategies, being air rail mail, commuter mail rail, mall haul, paper train and liquor line.

2.2.1.3 Tramways

Eighteen studies examine the use of tramways for urban freight distribution. Kortschak (1995) studies the use of a freight tram for Vienna. More specifically, this author suggests to make use of an ultra-low floor tram (ULF). Figure 13 shows pictures of such a pilot study that was conducted in 1995 in Vienna for supermarket BILLA (Kortschak, 2010). These trams are characterised by a floor which is at a height of 18 cm from the ground. Hence, roll cages can be loaded in the trams without the construction of loading and unloading platforms. The entrance doors are wide enough to put euro pallets or roll cages with the same dimensions on the tram.

Between 2004 and 2007, another pilot project of using a freight tram was conducted in Vienna. The freight tram was called “GüterBim” and consisted of a traction unit and a wagon of 17.4m length and 1.5m width, which could carry ten pallets. One person had to fix the loads on the wagon and loading and unloading occurred with forklifts. The total load was 13 tonnes (Kortschak, 2010). The costs of the pilot project were estimated at 1.4 million euro. The aim of the initiative was to use the freight tram during off-peak hours to transport retail goods. The commitment of private actors was needed, but not found (Ziegler, 2007).

Rien & Roggenkamp (1995) develop a case study of using a tram in Kassel for urban freight distribution. These authors pay especially attention to the development of a standard unit, called “Logistikbox” to transport the goods.

Figure 13 – Ultra-low floor tram design for Vienna

Source: Kortschak (1995) (left) and Deutsche Verkehrs Zeitung (1995) (right)

Neuhold (2005), Kortschak (2010) and Marinov et al. (2013) discuss the Cargo Tram in Zurich. This freight tram is the result of a cooperation between ERZ (Entsorgung und Recycling Zurich) and the public tram operator VBZ (VerkehrsBetriebe Zurich). This tram is used to transport residential waste, including bulk and electronic items. Pedestrians and cyclists can bring their waste to tram stops in the urban area of Zurich (see Figure 14). The tram transports the waste away from the urban area to a waste processing facility. The tram runs on the public tram network (Cleophas et al., 2018).

Figure 14 – Cargo Tram and E-Tram, Zurich

Source: Hiveminer (2019) (left) and Neuhold (2005) (right)

The freight tram example that is mentioned the most often in the literature, is the one of Volkswagen in Dresden (Arvidsson & Browne, 2013; Behiri et al., 2018; Cleophas et al., 2018; Kortschak, 2010; Marinov et al., 2013; Quak, 2008). In 1999, the Dresdner VerkehrsBetriebe (DVB), Volkswagen and the German Government initiated the CarGo Tram project in Dresden, which became operational in 2000. This tram connects the logistic centre of Volkswagen and the manufacturing plant (see Figure 15). The distance to be covered between these two centres amounts to four kilometres. The freight tram belongs to the Volkswagen supply chain and is therefore a closed flow. Goods are transported between the logistics centre and the manufacturing plant in both ways. The operation centre for the CarGo Tram is not dedicated; it also serves other tramlines. The tram operates six days per week and 16 hours per day, it can drive maximum 50km/hour and all tram wagons have an electric engine. The costs for the trams are estimated around €1.789.522[11] and the construction costs for a siding of 300m (factory) and 500 m (GVZ) were equal to €3.5 million (Arvidsson & Browne, 2013; BESTUFS, 2001; Cleophas et al., 2018; Eltis, 2015a).

Figure 15 – CarGo Tram Dresden

Source: zdeans97 (2018) (left) and EnercitEE (2011) (right)

Genta et al. (2006) show the feasibility of a freight tram, which would in the current research be considered as light rail, since it can drive both on tramways and on railways, based on the TADIRAM (Advanced Technologies and Innovative Tools for Freight Distribution in the Sustainable City) project that was carried out in Italy. The objectives are to show the feasibility of a new distribution method using the freight tram at different levels, such as administrative, economic, operational, social, technological and user's level. One of the topics of the project is the innovative use of non-road transport vehicles, more specifically a new version of the SIRIO cargo tram, belonging to AnsaldoBreda, transporting load units. The tram can operate on tramways as well as on railways, can be coupled to passenger trams and can be composed according to the demand. Another advantage of this tram is that it has a full flatcar which is at 350 mm from the rail plane and a shutter of more than six metres. In areas where no cables can be used for the energy supply, an alternative system, such as STRAM[12] or batteries, can be used. For the loading and unloading operations, semi-automatic systems are provided.

Gonzalez-Feliu (2014) and Ozturk & Patrick (2018) describe the TramFret project, which took place in Paris. The purpose of the project was to show the feasibility of the delivery of goods by tram and this by using a pilot study in the area of Ile-de-France. The project was launched in 2010, and in 2011, a first pilot was carried out. During 24 days, two empty trams were inserted on line T3, in between the passenger trams (Levifve, 2012). This is visible in Figure 16. The objectives of the pilot were to verify the feasibility of freight transport on the tram network, the capacity of the tramline in absorbing the extra trams and the perception of passengers on the freight trams in between the passenger traffic. In order to measure the passenger perception, surveys were carried out. This first analysis shows that the circulation of an extra tram in the network during the off-peak hours did not have an impact on the tram operations. However, one bottleneck was revealed, being part of the trajectory on which only one track is available for both directions. In 2014, a first experiment with Casino and Carrefour was executed.

[11] In the original source, costs of around 3.500.000 DM are mentioned. This is converted into euro based on the exchange rate established by the ECB (€1 = 1.95583 DM).

[12] STRAM works based on an electrical supply at the centre of the wagon, with a sliding block below the carriage, flexibly connected to the supply (Genta, Marangon, Messina, & Valentini, 2006)

Figure 16 – TramFret pilot project Paris, 2014

Source: TramFret (2019)

In 2017, the pilot project was extended in the French city of St-Etienne (see Figure 17). In the pilot, shops of retailer Casino were supplied by means of the cargo tram. After the pilot, Casino decided not to continue with the tram transport (Antkowiak, 2018).

Figure 17 – TramFret in St-Etienne, 2017

Source: Antkowiak (2018)

Arvidsson & Browne (2013) investigate tram systems in urban freight distribution from a European perspective. After giving an overview of different systems in Europe, a case study is carried out for Amsterdam. The City Cargo project is analysed in terms of conducted interviews, features of the city centre, process, operations and reasons for failure. Marinov et al. (2013) and Eltis (2015b) describe the pilot project that took place between 7 March and 3 April 2007. Two cargo trams were used in the pilot in order to demonstrate the feasibility of delivering goods by cargo tram. However, in 2008, the initiative was declared bankrupt and in 2009, the project stopped because of financing issues.

With the insights of the pilot project in Amsterdam, a theoretical trial for the city of Gothenburg is provided by Arvidsson & Browne (2013). These authors conclude with an overview of differences and similarities between freight tram projects in Amsterdam, Dresden, Vienna and Zurich and a definition of five hurdles for freight trams. These five hurdles are conflicting objectives amongst stakeholders, interference with passenger traffic, radius of action, scale of the project and stakeholder involvement. The authors indicate that the logistics solution for urban freight distribution does not exist.

Regué & Bristow (2013) describe a freight tram scheme for Barcelona. These authors identify the main costs and benefits involved with freight trams and define some main success factors. As a methodology, they use scenarios, a survey and a cost-benefit analysis. The two considered scenarios are the use of the freight tram for delivering goods at four shopping centres in the city centre of Barcelona and the use of the freight tram for collecting residential waste (see Figure 18). Both a face-to-face establishment survey and an observational vehicle count are carried out in order to predict trip rates per establishment type. The variables estimated by this method are trip rates, number of freight trams required, loads, kilometres saved by current commercial vehicles or urban consolidation needs.

The authors conclude that a freight tram is only potentially feasible in case economies of scale are exploited, a minimum demand is served and urban consolidation centres work efficiently, or in case niche markets are used in which the operational costs are currently high and only limited extra infrastructure is needed.

Figure 18 – Potential freight tram scheme in Barcelona

Source: Regué & Bristow (2013)

Gorçun (2014) investigates the potential of light rail systems in the urban area of Istanbul. The author includes the use of light rail, tramways and subways in his analysis and examines if these rail types could be used to supply shopping malls and stores. A cost-benefit analysis is performed for four different areas in Istanbul. Strale (2014) examines the potential of using a freight tram in Brussels. The analysis is done from a geographical perspective and for different types of supply chains. Zych (2014) analyses the potential of introducing a freight tram in Warsaw. The analysis is descriptive.

2.2.1.4 Underground rail transport

Concerning underground rail transport, eight studies are listed in Table 5. Bous (2001) provides a feasibility study on the use of the Amsterdam underground rail transport system for freight distribution. The objective of the study is to combine optimal logistics with a liveable, sustainable city. The study is elaborated along four lines: the long-term logistics scope, the possibilities of the metro system, the potential of the transport markets and the environmental conditions. Furthermore, three implementation stages do exist. The first stage starts "tomorrow", the second three years later and the third six years later. The author concludes that the proposed metro system is feasible under certain conditions, but that substantial investments are needed, while the returns are rather small. Questions that arise are whether the market wants this new system and how private actors can be convinced to cooperate. One of the main problems is the lack of reliable data to anchor better the research.

Taniguchi et al. (2001b) describe underground freight transport systems. In further research, Taniguchi et al. (2001a) define some critical design issues, being layout of the network, tubes, energy supply, terminals, vehicles, dock stations, freight flows and disturbances and recovery, and advise to use simulation modelling to assess these issues. Moreover, these authors describe the Tokyo underground freight transport case. Firstly, the network and the estimated amount of traffic using the network are determined. Secondly, an overview of the system is given and thirdly, a cost-benefit analysis is carried out. These authors conclude that the project would be useful from a socio-economic point of view.

Visser (2003) describes a case study of underground freight transport for the Netherlands and for London. In 1863, the UK Post Office was the first to think of underground freight transport. An underground vacuum tube was constructed over a distance of four kilometres. After a trial of ten months, this idea was abandoned since the tube could not be kept airtight enough. In 1911, a Departmental Committee in London recommended to build an underground autonomous and automated electric railway across central London over a distance of about ten kilometres. In 1914, the construction of the tunnel started. In 1917, the tunnel was finished. The stations are linked to the mail sorting offices by elevators. In 1995 the mail network was containerised (Dorner, 2001; Visser, 2003). Figure 19 shows how the mail train looked like. In 2003, Royal Mail stopped using the mail train, since it became too expensive compared to road transport (Powell, 2017).

Figure 19 – Mail rail in London (1863-2003)

Source: Powell (2017)

Kikuta et al. (2012) investigate the possibility to use the subway of the Japanese city of Sapporo to transport goods. These authors conducted an experiment in September 2010 to transport goods by subway on a hand cart with a gross weight of 60 kg. Figure 20 shows how the hand cart looked like. The results of the questionnaire that was sent out afterwards revealed that 80% of the passengers aboard of the subway did not feel annoyed or uncomfortable because of the hand cart.

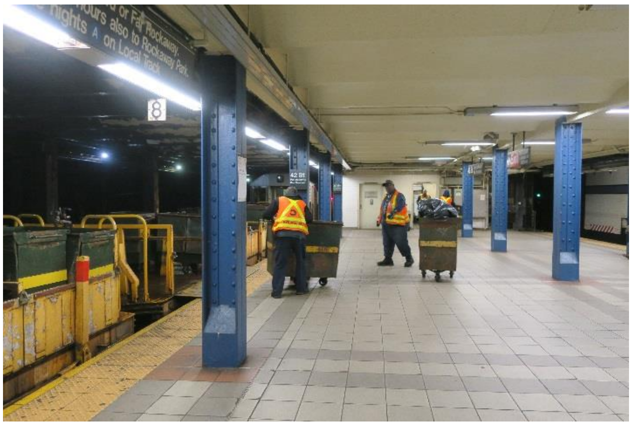
Figure 20 – Transporting goods by subway in Sapporo, Japan

Source: Kikuta et al. (2012)

Marinov et al. (2013) examine, following Motraghi & Marinov (2012) whether rail freight transport would be possible in the metro system of Newcastle-upon-Tyne. Two scenarios are investigated, being the use of dedicated freight metros, and the use of a metro unit that is shared by passengers and freight. The result of this study was that it is possible to insert these metros in between the passenger metros.

Behiri et al. (2018) describe the use of the New York subway system for waste collection. Annually, 14,000 tonnes of waste are collected like this overnight. Eleven garbage trains complete waste runs. This process is displayed on Figure 21.

Figure 21 – Waste collection in New York



Picture: Ann Verhetsel (2018, New York)

2.2.1.5 Rail freight stations

With respect to rail freight stations in an urban area, three studies are shown in Table 5. Dönnhöfer & Eisele (2001) describe the rail freight station in Nuremberg. This is located in a residential area and thus not easily reachable for lorries. These authors briefly describe the freight station in Nuremberg, Germany. Firstly, some characteristics on Nuremberg are provided, such as number of inhabitants, surface and economic structure. Secondly, a short overview is given of the freight station in the city. It is located in a residential area and as a result it is not easily reachable for lorries. A plan exists to move the station towards a freight village.

Ebrardt (2001) also treats this theme and outlines the role of rail freight stations in an urban context. Freight stations at some places are located in the urban areas, but they are not frequently used anymore. The SNCF[13] started in 2001 a project aiming at creating an innovative logistics chain that is better adapted to large urban areas. The project consisted of four main topics. Firstly, the SNCF wanted to promote the use of rail transport between large urban areas by using multi-lots fast trains. Secondly, urban logistic centres were created in the freight stations to load and unload the goods, offering extra services such as storage and showroom possibilities for companies. Thirdly, electric or gas powered lorries were used for the short distance between the urban logistics centre and the final destinations within the urban area. Fourthly, innovative handling materials were used to simplify the logistics activities such as loading/unloading. The project seemed to be economically viable, but it is difficult to convince the different players to change their current transport chains (Ebrardt, 2001).

Ruesch (2001) defines the following categories of benefits when implementing an urban rail freight station: improvement of location attractiveness, increase of rail services attractiveness, modal shift from road to rail, reduction of environmental effects and operational costs and upgrade of the regional rail freight market position. The cost categories consist of cooperation transaction costs, infrastructure measures and investments in for example education of drivers and rolling stock.

[13] SNCF = Société Nationale des Chemins de fer Français; this is the national railway operator in France.

2.2.2 Characteristics of the main urban rail freight initiatives

Several rail initiatives in urban freight distribution exist, all having different characteristics. In order to investigate the potential of rail for urban freight distribution, it is useful to discuss the main light rail and tramway projects more in depth. Table 6 shows the main initiatives[14], ranked chronologically with respect to their starting date, and their characteristics.

The main existing rail projects in urban freight distribution are carried out in Dresden (CarGo Tram), Zurich (Cargo Tram, E-Tram), Amsterdam (City Cargo), Vienna (GüterBim), Paris (Monoprix, TramFret), Rome (multimodal urban distribution centre) and Barcelona (freight tram scheme). These projects are now examined more in depth such that their features can be used when developing the social cost-benefit framework in Chapter 3.

The structure of Table 6 shows that there are two main data categories: the characteristics of the urban area and the characteristics of the initiative. All information provided about the characteristics of the urban area is grouped in five categories, following Figure 3 on page 12: environmental state, freight flows, geography, population density, regulatory framework and transport infrastructure. The column 'environmental state' provides information on the congestion present in the urban area, as well as on the air pollution. The column 'freight flows' offers data on the transport flows of goods considered for each initiative. The column 'geography' shows the size of the urban area, whereas the column 'population density' adds to this the number of inhabitants per square kilometre. The column 'regulatory framework' shows whether measures related to road transport are taken, and the column 'transport infrastructure' highlights whether rail infrastructure is available in the urban area.

The second part of Table 6 displays the characteristics of the project. Here, twelve categories of information are created. The added value category provides information on some added value systems, technology and potential security systems at the establishment or vehicle. The budget category explains the provided budget and the costs. The concession category shows the concession period, while the funding category explains which stakeholder is financing the project. The operational aspects include the rail running time, the current and maximum future frequency, the number of routes, the number of stops, the trip length and a potential limited timeframe. All stakeholders involved in the project in one way or another are displayed in the next column and comprise amongst others the project owner and the number and type of customers.

Savings by adopting the rail-based initiative include the saved road transport (in kilometres and movements), the saved running times, diesel, particle air pollution and other externalities. The transfer category provides information on the features of the transfer point, such as the (un)loading time and location and the equipment used. The transport modes used are discussed in the following column. In the category transport unit, the current and future number of trams, the length of the tram and the tram capacity are indicated. The type of goods comprises the goods that are transported by the rail-based initiative as well as waste and reverse logistics. Ultimately, the use of rail infrastructure outlines the distance travelled on the existing rail lines, the use of public railways and the use of extra railways.

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[14] The main initiatives are the ones for which at least half of Table 6 could be completed.

Table 6 – Overview of past and existing rail projects in urban freight distribution

Initiative	Urban area, country	Status	Characteristics urban area					
			Environmental state	Freight flows	Geography	Population density	Regulatory framework	Transport infrastructure
CarGo Tram	Dresden, Germany	Active since 2000			Small streets in the centre, 328.31 km²	1,696 inh/km² (2017)	Regulations for lorries	Tramways available
Cargo Tram, E-tram	Zurich, Switzerland	Active since 2003; since 2006 also for electric and electronic devices	Strongly congested during peak hours	Waste illegally disposed	99.88 km²	4,580.5 inh/km² (2017)		Tramways available
City Cargo	Amsterdam, the Netherlands	Pilot in 2007, declared bankrupt in 2008	Traffic congestion		164.89 km², narrow streets, many canals	5,186 inh/km² (2018)	Restrictions on lorry access	Tramways available
GüterBim	Vienna, Austria	Stopped in 2007 after pilot project		500,000 tonnes of waste per year	414.9 km²	4,552 inh/km² (2018)		Tramways available
Monoprix	Paris, France	Active between 2007 and 2016	Noise, greenhouse gas emissions, congestion	32 million tonnes of goods per year (2008)	12.012 km², canals	21,067 inh/km² (2017)	Larger time windows for clean vehicles	Tramways available
MUDC Scheme	Rome, Italy	Theoretical study in 2012	Serious congestion in the morning hours due to commuters' car traffic	2009: 80,600 tons of pre-packed white and red meat, various kinds of cold meat, cheese, gastronomy, 20,150 tonnes of industrial ice cream and frozen food, 80,000 tonnes of fruits and vegetables, 7,100 tonnes of fish food	1.287 km²	2,235 inh/km² (2017)		Tramways available; capacity of railway node in Rome is saturated by passenger rail traffic in daytime
Freight tram scheme	Barcelona, Spain	Theoretical study in 2013	27.5% of roads carry 82% of general traffic; 13% of road network is saturated; high levels of NO_2, PM10; failing to satisfy Directive 2008/50/EC on Ambient Air Quality and Cleaner Air for Europe	2008: 88% of establishments are street shops; only 2% is located in shopping centres; daily 475,000 trips to the city or 72,000 freight vehicles that access the city	101.9 km²	15,906 inh/km² (2017)		Tramways available
TramFret	Paris & St-Etienne, France	Pilots between 2014 and 2018			12.012 km², canals	21,067 inh/km² (2017)		Tramways available

Initiative	Urban area, country	Characteristics initiative			
		Added value	Budget	Concession	Funding
CarGo Tram	Dresden, Germany	Just in time, safer and more reliable transport	Cost of €3.5 million for the specialised tram units	15 years	Private: Volkswagen
Cargo Tram, E-tram	Zurich, Switzerland	New container carried on flat wagons, pulled by a converted tram; two standard refuse containers have been adapted on two four-wheeled flat wagons that are pulled by a tram and painted differently from passenger trams; there is a press for bulky goods in the new container	Cost of €32,000 for converting old trams and wagons in a functional unit; €3,200 per ride (in 2005); implementation took €20,000.		Public: municipality
City Cargo	Amsterdam, the Netherlands		15% cheaper on operational basis than conventional set up with lorries; project costs of €70 mln; €1 mln (2010) per km track for parking purposes; €150 mln was needed for the project; a budget of €69 mln from different companies such as Nuon and Rabobank was available	10 years (normally 6, but extended by the city)	Private: banks and City Cargo
GüterBim	Vienna, Austria		Cost of €1.4 million for the pilot project		Public: municipality
Monoprix	Paris, France	Pallets on rail shuttle, an integrated NGV public station near the area of Gabriel Lamé where the goods are sorted	Extra costs due to the use of rail transport, the operation of the depot at Bercy Station, additional transhipment and use of NGV; cost per pallet is now €17.61 (compared to €13.25 for old scheme)		Private: Monoprix
MUDC Scheme	Rome, Italy	Specially designed intermodal transport units that can be used for small pick-up/delivery vehicle in cities (conventional smallest ITU is more than 6 m long and 2.5 m wide with overall weight of 14-20 tonnes). This case: pallets with boxes of fish food in refrigerator cars for train leg and then transfer to refrigerated small lorries; alternative fuelling	The social cost decreases by 82% in the third scenario; operating costs per km in third scenario €1.92 (>< €1.14 in reference scenario) and operating cost per tonne €96.91 (>< €150.19 in reference scenario)		
Freight tram scheme	Barcelona, Spain		Retail deliveries operating costs per year: €534,000; waste collection operating costs: €352,000 per year; cost of new track for retail deliveries: €10,223,000 (2009) and for waste collection: €983,000 (2009); cost of a single freight tram: €1,800,000 (2009)		
TramFret	Paris & St-Etienne, France		Cost of €20,000 for the trial in Paris.		Paris: APUR, Ile-de-France, City of Paris, DRIEA, IAU, RATP, Railway network of France, Police department, Transport Trade Union Ile-de-France, ADEME

Initiative	Urban area, country	Characteristics initiative		
		Operational aspects	Stakeholders involved	Savings
CarGo Tram	Dresden, Germany	Current frequency of 1 tram/hour, maximum future frequency of 1.5 trams/hour; tram running day of 16 hours/day and 6 days/week; 1 route from the Volkswagen factory to the Volkswagen Logistics Centre without stops in between and a trip length of 15 min	Volkswagen (= only private customer; owner of the project), Transportation Services of Dresden (DVB), government	Yearly saved road transport of 200,000 km or 60 lorries/day (three lorries per tram)
Cargo Tram, E-tram	Zurich, Switzerland	Current frequency of 4 times a month; each time from a different pick-up point; drives from the tram terminus in Werdhölzli, next to the ERZ waste disposal yard and stops at 11 different locations	Entsorgung und Recycling Zürich (ERZ), tram company VBZ, municipality (owner of the project), public customers	Yearly saved road transport of 5,020 km, 960 hours and 37,500 l diesel; yearly saved CO_2 of 4.9 tonnes (2005)
City Cargo	Amsterdam, the Netherlands		GVB trams, Joint-venture of City Cargo BV (= private project owner) and City of Amsterdam, commercial customers	Yearly road savings of 2,500 movements; yearly saved air pollution of 15%; yearly operational cost savings of 15%
GüterBim	Vienna, Austria	One route and only movements of supplies between tram depots are tested; three city terminals	Ministry of Transport and Innovations (project owner), Wiener Linien, Wiener Lokalbahnen, two consulting companies; commercial/public customers	
Monoprix	Paris, France	Was operational from Monday to Friday, from two warehouses in Combs-La-Ville and Lieusaint (Seine et Marne), for 30 km on line D of the RER to the market Gabriel Lamé of the Bercy station; trip length of 1 hour by tram (tram leaves at 8 pm) and the lorry delivers the goods the day after	Samada (= subsidiary of Monoprix), Regional Direction of the equipment of Ile-de-France, Mayor of Paris, Region Ile-deFrance, Rail Network of Paris, Monoprix; in 2009, 90 stores of Monoprix, Monop' and Beauty monop were delivered	Yearly saved road transport of 700,000 km, 12,000 lorries and 70,000 l diesel; saved externalities by anti-noise devices on the vehicles and by automatic gearboxes; yearly saved CO_2 of 340,000 tonnes and yearly saved NOx of 25 tonnes
MUDC Scheme	Rome, Italy		Fresh Food Centre (FFC; logistics service provider for fresh food for supermarket chains)	In case of design scenario with hybrid vehicles: 77% CO_2, 99% CO, 95% HC, 96% NOX, 94% PM saved. But increase of SO_2 emissions: negligible for road but 106 g in rail
Freight tram scheme	Barcelona, Spain	Current frequency of three or four trams per day for retail; two trams for waste; stops at four large shopping centres and the Ecoparc; the tram drives 81.16 km per day and waste collection occurs during 1am and 5am when the passenger trams do not operate		Yearly saved road transport of 302,442 km for retail and 52,400 km for waste; 2.94 trips per week per establishment (342 establishments), 1,005 trips per week or 52,260 trips per year (35,432 by vans, 16,828 by lorries) for retail; seven waste collection lorries per year
TramFret	Paris & St-Etienne, France	Paris: two to four trams daily during pilot in 2014, two return journeys each day, from Monday to Saturday during off-peak periods; one route on the line T3 (Pont du Garigliano - Porte d'Ivry); two delivery points during the pilot	Paris: APUR, Ile-de-France, City of Paris, DRIEA, IAU, RATP, Railway network of France, Police department, Transport Trade Union Ile-de-France, ADEME, Carrefour & Casino (commercial customers)	

Initiative	Urban area, country	Characteristics initiative				
		Transfer	Transport mode	Transport unit	Type of goods	Use of rail infrastructure
CarGo Tram	Dresden, Germany	20 min cargo unloading time at the origin; cargo unloaded at the Volkswagen factory by means of forklifts	No pre-/post-haulage	Two cargo trams of 60 m, with a capacity of 214m³ or 60 tonnes	Volkswagen components (automotive parts); all parts except car frames	4 km on the existing public tramways and 1 km on an extra tramway
Cargo Tram, E-tram	Zurich, Switzerland	Residents can leave their bulky items at the tram stops from 3 pm to 7 pm	Walking, biking	Surplus tram units are used	Bulky waste from households, electronic home and industrial equipment; goods of low intrinsic value that are not time sensitive	Main lines of the tramway network and unused sidings are used; no extra tramways are constructed
City Cargo	Amsterdam, the Netherlands	Two transfer points in the city	Electric vehicles	Ten cargo trams (during pilot only two trams were running); in the next four years, 50 cargo trams would be used	Heineken beer for pubs, clothing for Mexx, commercial parcels, waste paper in reverse logistics	Public tramways are used, but only lines that have enough capacity to avoid problems with passenger trams and tramways that are no longer used; extra tramways were needed because the transport company did not allow City Cargo to use dead tracks (for parking)
GüterBim	Vienna, Austria		Rail and tram (for containers)		Hospitals, shops, retailers, waste disposal, spare vehicle parts	Use of the main public network
Monoprix	Paris, France	Cargo is loaded between 1 pm and 6.30 pm and unloaded at the Monoprix stores in the city centre of Paris	NGVs (26 lorries in 2008)	Five trains of 20 rail wagons	Textile, beauty products, soft drinks, hobby and housing products	Use of the public tramways of the RER, line D and extra connections between the two warehouses and the railway network
MUDC Scheme	Rome, Italy	2h for queuing before unloading, at stops and unloading (in conventional scheme); cargo unloading is between 4 am and 6 am (in conventional scheme)	Low pollution lorries such as diesel-electric hybrid vehicles, hybrid power train, fully electric vehicles		2.2 tonnes of fish	Use of public tramways for 2,5h (in conventional scheme)
Freight tram scheme	Barcelona, Spain			Two cargo trams per scenario (so four in total), with a capacity of 35 tonnes each	Waste, retail; average waste per person per year 349 kg general; 56 kg organic	Use of public tramways, use of extra tramways of 1.04 km for retail deliveries and 0.10 km for waste collection; the total track length for waste is 32.9 km
TramFret	Paris, France				Retail	Use of public tramways and railways

Source: Own creation based on Ajuntament de Barcelona (2018), Alessandrini et al. (2012), APUR (2014), Arvidsson (2010), Arvidsson & Browne (2013), Centre-Ville en Mouvement (2013), Cleophas et al. (2018), Delaître & De Barbeyrac (2012), Eltis (2015a, 2015b), Issenman et al. (2010), Janjevic, Kaminsky & Ballé Ndiaye (2013), Landeshauptstadt Dresden (2018), La prefecture et les services de l'Etat en region (2018), Levifve (2012), Madden (2011), Maes & Vanelslander (2011), Monoprix (2007b), Motraghi (2013), Neuhold (2005), OIS Amsterdam (2018), PRONET (2007), Regué & Bristow (2013), Roma (2017), Stadt Wien (2018), Strale (2014), Ziegler (2007)

A general observation from Table 6 is that only two of the initiatives are currently operational, being the CarGo Tram in Dresden and the Cargo- and E-Tram in Zurich. The other initiatives either stopped after a pilot period (City Cargo in Amsterdam, GüterBim in Vienna and Monoprix and TramFret in Paris), or are only theoretically explored (freight tram scheme in Barcelona and MUDC scheme in Rome). Some interesting lessons can be learned from the projects that are still operational, as well as from the projects that stopped. In Section 2.3, main success and failure factors are derived from these projects, and these factors are later on in this research used when developing the social cost-benefit framework.

2.2.3 Initiatives per type of tram and light rail transport

The rail-based initiatives are presented in Table 7 according to the rail typology discussed in Section 2.1.2. It is clear that most initiatives deal with a dedicated freight vehicle and with the transport of freight alongside passengers. Most initiatives with respect to a dedicated freight vehicle are however theoretical studies or projects that stopped, whereas almost all examples of transporting freight alongside passengers are real-life cases. For these real-life cases, especially newspapers and websites provide information. This is why these initiatives were not mentioned previously in this research. The transport of goods in a wagon attached to a passenger vehicle is the type of transport that is examined or used the least.

Table 7 – Urban rail freight initiatives according to the type of rail transport

Dedicated freight vehicle	Wagon attached to passenger vehicle	Freight alongside passengers
CarGo Tram Dresden	Drinks, Great Toronto and Hamilton Area	DHL runners, JogPost
Cargo Tram & E-Tram, Zurich	Supplying stores and malls, Istanbul	Express parcels Amtrak, USA
City Cargo, Amsterdam		Hand cart in subway, Sapporo
Freight tram, Barcelona		Lunchboxes dabbawalas, Mumbai
Freight tram, Brussels		Mailbox in tram Citipost, Bremen
GüterBim, Vienna		Parcels A-WayExpress, Canada
Logistiktram, Frankfurt		Parcels ic:kurier, Germany
TramFret, Paris/St-Etienne		

Source: Own creation based on Amtrak (2019), Arvidsson (2010), Arvidsson & Browne (2013), A-WayExpress (2019), Cleophas et al. (2018), Cochrane et al. (2017), Daily Mail (2012), Gonzalez-Feliu (2016), Kikuta et al. (2012), Marinov et al. (2013), Motraghi & Marinov (2012), Ozturk & Patrick (2018), Percot (2014), Posttip.de (2007), Regué & Bristow (2013), Strale (2014), time:matters (2019), VGF (2018)

2.2.3.1 Dedicated freight vehicle

The most examined way of transporting goods by tram is by using a dedicated freight tram. These trams were used until the beginning of the 20th century to transport various types of goods. Around 1950, these trams were taken out of operation due to the increasing popularity of the car (Annys et al., 1994; Van Heesvelde, Troubleyn, De Troy, & De Meyer, 2018). Some examples of more recent dedicated freight trams are the CarGo Tram of Volkswagen in Dresden (since 2000), and the Cargo-Tram and E-Tram in Zurich (since 2003) (Arvidsson & Browne, 2013; Cleophas et al., 2018; Marinov et al., 2013). Other pilot projects that have taken place are amongst others City Cargo in Amsterdam (2007) (Motraghi & Marinov, 2012), GüterBim in Vienna (2007), TramFret in Paris (2014) and St-Etienne (2018) (Cleophas et al., 2018) and Logistiktram/LastMile Tram in Frankfurt (2018) (ReLUT, 2018; VGF, 2018).

In the academic literature, several authors pay attention to the possibility of using a dedicated freight tram. Arvidsson (2010) suggests to use old passenger tram vehicles to transport freight. Arvidsson & Browne (2013) examine the success of the City Cargo freight tram project in Amsterdam. Regué & Bristow (2013) investigate the use of the tram infrastructure in Barcelona for the transport of retail products and waste and conduct a cost-benefit analysis. Strale (2014) evaluates the potential of using a freight tram in Brussels for different types of supply chains.

Gonzalez-Feliu (2016) examines the costs and benefits of the TramFret project in France. Ozturk & Patrick (2018) also describe the latter project, confirming that for this case study too, recycled passenger trams are used. Cochrane et al. (2017) analyse different freight on transit strategies, including the transport of packages between the airport and the central station in the Greater Toronto and Hamilton area by dedicated freight trains, and supplying retailers in a large shopping centre by a dedicated metro. Cleophas et al. (2018) describe the CargoTram and E-Tram in Zurich, which is a dedicated freight tram using the available public tram infrastructure. The GüterBim in Vienna is another case study discussed by these authors, where a dedicated freight unit also used the available passenger tram infrastructure. Some new tram sections had to be constructed in order to deliver the goods to some stores and restaurants in the city.

2.2.3.2 Freight wagon attached to passenger vehicle

Examples of freight vehicles attached to passenger trams are less occurring. In 1911, the so-called "suitcase tram" was used in Belgium. This was a closed freight wagon attached to a passenger wagon in which the suitcases of travellers were stored. During World War I, these freight wagons were used to transport other types of freight. Since 1961, the wagon is not operational anymore (Van Heesvelde et al., 2018, p. 110). Gorçun (2014) proposes to add one or two freight wagons behind passenger wagons for supplying stores and shopping malls in Istanbul during the daytime. Shen et al. (2015) explore the idea of transporting freight in trailers attached to a scheduled public passenger bus. In their proposed system, the trailers are automatically unloaded at a certain bus stop, while the passengers get on or off the bus. Cochrane et al. (2017) investigate the transport of drinks in a freight wagon attached to a tram during off-peak hours in the Great Toronto and Hamilton area. Behiri et al. (2018) propose to have some dedicated freight cars at the back of the train, which are inaccessible for passengers.

2.2.3.3 Freight in a passenger vehicle

The most known example of transporting freight in public transport passenger vehicles is the transport of mail. Examples of mail transport by passenger buses or trams are especially found for the 19th and 20th century, for example in Belgium and Germany (Annys et al., 1994; Cleophas et al., 2018; Fredriks.de, 2018). Robinson (1995) describes the use of multi-functional vehicles that can transport both passengers and parcels in rural areas in Scotland since 1979. The type of goods considered here are medical supplies between hospitals and surgeries. Since 2007, Citipost has placed mail boxes in trams in Bremen, in which passengers can depose their mail (Posttip.de, 2007).

In 2012, courier company DHL cooperated with JogPost to deliver parcels in London during the Olympic Games. The running couriers combined running with using public transport. By doing this, the couriers could avoid the increased road congestion during the Olympics (Daily Mail, 2012).

Kikuta et al. (2012) organised a pilot in which a hand cart was loaded on board of a passenger subway wagon in the Japanese city Sapporo. In more recent studies, both the use of a bus and a tram and train is examined. Cochrane et al. (2017) examine the transport of low-priority mail and packages in freight compartments in commuter trains. Pimentel & Alvelos (2018) propose a model in which the city bus network is used to transport parcels. The model is applied to buses following a fixed route. Hence, the system can be compared to an urban tram network, having as an intrinsic characteristic that the trams also have to follow a fixed route.

Which of these types of tram transport is appropriate for which transport flow depends on multiple factors, including amongst others the available transport infrastructure, the goods volume, the time of the transport, the measures taken by the authorities and the presence of congestion (Alejandro Cardenete & López-Cabaco, 2018; Arencibia, Feo-Valero, García-Menéndez, & Román, 2015; Regué & Bristow, 2013). In order to determine how critical these factors are to successfully implement a tram for urban freight distribution, a detailed cost-benefit analysis is necessary. Due to the complexity and the different environmental factors affecting the success potential, the need exists to develop a generic model that allows taking into account all kinds of complexity.

In Mumbai, India, the so-called dabbawalas deliver lunch boxes to office employees by travelling by public transport (Percot, 2014). In the USA, Amtrak offers an express shipping service. Small packages up to 23 kg can be shipped between more than 100 cities. Moreover, some major Amtrak stations handle pallets up to 227 kg (Amtrak, 2019). A-WayExpress is a courier company in Canada at which all couriers use public transport to deliver parcels (A-WayExpress, 2019).

In Germany, ic:kurier, part of Lufthansa Cargo Group, delivers parcels up to 20 kg within Germany and to and from Amsterdam, Basel, Paris and Vienna. The parcels are transported using IC, ICE and EC trains and the service is available in more than 140 train stations. Pick-up and delivery can also be included in the service, by more than 200 courier partners (time:matters, 2019).

In sum, several urban rail freight projects have been examined, and some of them are anno 2019 still operational (e.g. Dresden, Zurich). However, a detailed comparison of the characteristics of these initiatives in order to understand the conditions under which using rail for urban freight distribution is viable, is still lacking. Therefore, the following section focuses on deriving the main success and failure factors of urban rail freight.

2.3 Success and failure factors

In general, it is difficult to determine the conditions under which the use of rail transport for urban freight distribution is a success. This always depends on the local conditions (BESTUFS, 2001; Comi et al., 2014). Depending on the contextual factors, the solution can be successful or not for a specific initiative. Therefore, it is important to examine which characteristics of using rail transport for urban freight distribution are respectively leading to success or failure. The purpose of knowing the critical success factors is to apply them to the generic model that is developed in the next chapters to estimate the potential of rail for urban freight distribution.

Success and failure factors are defined in this research as factors that came up in urban rail-based initiatives and appear to be crucial for the success or failure of the initiative. A success (failure) factor can also be derived from a project that failed (succeeded) in the end, since other, negative (positive) factors can have caused the failure (success). A factor is considered successful if it contributes in making the urban rail-based initiative viable from a private and/or social perspective. In other words, it assists in providing net benefits when implementing the project.

Success and failure factors can be derived from the literature on modal shift and multimodal transport[15]. Often, no door-to-door rail service is available and thus, additional road transport is needed to complement the rail leg. Motraghi (2013) distinguishes among seven failure factors of

[15] Other concepts derived from multimodal transport include intermodal transport, co-modality (Agamez-Arias & Moyano-Fuentes, 2017), combined transport and synchromodal transport (Ambra, Caris, & Macharis, 2019). The difference between the meaning of these concepts is not crucial for the scope of this research and therefore, it is chosen to only refer to multimodal transport here.

multimodal transport, being the lack of cooperation between stakeholders, the lack of multimodal travel information services, the competition with other modes, interoperability and safety requirements, infrastructural hurdles, logistics concepts hurdles and financial and economic hurdles. Reis et al. (2013) state that the rail lead time has to be reduced in order to make rail an attractive mode. Moreover, the operational costs of multimodal transport are higher than the ones of road transport due to the additional handling. Success factors mentioned by these authors are the better environmental performance of rail compared to road. Failure factors include the additional handling, and political resistance. Islam et al. (2016) summarise the requirements of rail freight shippers in Europe, derived in the SPECTRUM study (Jackson, Islam, Zunder, Schoemaker, & Dasburg, 2014): fast and reliable rail lead times, lower operational rail costs, frequent service, high safety and security, and the better environmental performance of rail compared to road.

Behrends (2017) highlights the need for urban transport planning involvement in order to facilitate a modal shift. This author lists some critical issues related to the performance of multimodal rail transport. The high costs of rail transport on short and medium distances and the capacity bottlenecks on long distances are important to mention here. Islam & Zunder (2018) identify hurdles of multimodal transport for low-density high value goods based on some case studies. The main hurdles include the resistance of customers to change their current transport patterns, intense competition from the road sector, the lack of understanding of the railway sector of perishable goods, the lack of interest of the rail sector in new business markets, the lack of communication and innovation in the rail sector, the rail service level, the operating hours of handling and storage points, the lack of a power and control system to transport temperature controlled goods, capacity constraints in the rail network, and the rail lead time.

The success and failure factors listed in the paragraphs above give a first indication of the main success and failure factors of using rail transport. However, these factors are applicable to rail freight transport in general and not to an urban context specifically. It can be argued that the urban rail freight product has some specific characteristics given the relatively short distances that are covered. Therefore, this section offers an analysis of the success and failure factors of existing and past rail-based urban freight distribution projects. All the initiatives discussed in Section 2.2, whether they are still operational, in a pilot status, only theoretical, or stopped, give very interesting insights in the main success and failure factors of rail-based urban freight solutions. For the classification of the success and failure factors, the structure of Janjevic et al. (2013) is used. These authors propose a list of attributes for characterising a case study and the environment in which it is developed. The purpose of this list is to assess whether the implementation of the same initiative in another target urban area is likely to succeed.

2.3.1 Success factors

Success factors are derived from the past and existing projects provided in Section 2.2. Table 8 reveals different success factors for five main tram-based projects, being CarGo Tram in Dresden, Cargo Tram and E-Tram in Zurich, City Cargo in Amsterdam, GüterBim in Vienna and TramFret in Paris. The light rail initiative of Monoprix is not included in the analysis here. It is the only light rail initiative that is not only theoretical and that is discussed in Table 6. Hence, success and failure factors could be completely idiosyncratic to this specific case. Additionally, general success factors for urban freight distribution by tram are displayed. The factors are ranked according to the proposed structure of Janjevic et al. (2013), being a subdivision between the operations, the target city environment, the urban logistics spaces and the vehicles. The objective of Table 8 is to obtain a list of success factors, although this table does not offer a ranking of these factors yet. The ranking of importance of these factors is obtained in

Chapter 6 through sensitivity and scenario analyses. The different success factors are now discussed more in detail.

Table 8 – Success factors of using rail for urban freight distribution

Success factor		Urban rail freight initiative					
		CarGo Tram Dresden	Cargo Tram and E-Tram Zurich	City Cargo Amsterdam	GüterBim Vienna	TramFret Paris	Rail in general
Operations	Just in time strategy						Foyer (2001)
	Non-time-sensitive, low value commodity		Robinson & Mortimer (2004)				Maes & Vanelslander (2011)
	Standard units						Comi et al. (2014), Diziain et al. (2014), Dorner (2001), Rien & Roggenkamp (1995), Woodburn (2014)
	Time gains		Arvidsson & Browne (2013), Robinson & Mortimer (2004)				Comi et al. (2014), Marinov et al. (2013)
	Value added services						Behrends (2012b), Comi et al. (2014)
Target city environment	Congestion present		Arvidsson & Browne (2013)	Arvidsson & Browne (2013)			Diziain et al. (2014), Ruesch (2001)
	Good environmental performance of rail	Arvidsson & Browne (2013), Marinov et al. (2013), Zych (2014)	Arvidsson & Browne (2013), Marinov et al. (2013), Robinson & Mortimer (2004)	Arvidsson & Browne (2013), Marinov et al. (2013), Zych (2014)		Levifve (2012)	Alessandrini et al. (2012), Cochrane et al. (2017), Dorner (2001), Gorçun (2014), Mortimer (2008), Motraghi (2013), Regué & Bristow (2013), Strale (2014), Zych (2014)
	Low fatality risk			Arvidsson & Browne (2013)			Arvidsson & Browne (2013), Mortimer (2008), Regué & Bristow (2013)
	Other urban freight distribution measures						Comi et al. (2014), Le Martret & Perreau (2013)
Urban logistics spaces	Ancillary revenue						Comi et al. (2014)
	Synergies						Comi et al. (2014)
Vehicles	Tram dimensions	BESTUFS (2001)					

Source: Own creation

Concerning the operations, five main success factors are distinguished among: just in time strategy; non-time-sensitive, low value commodities; standard units; time gains and value-added services. Firstly, in case the final customer in the urban area that receives the goods applies a just in time strategy, rail transport could offer an option. However, in order to apply a just in time strategy, factors such as communication and security, intermodal synchronisation, size of the terminal and rail information have to be optimised. With respect to communication and security, interfaces have to be developed between different transport modes and between origins and destinations of freight (Foyer, 2001).

Secondly, non-time-sensitive, low value commodities are suitable for transport by rail (Maes & Vanelslander, 2011; M. Robinson & Mortimer, 2004a). Dorner (2001) states that the transport of time-sensitive goods is not appropriate to be done by rail transport. In Zurich, the CargoTram transports an example of this type of freight, i.e. waste.

A third success factor concerning the operations is to use standard units to transport goods (Centre-Ville en Mouvement, 2013; Diziain et al., 2014; Woodburn, 2014). Standardised logistics boxes with different standard sizes that can be used by both road and rail transport can offer a solution for urban freight distribution (Dorner, 2001). Rien & Roggenkamp (1995) describe the so-called "Logistikbox", which is a mix of a euro pallet and a container. The box can be transferred from a lorry to a train horizontally by forklifts. Multimodal long distance transport systems have benefited from the introduction of containerised units. In a trial in London, roll cages were used that are similar to trolleys that were used to transport mail and parcels in the 1970s (Woodburn, 2014). Maritime containers are not suitable for city transport (Comi et al., 2014; Foyer, 2001). ISO shipping containers and tri-axle containers are too large for urban freight distribution and for other containers often no standards exist. Therefore, it can be beneficial to develop a standard city container that is modular, space- and unload-friendly, secure and that fits for food, clothing, catering, consumer durables, etc. (Foyer, 2001).

Fourthly, time gains coming from a new initiative are crucial for its success (Comi et al., 2014; Marinov et al., 2013). By using new technologies, a higher speed is possible for rail transport than for road transport (Dorner, 2001). Due to increasing congestion in many urban areas, time gains could be obtained by using rail transport. This can for example lead to lower driver costs. Therefore, it is interesting to compare the road and rail costs for a certain urban freight distribution case in hours and not only in kilometres (Arvidsson & Browne, 2013). The Cargo Tram and E-Tram in Zurich for example offers a faster solution for the transport of waste than traditional lorries (M. Robinson & Mortimer, 2004a).

Another success factor is turning the additional transhipment point that is often needed for rail transport into an opportunity to offer value added services to the goods. It is important to compensate for the additional transhipment by offering efficiency gains (Comi et al., 2014). An example of a value added service is to provide inventory space for the shipper to store goods at the transhipment point. This leads to lower inventory costs for the shipper at its shop in the urban area (Behrends, 2012b). At the BESTUFS workshop (2001), this success factor was also raised in the sense that underground maintenance spaces for metros could be used for storage and transhipment purposes. However, railway stations are often not designed for accepting freight (Comi et al., 2014). A potential problem here is that elevators need to be available to bring the goods at street level (BESTUFS, 2001).

With respect to the target city environment, four success factors are derived: the presence of congestion, the good environmental performance of rail, the low fatality risk and other urban freight distribution measures. Firstly, the implementation of a transport solution that does not imply the use of road transport is more favourable in case some road issues are present in the urban area. Increasing congestion is a first example of a condition in which a rail-based solution could bring some benefits (Diziain et al., 2014; Ruesch, 2001).

The second success factor in this category is the better environmental performance of rail transport compared to road transport (Alessandrini et al., 2012; Cochrane et al., 2017; Levifve, 2012; Marinov et al., 2013; Zych, 2014). For example, the energy usage of rail lays 75% lower than road transport (Dorner, 2001). Rail transport has a lower energy and environmental impact than road transport (Mortimer, 2008). The potential to reduce accidents, air pollution, congestion, noise and road maintenance costs is present (Regué & Bristow, 2013). The reduction of air pollution, congestion and noise are mentioned by Motraghi (2013) and Strale (2014) as the main benefits of rail compared to road.

Thirdly, rail transport has the advantage of having a lower fatality risk than road transport (Arvidsson & Browne, 2013; Mortimer, 2008).

Ultimately, rail-based urban freight initiatives are often more successful when other measures are taken concerning road transport (Comi et al., 2014; Le Martret & Perreau, 2013). For example in 2020 in Paris, no diesel lorries will be allowed to enter the city centre any longer. In Montpellier, more and more areas are becoming pedestrian zones to which lorries do not get access (Centre-Ville en Mouvement, 2013). In Belgium, road pricing for heavy goods vehicles was introduced in 2016 (Viapass, 2018). This makes the use of a freight tram more attractive, since shippers will have to find other transport solutions. An important note here is that the costs for the operator and the price for the consumer are relative measures based on their perception. A rail solution that is under the current conditions more expensive than the road solution might be cheaper in case some measures for road transport are taken such as road pricing and tolls to enter the city centre by lorry (Comi et al., 2014).

In case transport operators have to pay to enter the urban area by road transport, the potential additional costs of using rail transport can be compensated for. Freight operators who want to enter the city of Rome for example, have to pay an annual fee of €500. This amount does not seem to be high enough to encourage operators to shift from road to rail. In many past and current projects examining the use of rail, the conclusion is that it is too expensive compared to the current road transport solution. This can be solved by increasing the cost of the current road transport, for example by internalising external costs (Comi et al., 2014).

Concerning the urban logistics space, two success factors emerge from existing projects: ancillary revenue and the presence of synergies. Firstly, rail initiatives can benefit from ancillary revenue. This is for example the case in Dresden, where part of the success of the freight tram of Volkswagen is related to ancillary revenue. By using the freight tram, the company shows that it wants to be sustainable (Comi et al., 2014). Another example is the LOGeco pilot project in Rome, carried out in the historic centre. The project drew the attention of Gucci, which wanted to participate because of marketing reasons (Filippi & Campagna, 2014). For example in a freight village near Padova, an urban freight solution was implemented in which the logo on the lorries was removed. This caused huge issues, because the visibility of the companies participating in the project disappeared (Comi et al., 2014).

The second factor leading to success here is to combine multiple activities in one warehouse and to obtain synergies. Potential locations for cross-docking activities are the railway stations within an urban area. Sometimes free space is still available there, which is sold for residential or commercial purposes. This space could also be used as a warehouse for the goods that arrive by train (Filippi & Campagna, 2014; Woodburn, 2014). By using the space for both warehousing and offices, the warehouse investment costs that have to be financed by the rail initiative decrease. The fact that a warehouse in the urban centre can be offered, can also attract stakeholders to use the rail-based solution (Comi et al., 2014).

Ultimately, one success factor related to the vehicles is derived. The key success factors of the CarGo Tram in Dresden are the length of the tram, which is 60 metres, the load capacity, which is equal to the capacity of 2.5 lorries with a load space of 214 m^3 and 60 tonnes of weight and the length of the contract between Volkswagen and DVB, which is 15 years. The main challenge in this project was to find a manufacturer who agreed to only build two trams. The final conclusion is that the project is profitable. However, by increasing the number of transfer points in the city, the operations would be unprofitable (BESTUFS, 2001).

As a conclusion of this section, the main success factors that emerge from existing and past projects are enumerated. In Table 8 it can be seen that especially the good environmental performance of rail transport is a factor leading to success. It is mentioned in almost all freight tram cases. This corresponds to the main success factor derived from the general modal shift and multimodal transport literature in the beginning of Section 2.3. A possible explanation for this is the fact that most freight tram initiatives are not feasible when assessed only from a business point of view. When adding the social-environmental aspects, such as the environmental performance of the transport mode, the analyses often lead to more positive results. Following the importance of the environmental performance, the presence of congestion in the urban area also influences the chance of success of a rail-based urban freight solution.

2.3.2 Failure factors

Following Arvidsson & Browne (2013), it is most interesting to investigate besides the success factors of projects also the failure factors. Therefore, Table 9 displays the main failure factors of rail-based urban freight distribution initiatives. The structure of Table 9 is similar to the overview of the success factors in Table 8 and here too, no ranking of the factors is made. No failure factors concerning the urban logistics space are derived and most factors are related to the operations.

With respect to the operations, seven failure factors emerge: amount of goods to be transported, high investment costs, lack of cooperation between stakeholders and stakeholder involvement, low flexibility, low service level, pre- and post-haulage, extra handling and transit time, and stakeholder resistance. These failure factors are discussed in depth in the following paragraphs.

The first failure factor related to the operations concerns the amount of goods to be transported. A certain critical mass is needed to make rail transport profitable (Comi et al., 2014; Strale, 2014). This critical mass is often higher than the critical mass needed to make road transport profitable (Arvidsson & Browne, 2013; Maes & Vanelslander, 2011; Mortimer, 2008). Especially on distances of less than 100km, the modal share of road transport is high, i.e. between 70-80%. Shipment sizes are decreasing, hence increasing the number of deliveries (Ruesch, 2001). Large volumes can be obtained from big retailers who already ship large volumes (Comi et al., 2014; Ruesch, 2001). Alternatively, freight of different suppliers can be consolidated (Comi et al., 2014). Local authorities could take the initiative to identify specific locations where freight is generated (Foyer, 2001; Haywood, 1999). Additionally, it is important to also consider reverse logistics. A large amount of goods has to be transported back from the retailers to the suppliers (Comi et al., 2014).

Table 9 – Failure factors of using rail for urban freight distribution

	Failure factor	Urban rail freight initiative					
		CarGo Tram Dresden	Cargo Tram and E-Tram Zurich	City Cargo Amsterdam	GüterBim Vienna	TramFret Paris	Rail in general
Operations	Amount of goods	Jonction & Verkehrs-Consult Dresden-Berlin (2013)					Comi et al. (2014), Dorner (2001), Haywood (1999), Maes & Vanelslander (2011), Mortimer (2008), Regué & Bristow (2013), Ruesch (2001), Strale (2014)
	High investment costs	Arvidsson & Browne (2013), Cleophas et al. (2018), Marinov et al. (2013)	Cleophas et al. (2018), Marinov et al. (2013)	Arvidsson & Browne (2013), Issenman et al. (2010), Marinov et al. (2013)	Regué & Bristow (2013)		Bergqvist (2007), Cochrane et al. (2017), Comi et al. (2014), Dinwoodie (2006), Diziain et al. (2014), Dorner (2001), Marinov et al. (2013), Motraghi (2013), Regué & Bristow (2013), Robinson & Mortimer (2004a), Ruesch (2001)
	Lack of cooperation between stakeholders & stakeholder involvement (including politicians)	Cleophas et al. (2018), Jonction & Verkehrs-Consult Dresden Berlin (2013)	Cleophas et al. (2018), Marinov et al. (2013)	Arvidsson & Browne (2013)	Regué & Bristow (2013), Ziegler (2007)		BESTUFS (2001), Bous (2001), Cleophas et al. (2018), Cochrane et al. (2017), Comi et al. (2014), Diziain et al. (2014), Dorner (2001), Macário & Marques (2008), Marinov et al. (2013), Motraghi (2013), Regué & Bristow (2013), Ruesch (2001), Strale (2014)
	Low flexibility	Marinov et al. (2013)					BESTUFS (2001), Dönnhöfer & Eisele (2001), Dorner (2001), Marinov et al. (2013), Robinson & Mortimer (2004a)
	Low service level						BESTUFS (2001), Ruesch (2001)
	Pre- and post-haulage, extra handling, transit time		Marinov et al. (2013)				Behrends (2012b), Bergqvist (2007), Cochrane et al. (2017), Comi et al. (2014), Dorner (2001), Foyer (2001), Mortimer (2008), Robinson & Mortimer (2004a), Ruesch (2001)
	Stakeholder resistance	Arvidsson & Browne (2013)	Arvidsson & Browne (2013)	Arvidsson & Browne (2013)	Arvidsson & Browne (2013)		Cochrane et al. (2017), Nuzzolo et al. (2007)
Target city environment	Interference with passenger transport	Arvidsson & Browne (2013)	Arvidsson & Browne (2013)	Arvidsson & Browne (2013), Marinov et al. (2013)	Arvidsson & Browne (2013)		Cochrane et al. (2017), Comi et al. (2014), Marinov et al. (2013), Motraghi (2013), Robinson & Mortimer (2004a), Ruesch (2001), Strale (2014), Woodburn (2014)
	Pressure on railway areas						Ruesch (2001)
Vehicles	Technological limitations			Arvidsson & Browne (2013)			

Source : Own creation

A first drawback of consolidation is that tracking and tracing of the freight becomes more complicated and the risk of loss and damage has to be reduced. A second drawback applies when different good with different requirements are combined into one load. Multi-temperature goods for example have different transport and handling requirements. Different security issues may appear as well (Comi et al., 2014). A third drawback is that separate shippers are transporting their goods to the transhipment point, which causes a large amount of separate trips, of which many are empty (Morlok, Sammon, Spasovic, & Nozick, 1995). This is for example the case when shippers bring their goods that need to get to a specific location in the city, to a terminal outside the city. Most of these shippers return empty from the terminal. Morlok et al. (1995) propose to let shippers share transport equipment in order to avoid empty driving.

Secondly, rail transport often involves higher costs compared to road transport (Dorner, 2001). Rail infrastructure projects are characterised by a marginal cost that is below the average cost, resulting in losses (Comi et al., 2014). Furthermore, high investment costs in infrastructure and rolling stock are often present (Cleophas et al., 2018; Cochrane et al., 2017; Comi et al., 2014; Graham, Couto, Adeney, & Glaister, 2003). Therefore, it is recommended to make use as much as possible of the existing infrastructure (Regué & Bristow, 2013). The needed rail freight infrastructure has to be determined for the long run (Ruesch, 2001). A trade-off has to be made here. Either an existing warehouse is used, that is adapted to use rail transport and for which tracks may have to be built, or a new consolidation centre is constructed that is located near the city and a railway or tramway (Comi et al., 2014; Gonzalez-Feliu, 2014).

Cleophas et al. (2018) name the fact that only 800m rail infrastructure had to be built for the CarGo Tram of Volkswagen in Dresden, as one of the key success factors. The same logic is mentioned by these authors with respect to the Cargo tram in Zurich, where no additional rail infrastructure had to be constructed. Diziain et al. (2014) mention the fact that no rail infrastructure had to be constructed for the waste transport in Kawasaki as one of the success factors. In order to compensate for these elevated costs, both the operations frequency and the load factors should be high (Dinwoodie, 2006). The high investment costs are one of the reasons why the City Cargo project in Amsterdam (Arvidsson & Browne, 2013; Issenmann et al., 2010) and the GüterBim initiative in Vienna failed. The main issue in implementing urban rail distribution is the infrastructure (Foyer, 2001).

The third failure factor is the lack of cooperation of different stakeholders in the urban context and in logistics chains. These urban actors often have conflicting objectives (Arvidsson & Browne, 2013; BESTUFS, 2001; Bous, 2001; Cleophas et al., 2018; Cochrane et al., 2017; Comi et al., 2014; Dorner, 2001; Macário & Marques, 2008; Ruesch, 2001). Private commitment, partnerships and cooperation are important factors that influence the success of a rail freight initiative. The involvement of the industry within the urban area in which a rail-based solution is implemented is a decisive factor determining the feasibility of the initiative (Bous, 2001; Comi et al., 2014). Mainly the cooperation of the suppliers, retailers and transport operators is crucial for the success of the initiative (Filippi & Campagna, 2014).

The freight tram solution in Dresden for example depends fully on the presence of Volkswagen and its cooperation with public transport operator DVB (Cleophas et al., 2018; Comi et al., 2014). Diziain et al. (2014) name the involvement of the Japan Railway Freight Company and the Ministry of Environment as key success factors for the transport of waste by rail in Kawasaki. Cleophas et al. (2018) highlight the high user acceptance of the Cargo Tram and E-Tram in Zurich as one of the key success factors. Strale (2014) also identifies this in the cases of Monoprix, Zurich and Vienna. The author adds that cases that aimed at large-scale urban freight distribution by tram failed. An example is the City Cargo in Amsterdam. Ziegler (2007) highlights the lack of interest from local retailers as one of the key failure factors of the GüterBim in Vienna.

Hence, involvement of the stakeholders is crucial for the success of a rail-based initiative for urban freight distribution. The role of the industry in the urban area might be a decisive factor. The role of the government concerns regulatory and/or financial support. The government should be clear about potential incentives for users of the system. Transport companies experience costs and problems of entering a city, but are often squeezed between the transport operators and the suppliers. It is important to know the decision maker in the supply chain.

Another important private stakeholder is the railway operator. However, railway operators are not very fond of urban rail freight. Costs for this rail segment are high, because the last mile is an expensive part of the supply chain. Passenger operators are not in favour of sharing the rail infrastructure with freight transport, since they often operate with franchising contracts comprising quality requirements such as 90% of the trains have to run with less than five minutes delay (Woodburn, 2014). Another possibility is to add a freight wagon to a passenger train. By adding an extra wagon, the cost for the railway operator increases due to an increased train tonnage. However, due to punctuality obligations for the passenger trains, the freight has to be (un)loaded in the railway station in only a few minutes (Comi et al., 2014).

Depending on the distribution of the benefits of the rail solution, different stakeholders can be involved in the financing (Ruesch, 2001). It is important to know the decision maker in the supply chain. Often, the transport operators experience the costs and problems of moving towards and within a city, but they are in between the suppliers and the retailers. For example, research of Bpost reveals that 70% of the transport operators experience problems when entering the city of Antwerp (Comi et al., 2014).

On the other hand, there is a role for the government, which is either regulatory or financial. Governments can support new rail projects financially at the first stages of the development (Bous, 2001; Comi et al., 2014). Ruesch (2001) agrees that different stakeholders have to cooperate. For example, concerning the financing of the infrastructure for regional rail freight it is debatable who has to pay. Political discussions in Düsseldorf are on the investments needed, such as for the rail freight station and the rail network, and the distribution of the benefits. The problem here is that only DB (Deutsche Bahn) would benefit, since it sells an unprofitable part to another railway company. Especially in the beginning, the largest part of the benefits of the project is consumer surplus. The business revenue, i.e. price multiplied by quantity, will be rather small due to extra costs of the new transport solution. The business revenue can be enlarged by increasing the price and thus, creaming off the consumer surplus. At this point, the government could intervene. The financial intervention of the (local) government can be a critical factor (Comi et al., 2014).

Governments can also have the role of facilitator and for example communicate clearly about the potential incentives for users of the system (Comi et al., 2014) or offer clear regulations (Centre-Ville en Mouvement, 2013) and implementing other measures that make entering the urban area by road transport more difficult and/or expensive (Comi et al., 2014). Public intervention to limit the circulation of heavy lorries in the urban areas increases the chances of success of a rail-based solution (Jonction & VerkehrsConsult Dresden-Berlin, 2013). Authorities could also establish a neutral party to attract freight from different shippers to obtain larger volumes, or to stimulate actors by taking the lead and communicating about potential incentives. Actors do not always have an incentive to cooperate and be involved in a new initiative. No first mover advantage is present in using rail for urban freight distribution and free-riding can be more beneficial (Comi et al., 2014).

The political and public acceptability of urban freight distribution measures determine whether implementation of a new measure can be successful (Cleophas et al., 2018; Woodburn, 2014). The most important failure factors according to Macário & Marques (2008) are political frameworks and public acceptance. This corresponds to the findings of Arvidsson & Browne (2013), who notice that the non-support of politicians is one of the main failure factors for City Cargo in Amsterdam, and the findings of Regué & Bristow (2013) who mention political issues as one of the critical failure factors for the GüterBim in Vienna.

Related to cooperation between stakeholders, involvement of the stakeholders in new transport initiatives contributes to more chances to success (Arvidsson & Browne, 2013). Regué & Bristow (2013) argue that only rail-based initiatives that are supported by the stakeholders have succeeded.

Fourthly, rail transport is in general considered to be less flexible than road transport (BESTUFS, 2001; Dönnhöfer & Eisele, 2001; Dorner, 2001; Marinov et al., 2013; M. Robinson & Mortimer, 2004a). An important limitation for the tram is the width of the load if the goods need to enter a passenger tram by the standard doors (BESTUFS, 2001).

Fifthly, Ruesch (2001) mentions the service level as one of the key issues that have to be solved concerning rail transport. This idea was confirmed during the BESTUFS workshop (BESTUFS, 2001). One of the aspects that could improve the service level offered by rail transport is to possess a sufficient amount of rail vehicles (Bous, 2001).

Sixthly, it is important to consider the whole supply chain when studying the potential of rail (Foyer, 2001; Jonction & VerkehrsConsult Dresden-Berlin, 2013). Since rail transport is bound to the rail infrastructure, it only covers a limited geographical range (Bergqvist, 2007; Dorner, 2001). As a result, the rail freight network only covers a limited number of corridors that mostly connect to sites that generate or receive large freight volumes. Hence, only a certain number of locations is reached by the rail freight network (Bergqvist, 2007). Consequently, the denser the rail network, the more opportunities for rail-based transport (Ruesch, 2001).

Following the infrastructure need, rail transport only offers a solution for part of the supply chain, unless both the supplier and the customer possess a rail connection. Thus, often other transport modes such as barges, lorries, electric vehicles or cargo bikes are still needed for the pick-up and delivery of the goods to and from the rail terminal (Comi et al., 2014; Woodburn, 2014). Rail transport has in general no door-to-door capability (Arvidsson & Browne, 2013; Mortimer, 2008; M. Robinson & Mortimer, 2004a). For the final delivery, the optimal vehicle size has to be determined, and this is not necessarily a small vehicle. Different types of shops require a different vehicle size (Gonzalez-Feliu, 2014).

The type of transport that is needed additional to the rail transport is referred to as pre- and post-haulage. This part of the supply chain causes long lead times (Ruesch, 2001) and is responsible for a large share of total transport costs (Behrends, 2012b; Gevaers, 2013). The most critical factors that determine this part of total transport costs are (Kreutzberger, Konings, & Aronson, 2006) the distance of shippers around a terminal, the freight density, the network productivity such as the number of round trips per load unit and (un)loading times and the resource productivity such as labour or fuel. It is important to use adapted vehicles for the pre- and post-haulage part. These are not necessarily electric vehicles, but in some cases rather cargo bikes, trolleys, etc. (Comi et al., 2014).

Related to the pre- and post-haulage, the use of rail transport causes the need for additional handling and cross-docking. These extra handling operations to change the transport mode increase the time and costs of the transport (Behrends, 2012b; Bergqvist, 2007; Cochrane et al., 2017; Comi et al., 2014;

Dorner, 2001; Ruesch, 2001). It is important to keep the cross-docking and handling costs as low as possible (Comi et al., 2014). Therefore, it is crucial that the handling operations are done as quickly as possible (BESTUFS, 2001). Foyer (2001) states that the location of a terminal is crucial for the transit times and the environment. The need to optimise the transit time of rail transport is significant (Foyer, 2001). In order to optimise this transit time, transhipment systems have to be improved (BESTUFS, 2001). This can be achieved for example by using appropriate containers and by clustering freight at the origin for a cluster of destinations. In general, cross-docking has a cost of €2-€3 per pallet. This cost could be reduced by always cross-docking the same unit (Comi et al., 2014). Other techniques that can be used in order to make transhipment operations happen as quickly as possible are for example electromagnetic or roll-based transhipments (BESTUFS, 2001). By combining warehouses with residential buildings and offices, costs can be split. This is done in Paris in the project of Chapelle International (SNCF, 2019).

The last failure factor is resistance of different stakeholders to try something new (Arvidsson & Browne, 2013; Nuzzolo et al., 2007). Acceptance by the stakeholders to consider a non-road solution is crucial (Ruesch, 2001). Behrends et al. (2008) argue that especially in the transport sector, resistance to new solutions is present. Cochrane et al. (2017) state that many stakeholders are resistant to combine freight and passenger movements in the same vehicles or on the same infrastructure.

With respect to the target city environment, two failure factors are distinguished: the interference with passenger transport and the pressure on railway areas. Several authors stress the issue of interference with passenger transport (Cochrane et al., 2017; Comi et al., 2014; M. Robinson & Mortimer, 2004a; Ruesch, 2001; Strale, 2014; Woodburn, 2014). In Europe, passenger trains have priority over freight trains. As a consequence, the capacity of the rail lines is partly dedicated to passenger transport (Ruesch, 2001). Passenger slots cannot be used and passenger tram units are also not appropriate to transport freight. Some specific points in the urban area have to be chosen where the freight can be loaded and unloaded without disturbing the passenger transport (Gonzalez-Feliu, 2014). In case the priority of passenger over freight transport is not reconsidered, a separate rail freight network might lead to more opportunities for freight transport in some cases (Ruesch, 2001). Another way to partly avoid the interaction with passenger transport is by operating the freight activities during the night. However, this causes noise-related issues and may interfere with maintenance activities on the rail lines (Comi et al., 2014). When passenger and freight activities share the same infrastructure, the issue of fragmentation emerges: how can costs and benefits be allocated to the passenger and freight activities (Woodburn, 2014).

Furthermore, in urban areas there is often a lack of space, which creates a pressure on railway areas as well. Deutsche Bahn for instance experiences pressure in Düsseldorf to shut down some rail tracks. Another consequence of the land use pressure is that often no freight stations are available in city centres (Ruesch, 2001).

Ultimately, technological limitations emerge as a failure factor concerning the vehicles. An example of a technological limitation is the battery life of an electric vehicle that operates the last-mile between the rail stop and the customer (Arvidsson & Browne, 2013). Another technological limitation is the maximum load that can be used on the rail network and on the axles of the rail vehicle (Jonction & VerkehrsConsult Dresden-Berlin, 2013).

In sum, based on Table 9, a list of failure factors is developed, although this list does not provide a ranking according to the actual impact of each factor. The most common failure factor is the interference with passenger traffic (Amsterdam, Dresden, Paris, Vienna, Zurich). Resistance from different actors is a second obstacle (Amsterdam, Dresden, Vienna, Zurich). Thirdly, the initial investment needed is crucial (Amsterdam, Barcelona, Dresden), as well as the commitment of different stakeholders (Amsterdam, Barcelona, Vienna). Furthermore, politicians play an important role (Barcelona, Vienna). Ultimately, some other issues have to be considered, such as the type of goods, the costs compared to road transport and the technology used. In Chapter 6, the relative importance of these factors is evaluated through sensitivity and scenario analyses.

These findings are first of all similar to what is stated by several authors. Arvidsson & Browne (2013) see conflicting objectives amongst stakeholders, interference with passenger traffic, radius of action, scale of the project and stakeholder involvement as the main hurdles for freight trams. Regué & Bristow (2013) state that a freight tram is only potentially feasible in case economies of scale are exploited, a minimum demand is served and urban consolidation centres work efficiently, or in case niche markets are used in which the operational costs are currently high and only limited extra infrastructure is needed. Ebrardt (2001) mentions the involvement of different stakeholders and inclusion of the urban environment in the analysis as critical factors. Secondly, these findings demonstrate the specific character of the urban context in which the rail freight distribution is examined in this research, compared to the use of rail freight in general. The interference with passenger transport is especially an important failure factor in an urban context. A factor that plays a smaller role in an urban context compared to long-distance rail transport comprises the interoperability and safety requirements.

2.4 Conclusion

This chapter provides insight in experiences with urban rail freight initiatives. Firstly, the key concepts of this research, being urban freight distribution and rail transport, are defined. Urban freight distribution is for the remainder of this research the transport of goods to, from and within urban areas by or for commercial or public entities. Rail transport is referred to as the use of trams and trains. Moreover, a distinction is made between using a dedicated freight vehicle, attaching a freight wagon to a passenger vehicle, or transporting parcels alongside passengers.

Secondly, several urban rail freight initiatives are listed and discussed. An overview of the literature demonstrates the existence of several studies on the use of rail for urban freight distribution. These studies deal with different types of rail transport (light rail, tramways, underground rail), focus on different case studies and apply different methodologies. The literature review makes it clear that most of the urban rail freight initiatives have failed, or have not been put in practice. This observation is a first indication that the potential of rail for urban freight distribution depends on several conditions. Most of the studies discuss and quantify the costs of using rail for urban freight distribution, but not the benefits. Furthermore, none of the available studies provides a generic framework allowing to examine the potential of rail for urban freight distribution from a financial, economic and socio-economic perspective. Hence, the key added value of the current research is the development of such a framework that can be used as a tool to assess the potential of urban rail freight for different types of rail and for different case studies. In the next chapter, the methodology used for the development of this framework is discussed. In Chapter 4, the framework is further elaborated from a financial and economic viewpoint and in Chapter 5, the socio-economic perspective is discussed. In both chapters, the framework is applied to a case study.

Thirdly, the main success and failure factors of using rail for urban freight distribution are derived based on past and existing experiences. The main success factors are the better environmental performance of rail transport compared to road transport, as well as the presence of congestion when entering the urban area. The most important failure factors are the interference with passenger transport, high investment costs related to rail transport, lack of cooperation between different urban rail freight stakeholders, as well as the involvement of these stakeholders in the project.

A list of success and failure factors is now available, although they cannot be ranked yet based on their effect on the outcome of the urban rail freight project. However, the factors do allow to develop the generic social cost-benefit framework in the following chapters. In particular, the success and failure factors are used in Chapter 6, where sensitivity and scenario analyses on the developed framework are performed, based on the factors derived in the current chapter. The next step is to determine the research approach and to decide upon the data collection methods. This is the subject of the following chapter.

3. Research approach and data collection methods

Multiple studies about using rail for urban freight distribution exist, each with their own scope and objective. Given the different aims of these studies, authors use a variety of research and data collection methods to find an answer to their research question. In order to answer the research questions set in Chapter 1, an appropriate research strategy has to be selected. This chapter provides an overview of the research approach used in this thesis, as well as the applied data collection methods. As the first step, the following section provides a review of the different research and data collection methods used in the literature.

3.1 Research and data collection methods in the literature

The next step after defining the relevant terminology and the scope of the research, is to decide upon the research approach. Table 10 displays several research and data collection methods used by different authors in order to assess urban rail freight distribution projects. The objective of this table is to know which research methods are applied by different authors in order to investigate the potential of rail for urban freight distribution. Based on this table, an appropriate research strategy for this thesis is derived. The focus of Table 10 is on the use of trams and light rail as was specified in Chapter 2. The authors are ranked chronologically per rail type. The overview covers the period 1995-2018. When excluding historical articles about urban rail freight projects from the first half of the twentieth century, no studies before 1995 are found.

In general, no clear difference of the research methods and data collection between light rail and tramways can be identified. The only exception concerns the data collection, where monitoring vehicles and O/D matrices are only used in studies about the use of light rail. Moreover, there is no clear evolution over time. The only exception is that the Delphi method and integer programming are only applied in recent studies of 2017 and 2018 respectively. The main observations of Table 10 are now discussed firstly with respect to the research methods and secondly, concerning the data collection methods.

Firstly, the different research methods used are case study, Delphi method, environmental effects analysis, (economic) feasibility study, integer programming, private cost analysis, (S)CBA, scenarios and social and private cost analysis. The choice for a certain method is in most studies dependent on the data availability and on the scope of the research. Most authors, both examining light rail and tramways, conduct a case study and combine this with a kind of private or social cost(-benefit) analysis and often also with scenarios. This approach has been applied for both light rail and tramways. Alessandrini et al. (2012) use an SCBA to assess the use of a rail shuttle to deliver fresh fish in the city of Rome. Regué & Bristow (2013) apply an SCBA to analyse the use of a freight tram for the city of Barcelona. Gonzalez-Feliu (2014, 2016) conducts an SCBA to investigate the use of a freight tram in Paris and Gorçun (2014) does the same for Istanbul. These examples correspond to the statement of amongst others Blauwens (1986, 1988) and van Wee (2007), who declare the need for ex-ante evaluations such as cost-benefit analyses for public railway projects. Siciliano et al. (2016) agree with this and argue that SCBA is the most commonly used method to evaluate rail infrastructure projects. However, in most SCBA studies, the authors start from the viewpoint of a retailer or operator. In the current research, the viewpoint of the SCBA is the government's perspective, as suggested by Sartori et al. (2015). It has to be added here that adopting the government's viewpoint does not imply that the government will operate the rail-based services. The government can organise auctions and then grant a concession to a private player for the operation of the service.

Table 10 – Research and data collection methods to examine the urban rail freight distribution potential

Rail type	Author (s) (year)	Applied research method(s)									Data collection					
		Case study	Delphi method	Environmental effects analysis	(Economic) feasibility study	Integer programming	Private cost analysis	(S)CBA	Scenarios	Social and private cost analysis	Interviews	Monitoring vehicles	O/D matrices	Secondary data	Surveys	Traffic/ vehicle counts
Light rail	Dorner (2001)	X		X	X									X		
	Dinwoodie (2006)	X								X	X			X		
	Nuzzolo et al. (2007)	X								X	X		X	X	X	X
	Issenman et al. (2010)	X												X		
	Sivakumaran et al. (2010)	X			X				X		X		X			
	Maes & Vanelslander (2011)	X									X			X		
	Alessandrini et al. (2012)	X							X	X		X		X		
	Delaître & De Barbeyrac (2012)	X							X	X	X	X		X		
	Marinov et al. (2013)	X												X		
	Diziain et al. (2014)	X												X		
	Filippi & Campagna (2014)	X										X		X		
	Gorçun (2014)	X						X						X		
	Cochrane et al. (2017)	X	X						X					X		
	Behiri et al. (2018)					X								X		
	Ozturk & Patrick (2018)					X								X		
Tramways	Kortschak (1995)	X												X		
	Rien & Roggenkamp (1995)	X												X		
	Neuhold (2005)	X		X										X		
	Genta et al. (2006)	X												X		
	Mortimer (2008)	X												X		
	Arvidsson (2010)	X									X			X		
	Issenman et al. (2010)	X												X		
	Kortschak (2010)	X												X		
	Arvidsson & Browne (2013)	X									X			X		
	Marinov et al. (2013)	X												X		
	Regué & Bristow (2013)	X						X	X					X	X	X
	Gonzalez-Feliu (2014, 2016)	X						X			X			X		
	Gorçun (2014)	X						X						X		
	Strale (2014)	X												X		
	Zych (2014)	X		X										X		
	Behiri et al. (2018)					X								X		

Source: Own creation

There are only a few exceptions of authors who do not use a kind of private or social cost(-benefit) analysis. Kortschak (1995, 2010) and Rien & Roggenkamp (1995) focus their analysis on the organisational and technical issues related to the use of a tram for urban freight distribution. Genta et al. (2006) describe the results of the Italian TADIRAM project, in which a new tram prototype was developed. Mortimer (2008) discusses the pros and cons of rail for urban freight distribution qualitatively and explains the case studies of Amsterdam and Vienna. Arvidsson (2010) and Arvidsson & Browne (2013) present the case study of the freight tram in Amsterdam and derive some hurdles. Issenman et al. (2010) analyse the accessibility, available surface and interaction with passenger flows issues if goods were to be transported in the Paris' underground. Many authors (Diziain et al., 2014; Filippi & Campagna, 2014; Maes & Vanelslander, 2011; Marinov et al., 2013; Strale, 2014; Zych, 2014) investigate the potential of using light rail or a freight tram by means of one or more descriptive case studies. Cochrane et al. (2017) conducted a Delphi method in which 34 transport experts were involved. The objective was to identify the main challenges and opportunities of using urban rail for freight distribution. Behiri et al. (2018) tackle the freight rail transport scheduling problem. The objective of the developed model is to understand the different dynamics in the urban rail system, as well as the impact of different decisions. Ozturk & Patrick (2018) develop a decision support framework for optimised urban rail freight transport at an operational level.

Secondly, the data collection methods are divided in interviews, monitoring vehicles, origin-destination (O/D) matrices, secondary data, surveys and traffic/vehicle counts. Most authors rely on secondary data, sometimes combined with primary data such as interviews, surveys and monitoring of vehicles or counts. Table 10 reveals that almost all authors rely on secondary data, in combination with describing a case study. Depending on the type of data, a specific method is appropriate. For instance, to collect technical vehicle data, or data about the vehicle emissions, vehicles are monitored. In order to get insight in freight flows, O/D matrices are used when available. Otherwise, traffic/vehicle counts are executed, or interviews or surveys are carried out. If these methods are too expensive given the scope of the research, secondary data are applied.

The objective of this thesis is to examine the potential of urban rail freight from a financial, economic and from a socio-economic perspective. From Table 10, it seems that a social cost-benefit analysis is an appropriate method to investigate this. Following other studies (Alessandrini et al., 2012; Cochrane et al., 2017; Delaître & De Barbeyrac, 2012; Regué & Bristow, 2013; Sivakumaran et al., 2010), adding scenarios to the SCBA is valuable as well. Moreover, a decision framework to evaluate the outcome of the SCBA is needed, and sensitivity analyses have to be carried out. Another important part of the research is the collection of appropriate data to feed the SCBA. Ultimately, almost all authors illustrate their calculations by applying them to a case study, so this seems to be an appropriate part of the analysis as well.

This chapter discusses all research and data collection methods used in this thesis in order to select the correct research approach and data collection methods for the current research. In Section 3.2, the social cost-benefit analysis is discussed in depth. In Section 3.3, the background for the sensitivity analyses is given, whereas Section 3.4 offers the scenario analysis. Section 3.5 offers an overview of all used data collection methods. Section 3.6 provides the decision framework. In Section 3.7, the case study to which the before mentioned research methods are applied, is explained. Section 3.8 explains the transferability theory that is used to transfer the results obtained in the current research to other cases. Ultimately, Section 3.9 provides the conclusion of this chapter.

3.2 Social cost-benefit analysis

Social cost-benefit analyses have been used for many years and for different types of projects. This section discusses the evolution of the (S)CBA concept (3.2.1), the theoretical background (3.2.2) and finally, the SCBA framework used in this thesis (3.2.3).

3.2.1 Evolution of the (S)CBA concept

The idea of examining costs and benefits was used for the first time in the seventeenth century by Richard Petty, who stated that the value of a saved human life exceeds the costs of the investment (Neumann, 2005; Warner & Luce, 1982). In 1844, Jules Dupuit, often seen as the first one who thought in terms of costs and benefits, published "*On the measurement of the utility of public works*" (Button, 2011; Hanley & Spash, 1993). Between the 1930s and the 1960s, the first applications of the cost-benefit methodology started to emerge. In 1950, the report "*Proposed practices for economic analysis of river basin projects*" was published. This report was later on referred to as the Green Paper and it was the start of a wide range of research publications on cost-benefit analysis (Hanley & Spash, 1993).

Otto Eckstein (1958) is generally referred to as the first academic who elaborated on this methodology, associating CBA with welfare economics. Hirshleifer et al. (1960), Arrow (1963) and Raiffa (1968) are other academics who elaborated on this.

In the 1960s, the quality of the environment started to be integrated in the analysis, leading to the term "social" cost-benefit analysis (SCBA). In the 1970s, the importance of non-user values started to be recognised (Cameron, 2011; Hanley & Spash, 1993). Moreover, the economic and environmental consequences of new technologies and scientific programs are assessed. However, the monetary evaluation of the environmental impacts was still very limited (Hanley & Spash, 1993). In 1989, the "*Blueprint for a green economy*", also known as the Pearce Report, was published (Pearce, Markandya, & Barbier, 1989), followed by guidelines on incorporating environmental impacts in policy appraisal in 1991 (Hanley & Spash, 1993).

Several academics continued to do research about SCBA. In the 1970s and 1980s, Blauwens (1986, 1988) refined the methodology and applied it to several cases in Belgium together with other authors, such as port investments (Virenque, Nonneman, & Blauwens, 1973), the road network (1979), and an air freight terminal (Blauwens & Van de Voorde, 1985b). Blauwens (1988, p. 131) states that a cost-benefit analysis "*considers the advantageous and disadvantageous effects of an investment, not only for the state treasury, or not only for the members of a certain interest group, or not only for the company operating the project*". Van Wee (2007, 2012) too is working on improving the SCBA methodology. Van Wee & Tavasszy (2008, p. 41) define a cost-benefit analysis as "*an overview of all the pros (benefits) and cons (costs) of a project*".

Some main challenges remain present in SCBAs. Van Wee (2007) argues that anno 2007, several external impacts are often still not quantified in SCBAs. An example is the emission of particulate matter (PM). Button (2014, p. 28) defines a cost-benefit analysis as "*estimating the monetary value of the widest range of effects of a project or policy over the long-term, taking into account such things as non-traded costs and benefits, and the implications of actions on future, as well as current generations*". In previous work (Button, 2011), this author states that the accurate valuation of externalities, such as the time costs of travel, congestion and environmental externalities, is still difficult to obtain. Externalities are defined by this author as "*items that are traded outside of markets*". The issues about quantifying the externalities have always been present in SCBA, but only recently have they become more important. This larger importance comes from the growing interest in the climate change and its welfare effects. The above-mentioned definitions explain what is done when conducting a social cost-benefit analysis. It has to be borne in mind that Button (2014) uses the term CBA and not SCBA, although he takes externalities into account.

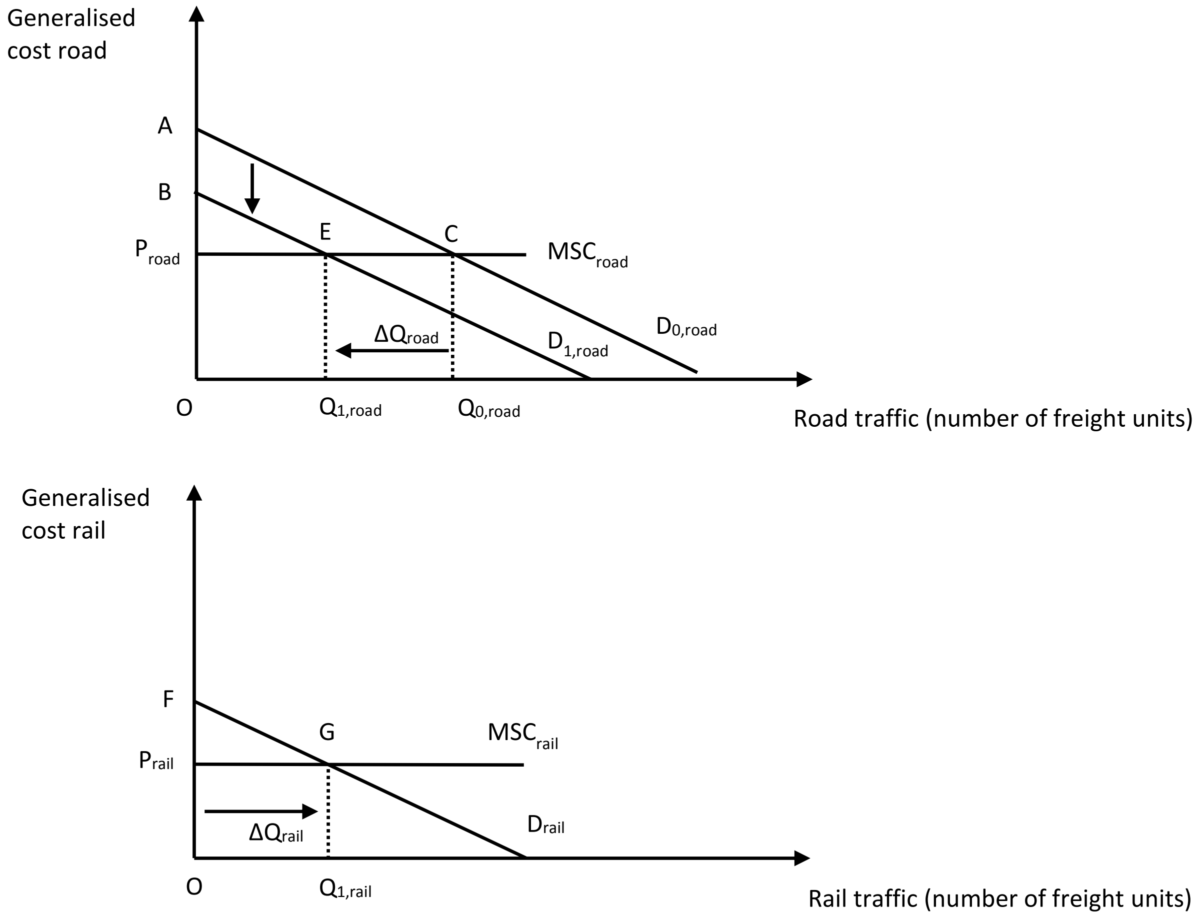
The previous overview of the evolution of (S)CBA shows that the concept has developed from a methodology in which only out-of-pocket costs were considered to one in which effects on the project users and all impactees are also taken into account. More specifically, the scope of the analysis was broadened from exclusively direct effects to the inclusion of indirect and external effects. Therefore, an investigation is made of some methodological and data collection choices that have to be made when applying an SCBA.

3.2.2 Theoretical background

The introduction of rail for urban freight distribution leads to a shift from road to rail traffic for a part of the total urban freight traffic. The socio-economic effect of this partial shift is illustrated in Figure 22. The upper part of this figure shows the change in the sub-market for urban road freight, whereas the lower part reveals the change in the sub-market for urban rail freight. The upper part of Figure 22 displays the initial demand curve for road freight $D_{0,road}$ and the new demand curve for road freight

$D_{1,road}$ after the introduction of a rail-based solution for urban freight, as well as the marginal cost curve of road freight MSC_{road}. The demand curve, which expresses the willingness-to-pay for a certain product or service, shifted downwards due to the new transport possibility that emerged in the market for urban freight distribution. Because of the downward shift of the demand curve, road traffic is reduced from $Q_{0,road}$ to $Q_{1,road}$, or in other words a reduction of ΔQ_{road} takes place.

Figure 22 – Social costs and benefits of shifting from road to rail on the road and rail urban freight market



Source: Own creation

The lower part of Figure 22 shows the demand curve D_{rail} and the marginal social cost curve MSC_{rail} for the newly generated rail traffic. It is assumed that the market is competitive and hence, the market equilibrium is reached at the traffic amount where demand equals the marginal social cost. This generalised cost comprises the operational costs, the time costs, as well as the marginal external costs (Blauwens, De Baere, & Van de Voorde, 2016; Blauwens, Vandaele, Van de Voorde, Vernimmen, & Witlox, 2006). With respect to the rail traffic, $Q_{1,rail}$ represents the traffic amount after introduction of the project. The traffic increases by ΔQ_{rail} from zero to $Q_{1,rail}$. The road traffic decreases by ΔQ_{road} after the introduction of the rail-based urban freight solution.

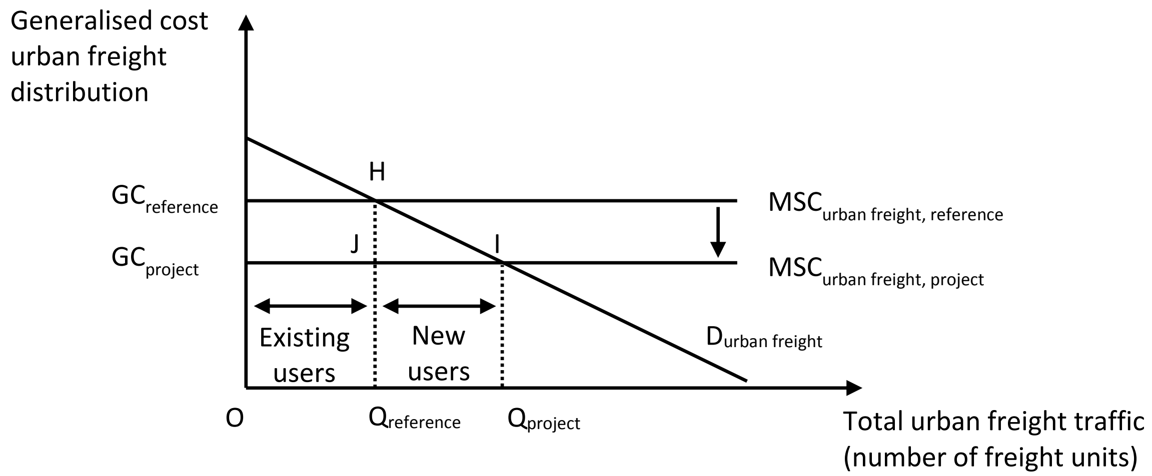
The socio-economic costs and benefits of introducing a rail-based urban freight solution can now be derived from Figure 22. The benefits are determined as the surface below the demand curve (Blauwens, 1986, 1988). In general, the benefits of a project consist of benefits for the existing users, benefits for users that shift mode and benefits for new users, so-called induced demand (Blauwens, 1988; Blauwens et al., 2016; Kidokoro, 2004; van Wee, 2007).

Kidokoro (2004) discusses the evaluation of an investment in a multi-mode environment. This author argues that the cost-saving approach leads to an overestimation of the project benefits. Instead, the change in consumer surplus for all transport modes involved has to be taken into account when determining the benefits of investing in one transport mode. The transport modes involved in this study are considered to be road and rail transport. It is assumed here that only the freight activities of both modes have to be taken into account in this analysis. It becomes important to take the passenger activities into account as soon as there are capacity constraints. It is assumed here that this is not the case. It was pointed out in Chapter 2 that the passenger traffic should not be disturbed when urban freight is transported by rail. Therefore, it is assumed that a dedicated rail vehicle only is allowed on the urban rail network if this does not cause capacity constraints. If freight is transported in a wagon attached to a passenger vehicle, no additional rail path is needed and if parcels are transported alongside passengers, this has no effect on the capacity of the rail infrastructure.

Following these theories, the benefits in the road market, shown in the upper part of Figure 22, decrease by the area $ACQ_{0,road}Q_{1,road}EB$. This area consists of a decrease in consumer surplus ACEB and a decrease in project revenue of $CQ_{0,road}Q_{1,road}E$. The costs are defined as the surface below the supply curve (Blauwens, 1986, 1988), represented on Figure 22 by the marginal social cost curve, and they decrease by $CQ_{0,road}Q_{1,road}E$. Thus, the net change in the road market is equal to the reduction in the consumer surplus of ACEB. The lower part of Figure 22 shows the benefits and costs in the urban rail freight market. The benefits are equal to area $FGQ_{1,rail}O$. These benefits consist of the total revenue for the project operator $GQ_{1,rail}OP_{rail}$ and the consumer surplus FGP_{rail}. The costs equal area $GQ_{1,rail}OP_{rail}$. Subtracting the costs from the benefits, the net benefits of the rail project equal area FGP_{rail}, or in other words, the consumer surplus. Combining the two graphs in Figure 22, the benefits of introducing an urban rail freight solution are equal to area FGP_{rail} – area ACEB. When the total benefits of a project are made clear, it can be analysed which part of the benefits goes to which stakeholder.

The social benefits of using rail for urban freight distribution are derived for the urban freight market in total in Figure 23. This figure shows the demand curve for urban freight distribution ($D_{urban\ freight}$), and the marginal social cost curve before the rail-based project is executed ($MSC_{urban\ freight,\ reference}$) and after the rail-based project is implemented ($MSC_{urban\ freight,\ project}$). The curve shifts downwards, since the generalised cost of urban freight distribution decreases after the implementation of the rail freight project.

Figure 23 – Partial shift from road to rail on the urban freight market



Source: Own creation

Demand depends on the generalised cost of the total supply chain to which all actors in the chain contribute. The generalised cost means that besides out-of-pocket costs, costs such as rates charged, time costs and costs related to reliability and risk are considered (Meersman, Van de Voorde, & Vanelslander, 2010). The generalised cost is expressed by Equation (1)[16] (Blauwens et al., 2016; Sartori et al., 2015):

$$GC = fee_{user} + VoT_{unit} * time \tag{1}$$

In which

GC	= generalised cost of urban freight distribution, expressed in euro;
fee_{user}	= the fee that is paid by the user for the urban freight distribution service, expressed in euro;
VoT_{unit}	= the value of time per time unit of the freight distribution, expressed in euro per hour;
time	= the total time of the round trip in which the goods are delivered at the customer, expressed in hours.

From Equation (1) it is clear that the generalised cost comprises the monetary cost, as well as the time cost. Thus, a decrease of the general cost, and hence, an increase of the consumer surplus, is related to the monetary cost or the time savings.

The value of time consists in general of different components. Travel time savings can lead to a decreased labour cost per trip, a decreased vehicle operating cost per trip and improved reliability. The decreased labour cost and vehicle operating cost per trip are in this research part of the operational cost. Hence, they are not taken into account here as part of the time savings benefit, since this would result in double counting. Therefore, the improved reliability is the only factor of the travel time savings that should be included in the calculations. The improved reliability can have as a result lower safety margins with respect to the departure time of the transport, better prices for perishables and less stockholding needs (Sartori et al., 2015).

In order to calculate the value of time, Sartori et al. (2015) suggest to use the capital lock-up approach. In other words, the value of time depending on the movement of goods includes the interest costs on the capital invested in the goods during the in-transit time, the decrease in value of perishable goods and the possibility that the production process is disrupted by missing inputs or the possibility that customers cannot be supplied due to a lack of stock (Blauwens et al., 2016).

In the literature, several value of time analyses exist, each of them leading to other results. The HEATCO report provides values, but according to Sartori et al. (2015), these values are high. In a study of KiM (2013), which is the basis of the research by de Jong et al. (2014), value of time results are presented for shippers and operators. The value of time of the shipper is the value of the travel time and reliability, comprising the goods transported, depreciation of the goods, interest, out of stock and production stops. The value of time of the operator includes factor costs such as depreciation of vehicles, maintenance, insurance, fuel and labour costs. De Jong et al. (2014) assign a cost of €26.55 (at 2018 price level) per hour per vehicle to non-containerised goods that are transported in a lorry of 2-15 tonnes on the road. For rail wagonload transport, a value of €1,270 (in 2018) per hour per train is used. Daubresse et al. (2019) provide value of time results for national freight transport in Belgium, which are also based on the same study done by KiM (2013). The value of time for a lorry equals €7.44 per tonne per hour in 2018, the one for a van is 139 euro per tonne per hour and the one for rail

[16] An overview of all equations used in this dissertation is provided in Appendix 15.

transport is €2.66 per tonne per hour. These authors also provide predictive growth rates of these values of time.

The increase in consumer surplus can be seen as the area $GC_{reference}HIGC_{project}$ in Figure 23. Mathematically, the consumer surplus is derived by Equation (2), which is known as the "Rule of Half" (Boardman, Greenberg, Vining, & Weimer, 2018):

$$\int_{GC_{project}}^{GC_{reference}} D(GC)dGC \approx \frac{1}{2}*(GC_{reference} - GC_{project})*(Q_{reference} + Q_{project}) \qquad (2)$$

In which

$GC_{reference}$	= the generalised cost in the reference case;
$GC_{project}$	= the generalised cost in the project case;
$Q_{reference}$	= the number of freight units transported in the reference case;
$Q_{project}$	= the number of freight units transported in the project case.

Before the urban rail freight project is implemented, the willingness-to-pay for urban freight distribution is for some potential future users lower than their generalised cost of urban freight distribution. After implementing the urban rail freight project, the generalised cost decreases and hence, some previously non-users decide to distribute urban freight. This is displayed in Figure 23 as the "new users". These new users cause an increase of total urban freight traffic of $Q_{project} - Q_{reference}$. For the existing users, the increase in consumer surplus after the implementation of the urban rail freight project consists of the decrease of their generalised cost (area $GC_{reference}HJGC_{project}$). For the new users, the increase in consumer surplus equals area HIJ. The latter area is calculated by means of Equation (3) (Sartori et al., 2015):

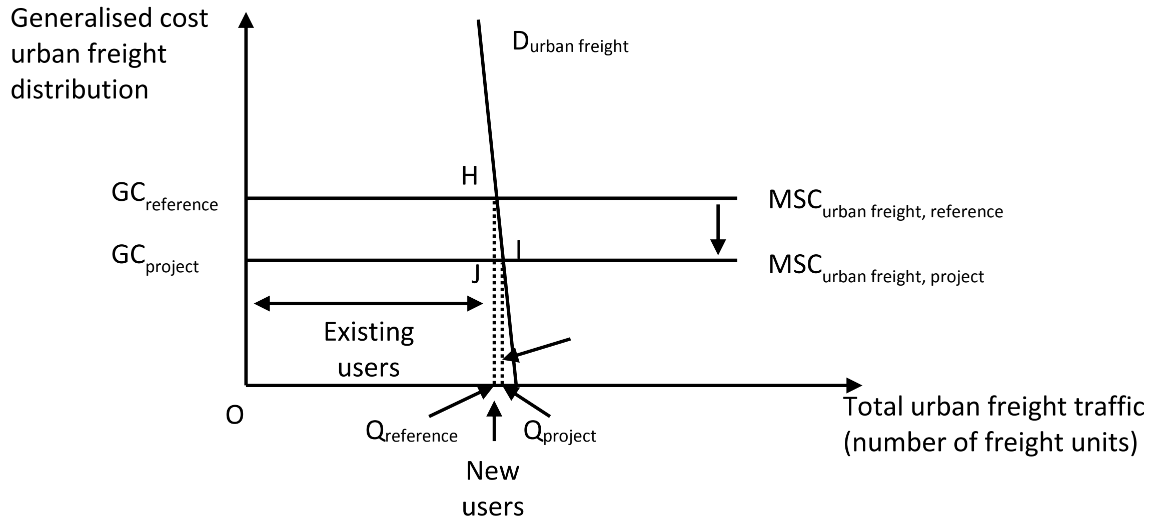
$$\Delta CS_{generated} = \frac{1}{2}*(GC_{reference} - GC_{project})*(Q_{project} - Q_{reference}) \qquad (3)$$

Equation (3) computes the increase in consumer surplus for the new users and shows that this depends on the change of the generalised cost curve, and the increase in traffic. One of the important aspects that determines the increase in traffic is the slope of the demand curve. The slope of this curve is determined by the price elasticity of demand. In the literature, several values for this elasticity are available, each of them leading to another slope of the demand curve. If the demand curve is almost perfectly inelastic, and thus, almost vertical, the increase in consumer surplus in Equation (3) is almost equal to zero. This is shown in Figure 24. The generalised cost decreases in Figure 24 identically as in Figure 23. By only changing the slope of the demand curve, the additional consumer surplus for new users (area HIJ) goes towards zero.

In order to get an in-depth insight in the actual and potential future urban freight demand, total freight flows and rail freight flows have to be estimated. Knowledge about these flows makes it possible to estimate the demand curve displayed in previous figures. Meersman et al. (2010, p. 219) state that "*the ultimate goal must be to arrive at the lowest possible cost for the chain as a whole*". The authors also state that the owners of the goods, paying for the transport, take into account the net revenue of a transport solution. This net revenue equals the added revenue of using a transport solution lowered with the costs of using the solution. In case the rail-based urban freight distribution chain is characterised by a lower generalised cost than the road-based chain, the rail-based chain is preferred.

The urban rail freight demand is difficult to capture by revealed preference, since it comprises a potential and not an existing demand. Thus, rail freight flows have to be estimated based on stated preference. With respect to this, two alternative research strategies can be distinguished in general: an SCBA in which the (future) demand is known or can be estimated versus an SCBA in which the minimum required demand to obtain a certain output is the outcome of the analysis. Jorge and de Rus (2004) use the first alternative, making the assumption that the future demand for the entire life of the project can be forecast. Campos and Hernández (2010) work according to the second alternative in their research about high speed trains. These authors assume that the uncertainty about the demand for high-speed rail transport is too high; and therefore, demand would not be a reliable input for the SCBA.

Figure 24 – Partial shift from road to rail on the urban freight market given an inelastic demand



Source: Own creation

Freight trams have not often been used since the end of the twentieth century (Annys et al., 1994), making it very difficult to make reliable estimations of the potential demand. Button (2014) too demonstrates the high level of uncertainty with respect to demand predictions. Introducing a rail-based solution in an urban freight context is in most urban areas a non-existing type of service that is offered. This makes the task of forecasting potential traffic for the service more challenging. As a result, it is beneficial for the reliability of the SCBA outcome to follow the idea of Campos and Hernández (2010) and use the SCBA to obtain the minimum required demand for the service. This also helps avoiding demand overestimations, which happens often according to Button (2011).

Next, multiple academics (Blauwens et al., 2016; Boardman et al., 2018; de Rus, 2010; Hanley & Spash, 1993; Sartori et al., 2015) define the steps that have to be followed when conducting an SCBA. These steps are displayed in Table 11 and are discussed in the next sections.

Table 11 – Steps of an SCBA

1. Specify the set of project cases and the reference case
2. Decide whose benefits and costs count
3. Identify the impacts and select measurement indicators (units)
4. Quantify and monetise all impacts
5. Discount costs and benefits to obtain present values
6. Evaluate each project case
7. Deal with uncertainty and risk
8. Make recommendations based on the previous steps

Source: Own creation based on Hanley and Spash (1993), de Rus (2010), Sartori et al. (2015), Blauwens et al. (2016), and Boardman et al. (2018)

3.2.2.1 STEP 1: Specify the set of project cases and the reference case

In the first step of an SCBA, the reference case and the set of project cases are determined. Van Wee (2007) mentions the difficulty to define the alternative cases, since a whole set of options is often present. The use of road transport is the reference case (see Table 12). A reference case is "*the status quo policy, or no change in government policy*" (Boardman et al., 2018, p. 7). Two innovative project cases are dealt with in this research: the use of a tram for urban freight distribution and the use of a train for urban freight distribution. Each project case can be put in practice by means of three types of traffic. The traffic type can be the use of a dedicated freight vehicle, the use of a freight wagon attached to a passenger vehicle, or the transport of parcels alongside passengers. All of these cases create a new dimension of performance of an urban freight distribution chain.

Table 12 – Urban freight distribution innovations

REFERENCE CASE		
Transport mode	Traffic type	Characteristics
0. Road	Dedicated freight vehicle	Light goods vehicle (<12t)
PROJECT CASES (INNOVATIONS)		
Transport mode	Traffic type	Characteristics
1. Tramways	1A. Dedicated freight vehicle	Freight tram
	1B. Freight wagon attached to passenger vehicle	Passenger tram + freight wagon
	1C. Parcels in passenger vehicle	Passenger tram
2. Light rail	2A. Dedicated freight vehicle	Freight train
	2B. Freight wagon attached to passenger vehicle	Passenger train + freight wagon
	2C. Parcels in passenger vehicle	Passenger train

Source: Own creation

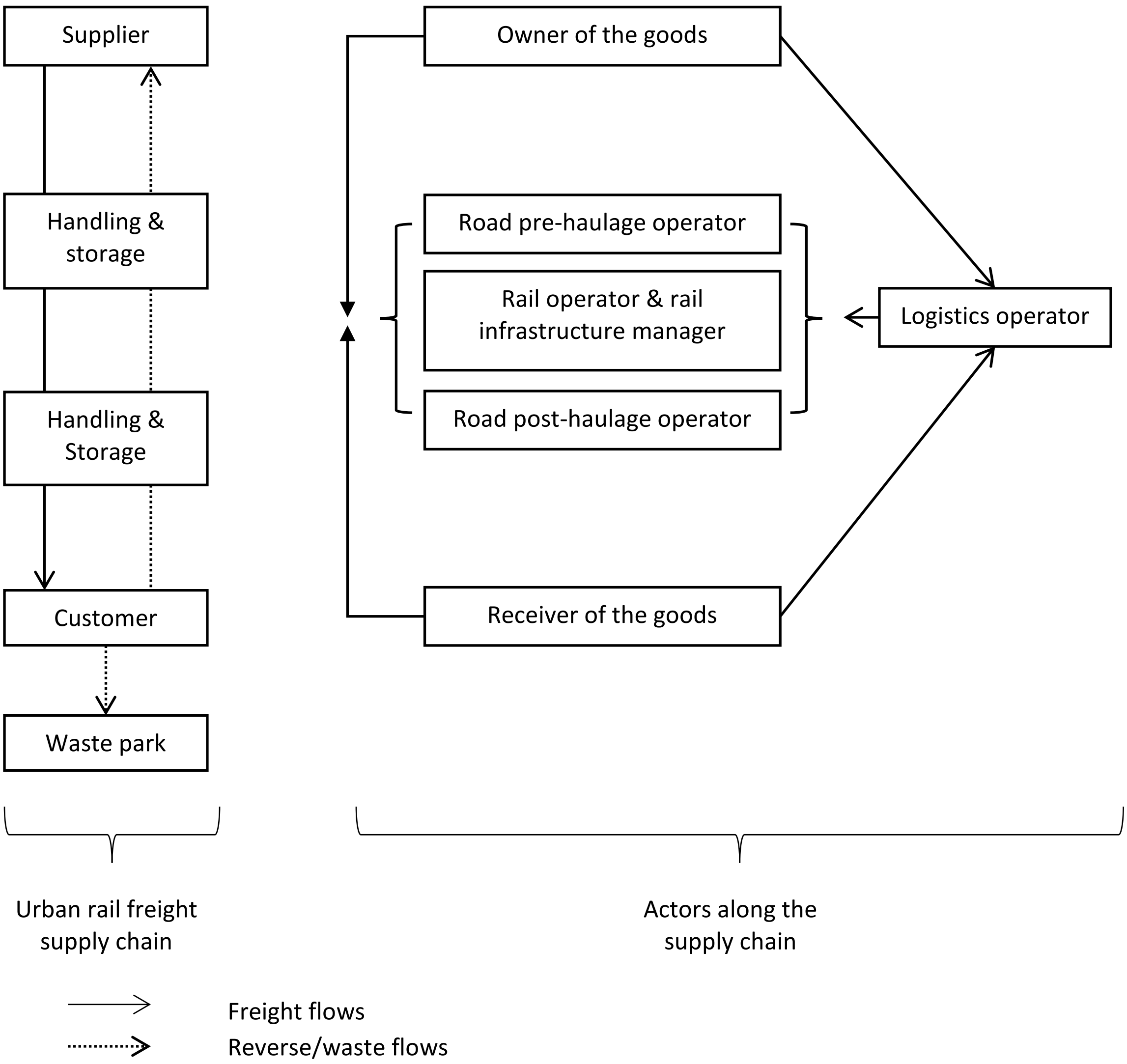
After this first step, it has to be decided whose benefits and costs count. This is explained in the next step.

3.2.2.2 STEP 2: Decide whose benefits and costs count

Before the relevant costs and benefits can be determined, it has to be clarified whose benefits and costs have to be included in the calculations. The analysis is done from a financial and economic perspective on the one hand, and socio-economic perspective on the other hand. In the financial and economic analysis, the cost of the government investing in the urban rail-based solution is calculated, as well as the generated revenue. Following Sartori et al. (2015), a consolidated analysis is carried out, in which the infrastructure owner and rail operator are considered as one actor, being the government. In the socio-economic analysis, the costs and benefits of the urban rail-based solution are examined, taking the time savings and external costs into account. To understand whose benefits and costs have to be taken into account in the socio-economic analysis, it is important to know all the actors of the supply chain. Furthermore, it is crucial to know which actor is taking which decisions. The owner of the goods (supplier), transport or logistics operator and the receiver of the goods (customer) are the main actors to be considered here next to the government (Meersman et al., 2010).

Figure 25 displays the freight and reverse or waste flows in the urban rail freight supply chain. The left part of Figure 25 shows the freight flows. The goods are transported from the supplier to the customer (see full arrow). Waste is transported from the customer to a waste park or back to the supplier, while reverse logistics flows are going from the customer back to the supplier (see dashed arrows). Handling and storage consists of loading and unloading and storage activities (Meersman, Pauwels, Van de Voorde, Vanelslander, & Monteiro, 2006) and it takes place in case a combination of pre-and/or post-haulage road transport and rail is used. Information flows are also present, but these are not shown in the figure in order to keep the figure readable.

Figure 25 – Freight and reverse/waste flows in an urban rail freight supply chain



Source: Own creation based on Meersman et al. (2006, 2010, p. 221), Troch et al. (2016), Vercammen (2016)

The right part of Figure 25 displays the actors and the directions of their decisions. The owner of the goods, i.e. the supplier, or the receiver of the goods, i.e. the customer, decides either upon a logistics operator, or on a train or tram operator and a road pre- and post-haulage operator if needed. The rail operator buys a rail path from the rail infrastructure manager. If a logistics operator is chosen, the latter organises the transport and is responsible for the choice of a rail operator and road pre- and post-haulage operator if necessary. Research of Vercammen (2016) shows that 40% of shippers in Belgium order a rail service through a logistics operator, 40% directly through the rail operator and the remaining 20% through a combination of rail operators and rail organisers. The rail operator in Figure 25 can be a private or public actor.

In this research, the revenue and costs of the government (including the operator) are taken into account in the financial and economic analysis, whereas the benefits and costs of all important stakeholders such as the impactees and urban freight users, i.e. the shippers and receivers, are added to the socio-economic analysis. The analysis in this research is done from the viewpoint of the public authorities initiating an urban rail freight service. In the remainder of this thesis, this stakeholder is referred to as the project leader. This perspective should be kept in mind when interpreting the SCBA model and the results. When the benefits of implementing the project are known, the effect on each stakeholder separately is derived. If some stakeholders experience costs when the rail-based urban freight project is implemented, they may change their behaviour. This effect is tackled by examining the resulting project benefits on each stakeholder.

3.2.2.3 STEP 3: Identify the impacts and select measurement indicators (units)

In the third step, impacts resulting from the innovation are identified and measurement units are selected. In order to examine the potential of the innovation, the impacts leading to a change in private revenue ΔR_p, private costs ΔC_p, social benefits ΔB_s and social costs ΔC_s have to be identified. Table 13 provides an overview of authors who conduct an (S)CBA with respect to the use of rail for urban freight distribution and the financial, economic and socio-economic components they measure.

Table 13 – Cost and benefit components considered in existing urban rail freight (S)CBAs

			Light rail		Tramways		
			Alessandrini et al. (2012)	Gorçun (2014)	Regué & Bristow (2013)	Gonzalez-Feliu (2014, 2016)	Gorçun (2014)
Financial and economic components	Capital investment	Logistics infrastructure		X	X	X	X
		Purchasing rolling stock		X	X	X	X
		Tracks			X	X	
	Operational costs	Energy consumption	X	X	X	X	X
		Handling and storage operations			X	X	
		Maintenance-repair	X		X	X	
		Pre- and/or post-haulage road transport				X	
		Rail operations	X		X	X	
	Operational income	Revenue				X	
		Road vehicle operating cost savings	X		X	X	
Socio-economic components	External cost changes	Accidents			X		
		Air pollution	X	X	X	X	X
		Climate change	X	X	X	X	X
		Congestion			X	X	
		Infrastructure damage			X		
		Landscape deterioration					
		Noise			X	X	
	Consumer surplus changes	Added value services UCC			X		
		In-store stockholding surface reduction			X		
		Reverse Logistics			X		
		Time savings				X	

Source: Own creation

From the viewpoint of the project leader, the costs and benefits of the urban rail freight project are the investment and operational costs on the one hand and the revenue on the other hand. The investment comprises the initial investment, the replacement costs if needed and the residual value if applicable. The residual value is determined by calculating the net present value of the cash flows in the remaining economic life of the infrastructure, which is beyond the time horizon of the analysis. The initial investment is equal to the sum of all financing sources, being the public contribution, loans and private equity. The operating costs are all costs that are related to the operation and maintenance of the new service. The revenues are the incoming cash flows that are paid by the users of the urban rail freight service, as well as ancillary revenue related to advertisement on the rail vehicles. Examples of these cash flows are the charges paid by the users for the use of the infrastructure such as track access charges, sale or rent of buildings or land, or payments for other services (Blauwens et al., 2016).

When doing the analysis from the viewpoint of the project leader, a financial and an economic analysis are carried out. In the financial analysis, the return on capital is calculated, whereas the return on investment is calculated in the economic analysis. In the financial and economic analysis, only cash inflows and outflows are taken into account. The cash flows should cover a time horizon which corresponds with the project's economic life. The cash flows are taken into account in real prices and a real financial discount rate is used, which reflects the opportunity cost of capital (Sartori et al., 2015).

The financial analysis is executed in order to examine the performance of the project from the perspective of the capital investors. In order to calculate the return on capital, the operational costs, infrastructure replacement costs, public contribution, private equity, loan repayments and interests are subtracted from the revenues and the residual value of the infrastructure (Sartori et al., 2015).

In the economic analysis, the investment costs are compared to the net revenues, i.e. the revenue cash flows reduced by the operating costs cash flows. The question is here to which extent the project net cash flows compensate for the investment, regardless of the financing sources used. In general, if the internal rate of return is lower than the used discount rate, the generated revenues cannot cover the project costs. The revenue cash flows are the total revenues and the residual value. The operating costs cash flows are the total operating costs, the initial investment and the replacement costs (Sartori et al., 2015).

Subsequently, the socio-economic analysis is carried out, in which the revenue is substituted by the willingness-to-pay. Hence, the effects on project users and impactees are added to the analysis. In the socio-economic analysis, the consumer surplus, producer surplus and non-market impacts on safety and the environment are included. Consumer surplus is calculated by the rule of half and is obtained if the generalised cost decreases. Producer surplus is the difference between the increased revenue and the operating increased costs. For existing traffic, the revenue for the project leader and the cost to the project user cancel each other out. For generated or induced traffic, the rule of half is used. In this research, the generalised cost curve is assumed to be horizontal and hence, no producer surplus exists. The non-market impacts consist of time savings and external cost savings (Blauwens, 1986; Blauwens et al., 2016).

From the analysis of the existing literature displayed in Table 13, firstly, it can be deducted that not all authors measure all components and not one component is measured by all authors. This might be due to a lack of data for the specific case that is examined, or because some components are irrelevant in some specific cases. Van Wee (2007) for instance mentions the lack of data on landscape deterioration when constructing new rail infrastructure. Secondly, these existing SCBAs are focused on specific case studies. Therefore, they cannot be applied to other urban areas, since they do not include all variables that determine the success or failure of using a rail for urban freight distribution. Thirdly, all authors shown in Table 13 conduct a cost-benefit analysis from the viewpoint of the supplier or shipper and not from the viewpoint of the government. However, the main added value of Table 13 is that it offers an overview of all impacts that have to be taken into account when developing an SCBA model. Hence, this table serves as the background for developing the social cost-benefit framework.

Alessandrini et al. (2012) include the costs of amortisation, fuel, insurance, labour, maintenance and taxes in the operational costs. Moreover, the same authors measure the external benefits of reduced air pollution and climate change effects. Regué & Bristow (2013) conduct an extended SCBA for the use of a freight tram for the transport of retail products and waste in Barcelona. These authors quantify almost all components shown in Table 13. Gonzalez-Feliu (2014, 2016) divides the capital investment costs in investments in linear infrastructure, i.e. the rail infrastructure, and nodal infrastructure, i.e. terminals and loading and unloading bays. Moreover, rolling stock has to be purchased. This author takes the need for road post-haulage into account. The benefits of using rail for urban freight distribution are the revenue generated by the rail-based transport, savings related to the part of the road transport that is not taking place anymore and potential time savings. Furthermore, external costs include pollution and noise during the construction of the rail infrastructure stage, as well as a potential loss of customers for retailers during this stage. The main external benefits comprise reductions in air pollution, congestion and greenhouse gases. Gorçun (2014) divides the generalised cost in investment costs, energy consumption costs and environmental costs. This author explicitly excludes noise, accidents, maintenance and repair and operational costs in his calculations.

Some other authors have not conducted an (S)CBA, but focus on one part of the total costs and/or benefits of using rail for urban freight distribution. Dorner (2001) considers the time and cost savings when using rail instead of road, the additional handling and storage costs, the investment costs and the maintenance costs in his evaluation of a shuttle train concept for Berlin. Neuhold (2005) measures the environmental effects of the use of the cargo tram in Zurich for waste collection. Dinwoodie (2006) calculates different private and social costs of using rail for urban freight distribution in Plymouth. However, benefits are not considered. Nuzzolo et al. (2007) estimate the investment and operational costs of a rail shuttle in Sorrentina, Italy, and add to this an analysis of the reduction of emissions and congestion. Delaître & De Barbeyrac (2012) conduct a private and social cost analysis of the Monoprix rail shuttle in Paris. The externalities taken into account are air pollution and climate change.

Sivakumaran et al. (2010) conduct an economic feasibility study, in which capital expenditure is not taken into account. These authors mention the potential benefits for the passenger rail operator, the freight carrier and for society of using the urban passenger rail infrastructure for freight transport. The main benefits for the passenger rail operator include the additional revenue of performing freight operations, the more efficient use of the existing capacity, and potential cross-subsidisation to improve the passenger activities. The main advantages for a freight carrier shifting from road to rail are also threefold: more reliable travel time for the goods, lower transport costs, and fewer lorry accidents. Ultimately, society could benefit in four ways. Firstly, less greenhouse gases will be emitted thanks to less lorry transport. Secondly, congestion due to road freight transport is reduced. Thirdly, road maintenance costs decrease, and fourthly, noise and accidents caused by lorries diminish. Zych (2014) does not conduct a cost-benefit analysis, but identifies air pollution, congestion, infrastructure damage and noise as important external costs that have to be measured.

The cost and benefit components related to the innovation can now be assigned to the stakeholders involved. Table 14 displays all impacts for the different stakeholders. The impacts experienced by the rail operator and public actors lead to financial and economic costs and benefits, while the impacts associated with the impactees (e.g. inhabitants, commuters and travellers) and shippers and receivers lead to socio-economic costs and benefits. Based on the cost and benefit calculation for a specific case, the impacts in Table 14 can be ranked.

Table 14 – Impacts per actor

Actor	Impact	Positive impact	Negative impact
Impactees	Fewer trains during construction works		X
	Landscape deterioration		X
	Reduction of externalities	X	
Rail operator	Emissions related to construction of vehicles		X
	Capital investment		X
	Operational costs		X
	Revenue	X	
Public actors	Welfare surplus	X	
	Subsidy		X
Shippers and receivers	Potential loss of customers for retailers during rail construction		X
	Reduced storage space needed	X	
	Reverse logistics	X	
	Time savings	X	
	Valued added services	X	

Source: Own creation based on Alessandrini et al. (2012), Aronietis (2013), Cochrane et al. (2017), Delaître & De Barbeyrac (2012), Dinwoodie (2006), Diziain et al. (2014), Dorner (2001), Gonzalez-Feliu (2014, 2016), Gorçun (2014), Neuhold (2005), Nuzzolo et al. (2007), Regué and Bristow (2013), Rien & Roggenkamp (1995), Sivakumaran et al. (2010), van Wee (2007) and Zych (2014)

With respect to the impactees, van Wee (2007) states that negative impacts related to the construction of new rail infrastructure have to be taken into account. These impacts include inconvenience for travellers, such as fewer trains and delays. Many authors see a reduction of the emissions as the main positive impact to the impactees (Delaître & De Barbeyrac, 2012; Dinwoodie, 2006; Diziain et al., 2014; Gorçun, 2014; Neuhold, 2005; Sivakumaran et al., 2010). Rien & Roggenkamp (1995), Dinwoodie (2006), and Gorçun (2014) mention the potential of using rail to minimise the road traffic and hence, to lead to time gains. Furthermore, using more rail than road transport can improve the air quality in the urban area. Van Wee (2007) mentions the importance of including changes in emission factors over time in the analysis. For instance, future fuel mix changes for electricity generation can be taken into account based on planned national policy. Zych (2014) sees the reduction of air pollution, noise, infrastructure damage and congestion as the main positive impacts on the impactees. Cochrane et al. (2017) identify the environmental benefits, including congestion reduction, as the main positive impact.

Concerning the rail operators, van Wee (2007) states that the energy use and emissions related to the production and maintenance of rail vehicles for instance have to be included when doing an SCBA. Moreover, the material gains when the vehicles are out of operation have to be added as benefits. Dinwoodie (2006) lists fixed capital, maintenance, crew, overhead and variable maintenance and fuel as annual locomotive costs. Furthermore, fixed annual wagon costs are present, consisting of fixed capital and maintenance and some small operational costs. Van Wee (2007) includes investment costs and maintenance and operational costs. Sivakumaran et al. (2010) mention the handling costs and the operating and labour costs.

Delaître & De Barbeyrac (2012) name investment costs in the rail infrastructure as the first impact on the logistics operators. Besides, additional operational costs may be present. These costs include the operational costs of the post-haulage transport and of the rail leg. An example of operational rail costs is the track access charges and the exploitation of the train. Other potential cost categories are the real estate costs for the handling and storage. Gorçun (2014) identifies energy consumption costs, purchasing costs of freight trains, maintenance-repair costs, logistics infrastructure installation costs and operations costs as the main impacts. Siciliano et al. (2016) divide the costs in infrastructure costs, development costs and operating costs. The infrastructure costs are related to the tracks, the development costs to the physical implementation of the transport, for instance the rolling stock, and the operating costs to consumption of materials and services, general production costs, maintenance and personnel. Cochrane et al. (2017) mention the new revenue stream for rail operators as a positive impact and the additional handling costs as the main negative impact.

With regard to the public actors, Nuzzolo et al. (2007) and Diziain et al. (2014) argue that the rail-based scheme could be complemented by some subsidies of the authorities. Cochrane et al. (2017) agree with this, but see the potential need for subsidies as a negative impact.

In relation to shippers and receivers, a potential loss of customers for retailers during the rail infrastructure construction period has to be mentioned (van Wee, 2007). Moreover, some positive impacts include the potential reduction of storage space needed, the possibility of adding reverse logistics to the rail-based solution and the potential value added services (Regué & Bristow, 2013). These benefits are called "user surplus" by Siciliano et al. (2016). Furthermore, travel time savings can be calculated by means of the value of time (de Jong, 2007; Mackie, Jara-Díaz, & Fowkes, 2001; van Wee, 2007).

Given the urban character of the SCBA in this research, two remarks are made. Firstly, travel time savings for diverting traffic as well as for newly generated traffic are in general a main benefit when applying SCBAs to new transport initiatives (Button, 2011). However, when using rail transport in an urban freight context, time savings are not the main incentive for the new transport initiative to be introduced.

Secondly, an important externality to be considered in an urban context is congestion. In urban areas, congestion is often present and it negatively affects the time needed to reach a certain location (Button, 2014; KiM, 2013). This externality is bypassed by rail-based solutions, while this is not the case when implementing improved road-based alternatives, such as cleaner lorries. On the other hand, Shefer and Rietveld (1997) find a negative relationship between density and the number of road accidents. When speeds are low, due to congestion, fatal accidents happen less frequently. This means that in an SCBA applied to an urban context, the assessment of the number of fatal accidents only has a minor effect on the output compared to an SCBA applied to a non-urban context.

Existing SCBAs (Alessandrini et al., 2012; Regué & Bristow, 2013) show that these rail-based urban freight projects have not proven to be profitable from a business-economic point of view under the conditions that they were applied. Therefore, the incorporation of socio-economic effects in the analysis has been necessary in the existing cases to obtain a profitable outcome. More important incentives to opt for rail transport as a (partly) substitute for road transport are in this case the reduced externalities and not necessarily the time savings.

In order to monetise all the impacts identified in Table 13 and Table 14 in the next step, the unit for which all costs and benefits are calculated has to be defined. In the social cost-benefit analysis, costs and benefits are calculated in euro, for a given time horizon. For the transport of parcels in a passenger vehicle, a private cost analysis is carried out from the viewpoint of a shipper or receiver. A shipper or receiver is more interested in knowing the cost difference expressed in euro per unit. Gevaers (2013) estimates the costs of the business-to-consumer (B2C) last mile in euro per parcel. Ayadi (2014) calculates costs and benefits of urban freight distribution chains per tonne. Cárdenas et al. (2015) measure the e-commerce last-mile cost in euro per stop. The unit chosen for the private cost analysis performed in this research is the cost per parcel and more specifically euro per parcel. A certain number of rail stops is given in a specific project case. By expressing the project costs and benefits in euro per parcel, it is possible to directly apply this figure in pricing strategy calculations. Conversion of costs and benefits in other units than in euro per parcel is done based on the conversion key provided by Ayadi (2014). Table 15 displays the different units discussed by Ayadi (2014) and their conversion to tonnes.

The first unit discussed in Table 15 is the number of euro pallets. This unit is often used when expressing the vehicle capacity, or the utilisation rate of the vehicle and the storing capacity in the upstream part of the supply chain. In order to convert this to tonnes, the number of euro pallets is multiplied by the average weight of a full euro pallet. This weight depends on the packaging and the product type. Ayadi (2014) makes a distinction between cooled food products (m=1), frozen food products (m=2), non-cooled food products (m=3) and non-food products (m=4). By means of surveys amongst distribution centres in France, the author determines the average weight of a full euro pallet for these four product types.

The second unit in Table 15 is the surface in square meter. With respect to the vehicles, one euro pallet with dimensions 0.8m by 1.2m equals 0.96m² (Ayadi, 2014). Concerning the logistics buildings, it has to be taken into account that corridors have to be available in between the stacked pallets. On the other hand, pallets in distribution centres are typically stacked on multiple layers. Hence, one pallet needs on average less floor space. A distinction still has to be made between cooled and non-cooled products. Non-food and non-cooled food products need a floor space of on average 0.96m², while cooled and frozen products take on average 0.8m². In order to calculate the rent costs of storing the goods in an urban distribution centre, the measure €/m² is often used. The daily rent cost is obtained by dividing the monthly rent by the number of days per month. Subsequently, this cost is divided by the surface of the distribution centre in order to know the daily cost per m².

Table 15 – Different units in the urban freight distribution supply chain (retail products)

Unit	Part of the chain	Conversion to tonnes
Number of pallets	Vehicle & storing capacity	Multiply by average weight of a full euro pallet (lorry 11t net): 230 kg for cooled food 300 kg for frozen food 340 kg for non-cooled food 400 kg for non-food And add tare weight of the euro pallet: 25 kg/pallet
Surface (m²), Volume (m³)	Vehicles	One euro pallet = 0.96 m², or 1.04 pallets per m² if stacked one layer high
	Buildings	Non-food, non-cooled food: one euro pallet = 0.96m², or 1.1 pallet per m² Cooled & frozen food: one euro pallet = 0.8 m², or 1.25 pallet per m²
Number of articles	Customers	Multiply by the unit weight of the product
Number of parcels	Handling & storage	Multiply by the average number of parcels per pallet[17]: 70 parcels times 6 kg for non-cooled food 70 parcels times 4.5 kg for cooled food 70 parcels times 5.5 kg for frozen food

Source: Own creation based on Ayadi (2014)

The third unit is the number of articles. This unit is often used in the downstream part of the supply chain, for example in supermarkets. The fourth unit is the number of parcels. Ayadi (2014) makes the

[17] The weight of the parcels here is the weight when transported in a lorry of 25 tonnes net.

assumption that one pallet carries about 70 parcels. Hence, for different types of goods, Table 15 shows the weight per parcel.

All costs and benefits are now converted to one and the same unit for the whole urban rail freight supply chain. Since the transport is taking place in an urban context, and thus, light goods vehicles are used, the reasoning of Gevaers (2013) is followed and the parcel is the unit chosen. Table 16 shows how all costs and benefits can be calculated per parcel, starting from the original unit for the part of the supply chain in which they occur. The rail vehicle is either a dedicated rail vehicle or a freight wagon attached to a passenger vehicle. In case of the transport of parcels alongside passengers, no pallets are used, so the conversion in Table 16 is not used. In case another type of transport unit is used than pallets, such as roll cages, the costs and benefits in euro per parcel can be derived analogously as in Table 16 by adapting the average weight, volume and loading metres per transport unit.

Table 16 – Conversion to euro per parcel for the different supply chain legs

Unit	Road	(Un)loading	Storage	Rail vehicle
Original unit	€/lorry	€/euro pallet	€/m² or €/pallet	€/rail vehicle
Conversion	1 lorry = X tonnes 1 lorry = Y loading metre 1 pallet = 0.4 loading metre 1 pallet = 300 kg for frozen food 230 kg for cooled food 340 kg for non-cooled food 400 kg for non-food + tare weight of 25 kg/ pallet		1 pallet = 0.96m² for non-food and non-cooled food 1 pallet = 0.8m² for cooled and frozen food	1 rail vehicle = X tonnes 1 rail vehicle = Y loading metre 1 pallet = 0.4 loading metre 1 pallet = 230 kg for cooled food 300 kg for frozen food 340 kg for non-cooled food 400 kg for non-food + tare weight of 25 kg/pallet
€/pallet		1 pallet = 70 parcels		
€/parcel		€/parcel		

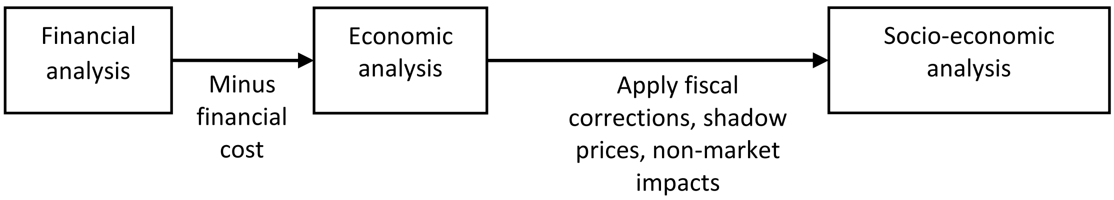
Source: Own creation based on Ayadi (2014) and Logistics Glossary (2019)

Sartori et al. (2015) recommend to conduct both a financial and an economic analysis when doing cost-benefit analyses. According to these authors, the return on investment and the return on capital are evaluated in the financial analysis, whereas the project's contribution to welfare is assessed in the economic analysis. Limon & Crozet (2017) make a distinction between a financial analysis, an economic analysis and a socio-economic analysis. In their research, a financial analysis evaluates the return on capital, an economic analysis assesses the return on investment and the socio-economic analysis deals with the welfare contribution. Hence, Sartori et al. (2015) and Limon & Crozet (2017) use the same measures, but use different terms.

In this research, the terminology suggested by Limon & Crozet (2017) is used, to make a more clear distinction between the different types of analysis. A distinction is made between a financial, economic and a socio-economic analysis. Figure 26 shows how these three types of analysis are connected to each other. The financial analysis provides the cash flows needed to carry out the economic analysis. Sartori et al. (2015) argue that a financial analysis should be conducted when doing a cost-benefit analysis, since it measures the financial performance of the project under consideration. More specifically, it evaluates the profitability of the project as a whole, the profitability of the project for the project leader and other stakeholders, and the financial sustainability of the project. The method used in this analysis is the discounted cash flow method (Limon & Crozet, 2017; Sartori et al., 2015).

In the economic analysis, the return on investment is determined. When measuring this, the investment costs are compared to the net revenue, i.e. the revenue reduced by the operating costs. The main difference with the financial analysis is that in the economic analysis, the financial costs are not taken into consideration (Limon & Crozet, 2017; Sartori et al., 2015).

Figure 26 – Link between financial, economic and socio-economic analysis



Source: Own creation based on Limon & Crozet (2017) and Sartori et al. (2015)

The socio-economic analysis is carried out in order to assess the effect of the project on group welfare. The main difference between the socio-economic analysis and the economic analysis is that the socio-economic analysis is conducted from the social viewpoint on how future costs and benefits are evaluated. Given this social viewpoint, a social discount rate is applied instead of a financial one (Sartori et al., 2015). Moreover, fiscal corrections are applied, market prices are transformed into shadow prices and non-market impacts and externalities are evaluated. Fiscal corrections include the exclusion of VAT and taxes on the input and output prices. However, taxes serving as a correction for externalities can be included. Shadow prices are used in case the market prices do not reflect the opportunity cost of inputs and outputs (Blauwens et al., 2016). An example is the revenue, which should be substituted for by the willingness-to-pay for the project. Another example is the wage, which is sometimes distorted. In this research, it is assumed that the labour force of the rail-based initiative used to be employed in similar activities, such as road transport. It is then argued that the shadow wage is very close to the market wage and hence, the wage is not distorted. Non-market impacts include for instance savings in travel time and reduction of external costs (Sartori et al., 2015). Siciliano et al. (2016) add to the calculations the benefits from reduced externalities, time savings and safety improvements. Time savings are calculated based on the value of time of the goods that are transported.

Different approaches are possible for measuring the externalities. Jones-Lee and Looms (2003) offer for example insight into the methodology for monetising accident reductions. In order to monetise the costs of accidents, amongst others the value of life has to be determined. Button (2014) gives an overview of the evolution of approaches to estimate value of life. These approaches have evolved from a revealed preference technique of ex-ante and ex-post evaluations to a framework in which individuals are asked about their willingness-to-pay to reduce the probability of an accident. However, an issue in this willingness-to-pay approach is that it is crucial to define the correct sample and to ask the individuals the correct questions. If these conditions are not met, the benefits of reducing accidents cannot reliably be forecast. The way external costs are derived and quantified is discussed more in detail in Chapter 5.

In the remainder of the analysis, socio-economic costs and benefits related to the impacts are classified based on Blauwens and Van de Voorde (1985b), who distinguish among investment and operational expenses on the cost side and consumer surplus and operational income on the benefit side. Since the role of rail in urban freight distribution is in the present research examined from a financial, economic and a socio-economic point of view, costs and benefits are further subdivided in financial, economic and socio-economic costs and benefits[18]. After having identified all the impacts of an urban rail freight initiative leading to costs and benefits and after having determined the unit of analysis, the impacts have to be quantified and monetised in the following step.

3.2.2.4 STEP 4: Quantify and monetise all impacts

In the fourth step, all impacts are quantified and monetised, i.e. all impacts are expressed in euros. The monetisation as such is not explained in detail here, since the values of the costs and benefits are case-specific. All used values from the literature have to be expressed in values for the same base year, which is in this research the year 2018. In other words, all figures are discounted to the year 2018. In order to do that, the consumption price index (CPI) and the purchasing power index (PPI) are used. The consumption price index k_t is proposed by Rebel (2013) and is expressed by Equation (4):

$$k_t = k_s * \frac{CPI_t}{CPI_s} \tag{4}$$

in which
s = basic year of the figure;
t = basic year of the SCBA (t>s) = 2018;
k_s = value of the figure in year s;
k_t = value of the figure in year t;
CPI_s = value of the consumption price index in year s;
CPI_t = value of the consumption price index in year t.

Following Rebel (2013), the consumption price index is used to discount figures related to economic costs to the basic year 2018. Since some costs increase in relation to the purchasing power, the purchasing power index PPI_{st} is introduced by Rebel (2013) to correct for the historic evolution of the purchasing power. This index is expressed by Equation (5):

$$PPI_{st} = \frac{GDP_t}{GDP_s} * \frac{POP_s}{POP_t} \tag{5}$$

in which
s = basic year of the figure;
t = year for which the figure is needed (t>s) = 2018;
PPI_{st} = purchasing power parity in year t compared to year s;
GDP_s = gross domestic product at current prices in year s;
GDP_t = gross domestic product at current prices in year t;
POP_s = population in year s;
POP_t = population in year t.

The figures for the GDP and POP come from NBB (2019a, 2019b). Following Rebel (2013), the PPI_{st} is used for discounting the external cost figures to the base year 2018. Concerning the external congestion costs, an additional adaptation is made. On average, freight vehicles only represent a low share of total Flemish road traffic. In the region around Antwerp, the share of freight vehicles is the highest (20-30%), whereas in the Brussels region this share is less than 15% (MORA, 2018). Hence, the largest part of the external congestion costs is borne by passengers. In other words, these costs consist especially of the value of time of people.

[18] When extending the analysis by including effects on other markets, such as the labour market, Harberger's rule is used. More information on this rule is available in Debisschop (2002).

Empirical research (Commissariat General du Plan, 2001; de Jong, Bakker, & Pieters, 2004; Mackie et al., 2003) shows that the real growth of the value of time of travellers is related to the income growth with a factor of 0.5 to 1. Therefore, Rebel (2013) assumes that the future external road congestion costs increase by 75%, i.e. the average of the factors 0.5 and 1, of the growth of purchasing power. The external congestion figures obtained in this way are also used by Gérard, Struyf, Sys, Van de Voorde & Vanelslander (2015). With respect to climate change costs, the reasoning of Rebel (2013) is followed by not adapting these figures as a function of the year for which the figure is needed. Climate change costs are global costs and thus, it does not make sense to correct them for the evolution of prices.

After having set all costs and benefits in $euro_{2018}$ values, the costs and benefits of the initiative are calculated over the time horizon of the project. Blauwens et al. (2002; 2016) argue that the discounting period should equal the total lifetime of the project effects. It can be assumed that the project effects after finishing the discounting period will equal the effects of the last year of the discounting period. Siciliano et al. (2016) agree with this and state that the time horizon of the SCBA has to be equal to the economic life of the main assets. Gwee et al. (2008) indicate that the most commonly used time horizon for SCBA projects is 20-30 years. Regué & Bristow (2013) use a horizon of 25 years for a freight tram scheme in Barcelona.

Vadali et al. (2017) estimate the lifetime of a freight rail to be 35 years and the one of a freight transfer centre to be 25 years. These authors also indicate that the European Union typically uses a lifetime of 30 years for rail projects, which is indeed recommended by Sartori et al. (2015). The latter authors suggest the following time horizon: 25-30 years for road projects, 30 years for rail projects and 25-30 years for urban transport. The project under consideration in this research lies on the intersection between these three types of infrastructure and thus, a time horizon of 30 years is chosen. Hence, all costs and benefits are calculated over this period of 30 years, i.e. all costs and benefits occurring between 2018 and 2047 are taken into account. In order to do this, the inflation rate is used. For applying the model to a Belgian case study, the inflation rate of December 2018 is used and this rate was equal to 2.3% (NBB, 2019c).

3.2.2.5 STEP 5: Discount costs and benefits to obtain present values

In the fifth step, all costs and benefits that occur over the lifetime of the project case are discounted to present values, i.e. to values of 2018. In order to do this, the discount rate has to be chosen. Since the financial, economic as well as the socio-economic costs and benefits are calculated, a financial and social discount rate have to be determined.

Several authors (Blauwens et al., 2016; Boardman et al., 2018; de Rus, 2010; Vadali et al., 2017; Verbruggen, 2008) highlight the importance of the discount rate with respect to the end result of the SCBA. However, these authors also recognise that there is no consensus on the correct value of the rate. When choosing for a high discount rate, benefits occurring in the near future are characterised by a higher value, whereas benefits taking place in the far future are characterised by a higher value when choosing for a low discount rate. In general, a low discount rate is in favour of projects with high total benefits, independent from when they occur during the lifetime. A high discount rate is in favour of projects with high benefits at the beginning of the lifetime (Boardman et al., 2018).

Appendix 3 provides a chronological overview of discount rates used for various transport-related projects. Not all authors mention if they apply a financial or a social discount rate. Three conclusions can be drawn from Appendix 3. Firstly, values between 2.5% and 10% are used over the time considered, which is the period 1988-2017. This confirms the statement of several authors (Blauwens, 1988; Blauwens et al., 2016; Boardman et al., 2018; de Rus, 2010; Vadali et al., 2017; Verbruggen,

2008) that there is no consensus on the exact discount rate value. However, almost all values lie between 2.5% and 6%, with the largest part of the most recent studies using a rate around 4%. Secondly, some studies use a real discount rate, others a nominal rate and others do not specify which rate they use. Thirdly, some studies provide ranges for sensitivity analyses. As suggested by Blauwens et al. (2016), the discount rate will be halved and doubled in the sensitivity analyses in Chapter 6.

Raicu et al. (2012) state that the use of high discount rates is not proven productive in SCBAs. These authors state that discount rates between 4% and 6% are often used in sensitivity analyses. Rebel (2013) also uses a discount rate of 4% for transport infrastructure projects in Belgium. This value is adopted by Maes (2017) for evaluating the use of bike couriers for urban freight distribution. The value obtained by Rebel (2013) is based on the real, risk-free discount rate in the long term, such as government bonds. It is a real rate, so inflation is excluded from this rate.

Blauwens et al. (2016) and Boardman et al. (2018) explain the distinction between using a nominal versus a real discount rate. This distinction is shown in Table 17. When using a real discount rate, the future prices are displayed in a currency with constant purchasing power, whereas for a nominal discount rate this is by a currency subject to inflation. With respect to the time preference, the real discount rate indicates a real time preference, while the nominal discount rate reflects a nominal time preference. Thus, the difference between the real and the nominal discount rate is the inflation. Using the real or the nominal discount rate in SCBA calculations should in theory lead to the same result, since the higher costs and benefits when using the nominal discount rate are compensated for by a higher discount rate. Boardman et al. (2018) argue that both real and nominal discount rates can be used. In the private sector, the nominal discount rate is often used, whereas the real discount rate is commonly used in the public sector. Blauwens et al. (2016) recommend expressing costs and benefits in prices with constant purchasing power, hence, without adding inflation. As a result, the real discount rate, excluding inflation, is recommended by these authors. In this thesis, it is opted to apply the real discount rate since this one is also recommended by the European Union (Sartori et al., 2015) and by the Flemish Government (Rebel, 2013).

Table 17 – Real versus nominal discount rate

Characteristic	Real discount rate	Nominal discount rate
Future prices	Currency with constant purchasing power	Currency subject to inflation
Time preference	Real time preference	Nominal time preference
Costs and benefits	Expressed in real euros	Expressed in nominal euros

Source: Own creation based on Blauwens et al. (2016) and Boardman et al. (2018)

In order to convert a nominal discount rate to a real one, Boardman et al. (2018) provide Equation (6):

$$r = \frac{i - m}{1 + m} \tag{6}$$

in which
r = the real discount rate
i = the nominal discount rate
m = the inflation

From Equation (6), it can be seen that the difference between the nominal and the real discount rate is indeed the inflation.

Since a socio-economic analysis is conducted in this thesis, the choice of the social discount rate is important. This rate often varies between 2.5% and 6% (de Bruin, Goosen, van Ierland, & Groeneveld, 2014). Button (2011, 2014) observes the challenge of defining an appropriate social discount rate. This author concludes that if a basic assumption of the analysis is that resources have to be maintained for future generations (Brundtland, 1987; Treasury, 2007), the discount rate in an SCBA has to be close to zero. This means that long-term predictions about traffic and accidents play a larger role in the NPV of projects. Thus, reliable forecasts are becoming more important for the accuracy of the SCBA.

Appendix 4 provides the social discount rates used per country for different types of projects. In Belgium, the social discount rate lies between 4% and 5% (Federaal Planbureau, 2017). Goldmann (2017) recommends for Germany a social discount rate of 3.5% for evaluating inland waterway transport, rail and road freight infrastructure projects. In the UK, social discount rates are according to the Green Book (HM Treasury, 2018) based on the social time preference rate following Ramsey (1928). Freeman, Groom & Spackman (2018) examined the social discount rate for the UK that is used in the Green Book (HM Treasury, 2018) and recommend to use a rate of 3.5%. In the USA, two constant discount rates have to be used. The lower one (3%) represents the social time preference rate, whereas the higher one (7%) expresses the opportunity cost of capital (Ni, 2017).

Based on this overview, in this research, a real financial and social discount rate of 4% is used as a starting point of the analysis. The rate of 4% is chosen, because it is within the range recommended for Belgium (Federaal Planbureau, 2017) and for the Netherlands (Eijgenraam, Koopmans, Tang, & Verster, 2000), and it lies in between the rates recommended for neighbouring countries of Belgium such as France (4.5%) and Germany (3.5%). A declining rate should be used, but in most studies, the rate only starts to decline after a time horizon of 30 years. In this research, a time horizon of 30 years is used and hence, the rate of 4% can be used for this whole time frame. In the sensitivity analyses, the output of the SCBA is calculated for values of the discount rate ranging between 2% and 8%. By using 8%, the risk is for a large part reduced from the calculations. In other words, if the project case is not feasible under a discount rate of 8%, it is better to stop the case.

After having decided upon the social discount rate, the discounted free cash flow over the time horizon has to be calculated. In order to do this, the steps shown in Table 18 are followed.

Table 18 – Calculation of the annual cash flow

Step	Item	Calculation
1	Total benefits	Operational income + consumer surplus change + external cost savings
2	Total operational cost	Rail + road pre- and post-haulage + handling & storage
3	EBITDA	(1) – (2)
4	Depreciation	Capital investment/ life span project
5	Operational result	(3) – (4)
6	Interest	Loan * interest loan
7	EBT	(5) – (6)
8	Taxes	If (7) <=0,0; if (7)>0, (7)*taxes on profit
9	Net result after taxes	(7) – (8)
10	Cash flow	(9) + (4)
11	Pay back loan	Loan/ life span loan
12	Free cash flow	(10) – (11)
13	Discounted free cash flow	(12)/(1+discount rate)^year number

Source: Own creation based on Paelinck (2002)

Firstly, the total benefits of the project are calculated. In this research, this includes the operational income and the consumer surplus. The operational income is expressed as the willingness-to-pay for the rail-based initiative and it is assumed that this does not exceed the operational costs of the current transport by road. The consumer surplus consists of aspects such as ancillary revenue, reduced storage space needed in the urban area and time savings.

In the second step, the total operational cost is determined. This cost consists of the operational costs of the rail-leg, the road pre- and post-haulage, and the handling and storage.

Thirdly, the earnings before interest, taxes, depreciation and amortisation (EBITDA) are obtained based on the difference between the total benefits and the total operational cost. In order to arrive at the operational result in step 5, the depreciation of the capital investment needs to be subtracted from the EBITDA. Boardman et al. (2018) state that accounting depreciation should never be counted as a cost in an SCBA. It is the real depreciation that has to be included in the calculations, being the economic value decline over time. This means that the capital investment and the life span of the project need to be known. The capital investment in this research consists of the investment in tracks and switches, rolling stock and a transit platform or distribution centre.

Vadali et al. (2017) recommend to report the cost of financing as a separate cost in case the actor investing does not possess the full investment price and has to borrow money from another actor. The first component of the total capital investment is the loan that has to be paid to the bank. This can vary between 0% and 100% of total capital investment needed. A payback period for the loan has to be decided upon. In this research, a payback time of 30 years is assumed. This means that the total loan is paid back linearly over 30 years. When subtracting the interest paid on the loan from the operational result, the earnings before taxes (EBT) are obtained in step 7. The interest is known by multiplying the loan and the interest on the loan (step 6). The interest on the loan is derived from the National Bank of Belgium and was equal to 1.35% in December 2018 (NBB, 2019d).

In step 9, the net result after taxes is obtained by subtracting the taxes from the earnings before taxes. The taxes equal the product of the EBT and the taxes imposed on private company profit. In Belgium, a maximum tax rate of 33.99% is applied to private companies (Belgische Federale Overheidsdiensten, 2019). Since the maximum rate is used, the net result after taxes is no overestimation with respect to the taxes to be paid in Belgium. Taxes are only imposed on profit. If no profit is made, i.e. the net EBT is negative, no taxes are imposed. Hence, the net result after taxes equals the earnings before taxes.

The cash flow is obtained in step 10 by adding the result after taxes and the depreciation. Subsequently, the loan has to be paid back (step 11). Thus, the free cash flow equals the cash flow reduced by the pay back of the loan (step 12). As the last step, the free cash flow of each year has to be discounted to the same base year 2018. For this calculation, the time horizon and the discount rate are used. The equation used in general for discounting is expressed by Equation (7) (Blauwens et al., 2016; Boardman et al., 2018; de Rus, 2010; Harberger, 1972; Vadali et al., 2017; Verbruggen, 2008):

$$NPV = \sum_{t=0}^{T} \frac{NB_t}{(1+i)^t} \tag{7}$$

In which

i = the annual discount rate;

t = the delay length, i.e. the moment that the cost or benefit occurs, expressed in years after the base year of the analysis;

NB = the net benefits for every year t;

NPV = the present value of NB, which occurs between the base year of the analysis and year T.

3.2.2.6 STEP 6: Evaluate each project case

After step 5, all costs and benefits are known in present values, i.c. $euro_{2018}$, for the full time horizon of the project. In order to evaluate the result of the SCBA, an appropriate appraisal method has to be chosen.

Multiple appraisal methods can be found in the literature to evaluate the result of an SCBA. Blauwens (1988) calculates the net present value, internal rate of return and the ratio of the present value and the capital investment for projects in Belgium. Gwee et al. (2008), Sartori et al. (2015) and Vadali et al. (2017) state that the most often used criteria for single multimodal projects are the net present value, the benefit-cost ratio and the internal rate of return. Gwee et al. (2008) provide an overview of the decision criteria used by multiple countries with respect to urban rail development. Table 19 gives the overview of the four mentioned methods for different countries. It is clear that in almost all countries, the net present value is used as an appraisal method. The internal rate of return and the present value to capital ratio are never used as a method on their own, but are always accompanied by a net present value analysis. The use of the net present value and the internal rate of return for France is confirmed in the research done by Gonzalez-Feliu (2016), who uses the same two methods for evaluating a freight tram in France. The four methods presented in Table 19 are now briefly discussed.

Firstly, de Rus (2010) and Blauwens et al. (2016) are very cautious with respect to the benefit-cost ratio. This measure provides a relative comparison of costs and benefits, but does not say anything about the absolute costs and benefits. De Rus (2010) adds that using the benefit-cost ratio can provide a wrong ranking of alternative projects. However, when executing several projects given a certain budget restriction, the costs and benefits are indirectly included in the analysis based on the ranking of the projects. De Rus (2010) and Blauwens et al. (2016) provide a static criterion for choosing between mutually exclusive projects. The objective is to maximise the net present value. Blauwens et al. (2016) state that multiple projects should be ranked by decreasing present value to capital ratio. Next, a required yield has to be identified. Subsequently, only projects characterised by a present value to capital ratio larger than or equal to the yield can be accepted. Ultimately, the project with the highest value when subtracting the yield, multiplied by the capital, from the NPV is chosen.

Table 19 – Appraisal methods used in different countries/regions concerning urban rail development

Country/region	Benefit-cost ratio (BCR)	Internal rate of return (IRR)	Net present value (NPV)	Present value to capital ratio (PVTCR)
Australia	X		X	
Belgium			X	X
Canada			X	
European Union	X	X	X	
France		X	X	
Germany	X			
Hong Kong		X	X	
Japan	X			
New Zealand	X			
Republic of Korea	X	X	X	
Singapore	X			
The Netherlands		X	X	
UK			X	
USA			X	

Source: Own creation based on Blauwens et al. (2002, 2016), Gwee et al. (2008) and Sartori (2015)

Secondly, the internal rate of return (IRR) is mentioned by multiple authors (Blauwens, 1988; Blauwens et al., 2016; Boardman et al., 2018; de Rus, 2010) and is the discount rate at which the net present value equals zero. The higher the internal rate of return, the better the result. In general, a project is accepted if the IRR exceeds the discount rate and a project is rejected if the IRR is smaller than the discount rate. Harberger (1972) identifies the fact that the IRR can be calculated by only using project data as the main advantage of this method. However, other authors (Blauwens, 1986; Blauwens et al., 2016; Boardman et al., 2018; de Rus, 2010; Harberger, 1972) warn for two very important caveats. This method is in favour of small investments, since it takes the relative benefits compared to the investment into account instead of the absolute benefits. Furthermore, if costs and benefits occur in n different years and change sign more than once, an equation of degree n has to be solved, meaning that the solution found is not always unique. Gwee et al. (2008) state that the IRR should always be used only as a complement to the NPV result. Boardman et al. (2018) add that the IRR is a good decision rule if only one project alternative is available.

Thirdly, most studies (Blauwens, 1988; Blauwens et al., 2016; de Rus, 2010; Gwee et al., 2008; Sartori et al., 2015) use the net present value to evaluate the result of an SCBA. De Rus (2010) states that the most reliable method to evaluate the result of an SCBA is the net present value. The net present value is defined as the sum of all net benefits occurring during the project life time, discounted to the same base year. Fourthly, Blauwens (1988) also calculates the ratio of the present value and the capital investment. If dividing the present value by the capital invested returns a negative value, the project should be eliminated.

Following Sartori et al. (2015) and Limon & Crozet (2017), the SCBA consists of a financial, economic and a socio-economic analysis. The financial profitability is measured by calculating the financial net present value on capital (FNPV) and the financial rate of return (FRR) on capital. The financial return on capital measures the project performance for the public and private investors. The financial NPV is expressed by Equation (8):

$$FNPV = \sum_{j=t_p-t_r}^{j=t_n-t_r} \frac{-\Delta I_j + \Delta R_j - \Delta C_j - \Delta F_j}{(1+r)^j} + \frac{K_{t_n}}{(1+r)^{t_n-t_r}} \tag{8}$$

In which

I_j	= the investment & replacement costs made in year j
R_j	= the revenue in year j
C_j	= the operating costs in year j
F_j	= the financial costs in year j
K_{tn}	= the residual present value of the infrastructure
r	= the financial discount rate
t	= time horizon

In the financial analysis, a financial discount rate is adopted, reflecting the opportunity cost of capital. The first component of the numerator in Equation (8) is the investment *I*. This component consists of three parts: the initial investment, the replacement costs and the residual value. The initial investment is defined as the capital costs of all fixed and non-fixed assets. Relevant examples are the rail infrastructure, land, the construction of distribution centres or unloading bays and the rail vehicle. The costs to replace the infrastructure which take place during the time horizon of the project then have to be added. In this research, it is possible that the rail vehicle has to be replaced given the considered time horizon of 30 years. If the economic life of an asset is longer than the time horizon of the SCBA, the residual value of the asset *K* has to be taken into account as well (Sartori et al., 2015).

The second component of the numerator in Equation (8) is the revenue *R*. The revenue is defined as "*cash in-flows directly paid by users for the goods or services provided by the operation, such as charges borne directly by users for the use of infrastructure, sale or rent of land or buildings, or payments for services*" (European Parliament & Council of the European Union, 2013; Sartori et al., 2015, p. 46).

Hence, the revenue depends on the demand for the rail-based solution. Only revenue directly resulting from project operations is taken into account.

The third component of the numerator in Equation (8) is the operating cost *C*. This component includes all the costs needed to operate and maintain the rail-based urban freight solution. Examples are the personnel, energy, fuel, maintenance of the vehicle, rent of a distribution centre and insurance (Sartori et al., 2015).

The fourth component of the numerator in Equation (8) is the financial cost *F*. Sartori et al. (2015) list four possible financing sources, being an EU grant, a national public contribution, a contribution of the project leader, i.e. his own equity or a loan, and a private contribution under a public-private partnership (PPP) construction. The total amount provided by these four financing sources has to be equal to the total initial investment cost. All financial costs related to the investment costs, such as interest on a loan, are included in variable *F* in Equation (8).

The net cash flow used to calculate the FNPV in Equation (8), is obtained by subtracting the total outflows from the total inflows. The total outflows include the public contribution to the investment, the private equity contribution, the loan repayment including interest and the total operating and replacement costs. The total inflows comprise the total revenue and the residual value of the infrastructure (Sartori et al., 2015).

If the rail project is led by a consortium of a public and private stakeholder, the return on capital now has to be assigned to each party. The return for the public stakeholder is obtained by calculating the return on public equity (FRRg), while the return for the private stakeholder is measured by evaluating the return on private equity (FRRp) (Sartori et al., 2015).

If the result of Equation (8) is larger than or equal to zero, the project is called rational. This means that it is financially feasible to the extent that the profitability equals at least the discount rate *i* (Verbruggen, 2008). Blauwens et al. (2016) and Vadali et al. (2017) state that projects with an NPV larger than zero are rational and can be chosen to be carried out, whereas projects with an NPV smaller than zero are irrational. The rational projects still have to take budget constraints into account. This is also what de Rus (2010) states, namely that a positive NPV is a necessary condition to go on with a project, but not a sufficient condition.

The corresponding financial rate of return on capital (FRR) can then be determined as the discount rate that is obtained when setting Equation (8) equal to zero. When the FRR is lower than the financial discount rate, the project is not financially profitable. Moreover, the present value to capital ratio can be calculated.

For the economic analysis, the economic net present value (ENPV) is expressed by Equation (9):

$$ENPV = \sum_{j=t_p-t_r}^{j=t_n-t_r} \frac{-\Delta I_j + \Delta R_j - \Delta C_j}{(1+r)^j} + \frac{K_{t_n}}{(1+r)^{t_n-t_r}} \tag{9}$$

In other words, the net cash flow used to calculate the ENPV in Equation (9) is obtained by subtracting the total operating costs *C*, the initial investment and replacements costs *I* from the sum of the total revenue *R* and the residual value *K*. Together with the ENPV, the economic rate of return (ERR), and the present value to capital ratio can be calculated.

The socio-economic net present value (SNPV) is expressed by Equation (10):

$$SNPV = \sum_{j=t_p-t_r}^{j=t_n-t_r} \frac{-\Delta I_j + \Delta R_j - \Delta C_j - \Delta E_j}{(1+s)^j} + \frac{K_{t_n}}{(1+s)^{t_n-t_r}} \tag{10}$$

In which
E_j = the external costs and benefits of a public investment
s = social discount rate

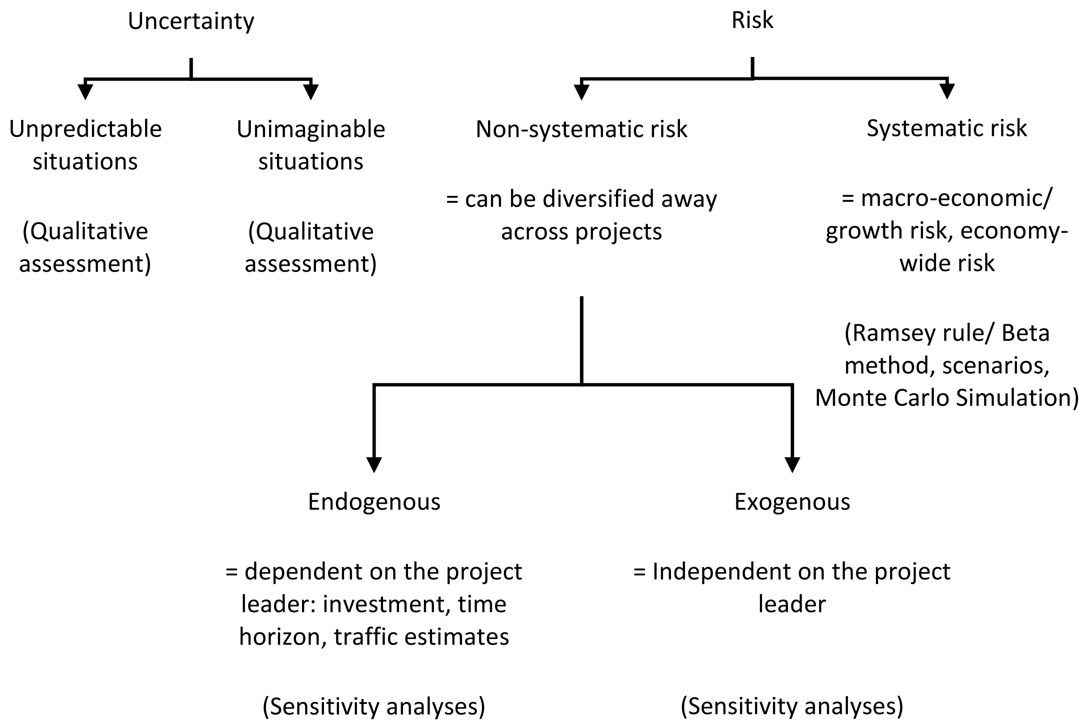
The net socio-economic benefits are calculated by subtracting the total costs from the total benefits. The total costs equal the sum of all operating costs, the initial investment, the replacement costs and the residual value. The total benefits equal the willingness-to-pay and the reduced external costs. The socio-economic rate of return (SRR) can be calculated (Sartori et al., 2015) as well as the present value to capital ratio.

In sum, the existing SCBA literature provides multiple appraisal methods and highlights the main strengths and weaknesses of each method. Following many authors (Blauwens, 1988; Blauwens et al., 2016; de Rus, 2010; Gwee et al., 2008; Sartori et al., 2015) the net present value is used as an appraisal method in this research, complemented by the internal rate of return (Boardman et al., 2018; Gwee et al., 2008; Sartori et al., 2015) and the present value to capital ratio (Blauwens, 1988; Blauwens et al., 2016).

3.2.2.7 STEP 7: Deal with uncertainty and risk

In order to deal with uncertainty and risk, Quinet (2013) and Limon & Crozet (2017) provide a typology of risk and uncertainty types. This typology is shown in Figure 27.

Figure 27 – Typology of risk and uncertainty



Source: Own creation based on Freeman et al. (2018), Limon & Crozet (2017) and Quinet (2013)

Firstly, a distinction is made between uncertainty and risk. The main difference between these two concepts is that risk can be quantified based on probabilities, whereas uncertainty comprises risk for which the probability cannot be quantified, since the situation is unpredictable or unimaginable. Therefore, it is suggested by the authors not to add the latter type of uncertainty to the quantitative calculations, but to assess it in a qualitative way. Van Wee (2007) mentions in this category for example the uncertainty related to new technologies.

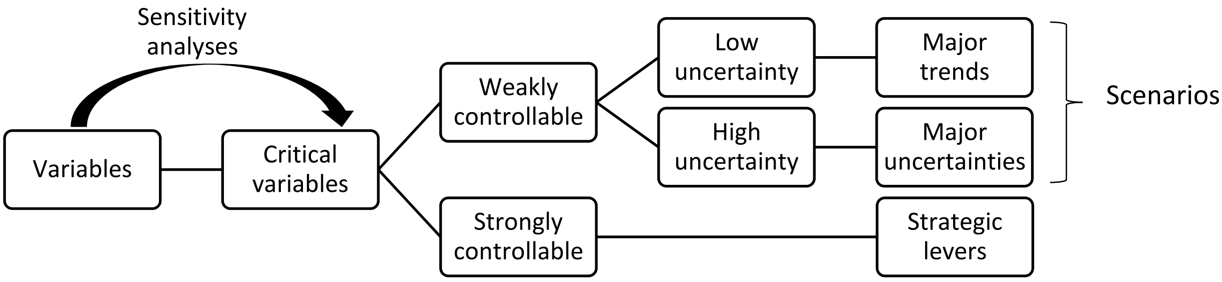
Secondly, two types of risk have to be taken into account in quantitative analyses: non-systematic and systematic risk. Non-systematic risk does not depend on the macro-economic context and therefore, can potentially be compensated for at society level. It can be divided into endogenous and exogenous risk. Endogenous risk comes from estimations made by the project leader, such as investment costs, time horizons and traffic estimates. This risk is often part of the strategy of the project leader, including the overestimation of the project benefits and the underestimation of the project costs. Exogenous risk originates from sources that are not related to the project leader. In both cases, the risk often results from the use of unreliable data. It is argued by Limon & Crozet (2017) that non-systematic risk should be tackled by carrying out sensitivity analyses.

Systematic risk is related to the macro-economic environment and it affects the society as a whole. Some examples are risk related to GDP growth, energy prices and raw material prices. Often used methods to deal with systematic risk are the Beta method, scenarios and Monte Carlo Simulation. The Ramsey rule, sometimes called Beta method or denominator method, builds on the Capital Asset Pricing Model (CAPM) that is used in financial markets. The main idea of this method is to internalise systematic risk in the discount rate, which is present in the denominator of the net present value equation (Equation 8-10). Scenarios internalise risk concerning the costs and benefits of the project and occur in the numerator of the net present value equation. Different cash flows are quantified for different potential macro-economic scenarios with a given probability. Monte Carlo Simulation is another numerator method in which thousands of scenarios are applied to multiple variables (Limon & Crozet, 2017).

In order to take risk into account in a cost-benefit analysis, the non-systematic and the systematic risk have to be incorporated. With respect to the non-systematic risk, sensitivity analyses are carried out. Concerning the systematic risk, scenarios are formulated. Sartori (2015) and Vadali et al. (2017) also highlight the importance of uncertainty and risk in an SCBA. Uncertainty is according to Vadali et al. (2017) present when making assumptions in the analysis, and when choosing inputs. The authors recommend to make a categorisation of the uncertainty and risk sources and highlight whether these sources affect the costs or the benefits of the project. Several authors highlight the importance of uncertainty in SCBAs (Blauwens et al., 2016; Boardman et al., 2018; de Rus, 2010; Sartori et al., 2015; Vadali et al., 2017). Different methods to deal with uncertainty are available in the literature (Boardman et al., 2018; de Rus, 2010; Sartori et al., 2015; Vadali et al., 2017).

Crozet (2003) offers, based on Arcade (2003), a framework for dividing the variables characterising the reference and project case depending on their risk and uncertainty level. Figure 28 shows this framework. Firstly, it has to be determined which variables are critical variables. In order to know which variables are critical, Sartori et al. (2015) suggest to conduct sensitivity analyses. Secondly, the critical variables are divided into variables on which the project leader only has a weak control and variables that can be strongly controlled. The level of control is assessed with respect to the short run. Besanko & Braeutigam (2014, p. 787) authors define the short run as "*the period of time in which at least one of the firm's input quantities cannot be changed*". The variables that can be strongly controlled by the project leader are the strategic levers. These variables correspond to the endogenous variables introduced in Figure 27.

Figure 28 – Classification of variables



Source: Own creation based on Arcade (2003), Crozet (2003, p. 60) and Sartori (2015)

Thirdly, the weakly controllable variables are divided in variables characterised by low uncertainty and variables that are highly uncertain to the project leader. The low uncertainty variables are called the major trends. These variables correspond to the exogenous variables defined in Figure 27. An example in the context of urban rail freight is the presence of rail infrastructure. This is before the implementation of a project not easy to control, but the presence is known in advance. Hence, there is only limited uncertainty concerning this variable. The high uncertainty variables are defined as the major uncertainties, corresponding to the systematic risk in Figure 27. These variables can only weakly be controlled and are characterised by a high degree of uncertainty. An example is the demand for urban rail freight. Wright & Cairns (2011, p. 9) developed a similar framework, dividing variables in three categories, being critical uncertainties, important predetermined trends and the behaviour of actors. These three categories are in line with respectively the major uncertainties, major trends and strategic levers defined by Arcade (2003) and Crozet (2003).

Crozet (2003) suggests identifying scenarios with respect to the major trends and major uncertainties, as shown in Figure 28. This is not fully in correspondence with the suggestion in Figure 27, where it is stated that scenarios are to be carried out with respect to the systematic risk, which equals the major uncertainties in Figure 28, but not the major trends. An explanation is that when considering a certain reference project, the major trends are given. Therefore, they are not considered as systematic risk. However, when evaluating the use of rail for urban freight distribution in general, multiple reference projects exist. Hence, it is useful to use the major trends variables as well in the development of scenarios in this research.

In sum, sensitivity analyses are carried out in order to know the effect of the critical variables, as well as the effect of combinations of several variables, in quantitative terms. Based on the results of the sensitivity analyses, scenarios are formulated with respect to the major trends and major uncertainties.

3.2.2.8 STEP 8: Make recommendations based on the previous steps

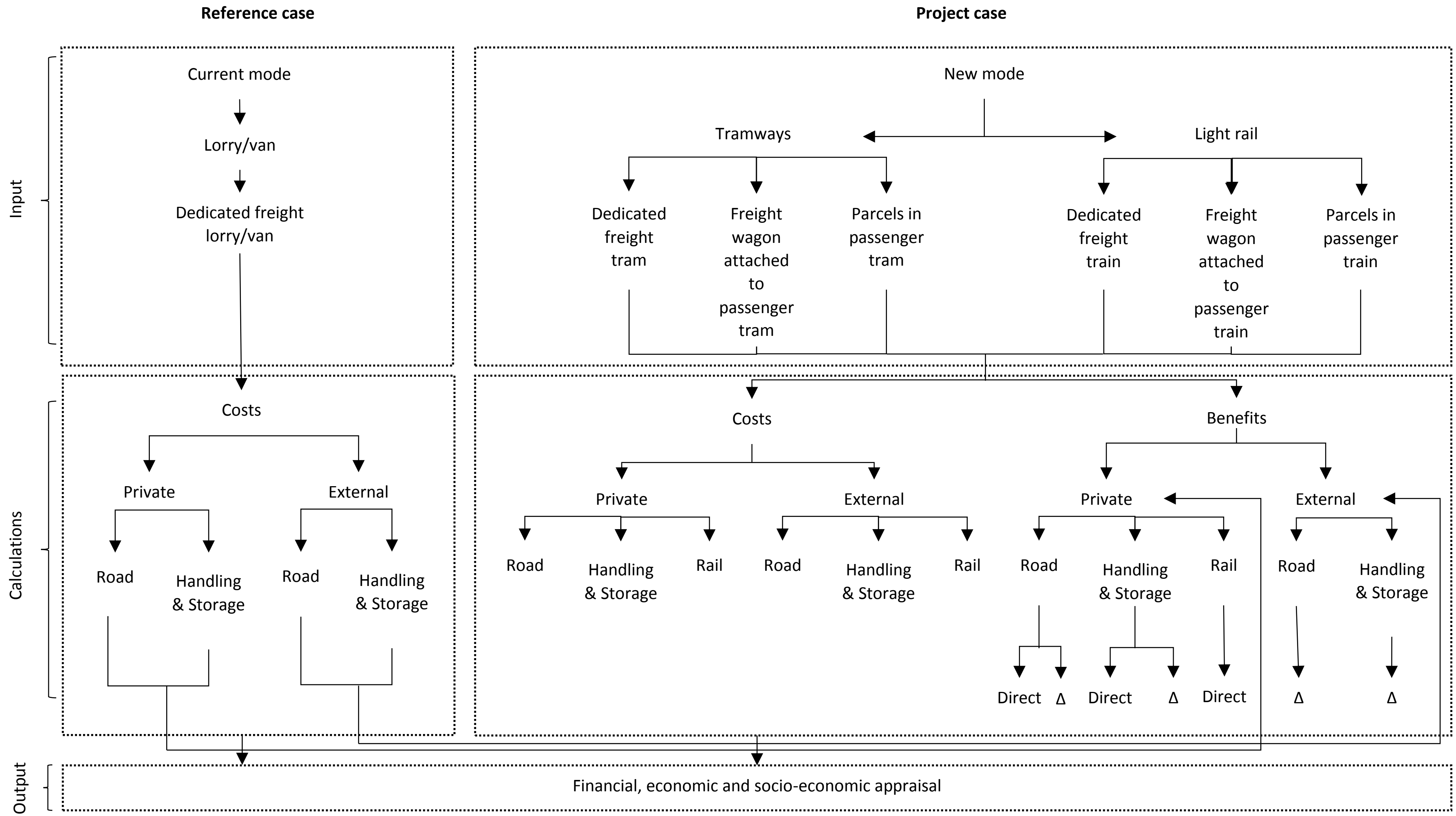
Based on the appraisal measures and the sensitivity analyses and scenarios, recommendations are formulated for different stakeholders. The eight steps that have to be carried out when conducting an SCBA are now made clear. Hence, the SCBA framework used in this research is summarised in the following section.

3.2.3 SCBA framework

Based on the eight steps discussed in Section 3.2.2, an SCBA framework is developed for this research. Figure 29 shows the reference case and the project case, as well as the way they are connected to each other for the calculations of the costs and the benefits. Private and external costs and benefits are calculated for the road-, rail- and handling & storage legs of the urban freight supply chain. In the reference case, the current transport is carried out by means of a dedicated lorry or van. In the project case, the urban freight distribution is done by means of either tramways or light rail. For both rail types, either a dedicated freight vehicle is used, a freight wagon is attached to a passenger vehicle, or parcels are transported alongside passengers.

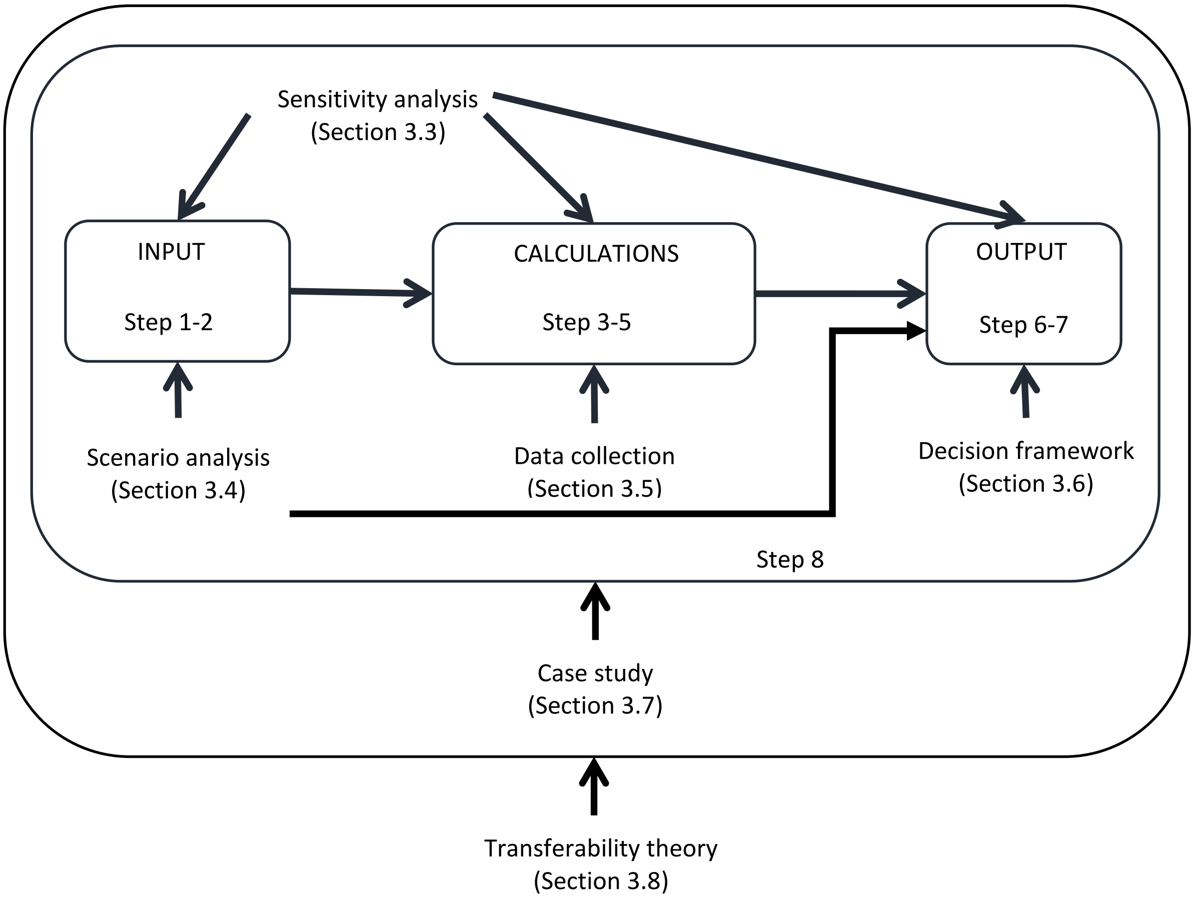
In the calculations part, all financial, economic and socio-economic costs and benefits of the reference and project case are determined. The financial and economic costs of the reference case are used to calculate the benefits of the project case for the project leader. This is shown in Figure 29 by Δ. This part of the project leader benefits of the project case equal the saved costs of the reference case. The external costs of the reference case serve as an input for the external benefits of the project case (Δ). Thus, this part of the external benefits consists of the saved external costs related to the fact that the reference case does not take place anymore. With respect to the project case, the socio-economic costs and benefits are calculated for the road-leg, handling and storage and rail-leg. The direct socio-economic benefits of the project case are also added to the calculations. Based on all costs and benefits calculated with respect to the reference and project case, the rail-based initiative is appraised from the viewpoint of the project leader and a socio-economic perspective.

Figure 29 – SCBA framework



In sum, Figure 30 displays the social cost-benefit model framework for this research. The model consists of three main elements: the input, the calculations and the output, as was made clear in Figure 29. The eight steps in the SCBA that were discussed in this section are related to these three elements in Figure 30. With respect to the input of the model, the reference and project case are defined (step 1) and it is decided whose benefits and costs count (step 2). Concerning the calculations, the impacts are identified (step 3), the costs and benefits are quantified and monetised (step 4) and costs and benefits are discounted (step 5). With regard to the output, each project case is evaluated (step 6) and uncertainty and risk is dealt with in step 7. In step 8, recommendations are formulated based on the entire model.

Figure 30 – SCBA steps and research approach



Source: Own creation

A combination of sensitivity analyses, scenario analyses, data collection, decision framework, case study and transferability theory is used. These extra methods are the subject of the next sections. Section 3.3 offers the background information needed to conduct sensitivity analyses. Section 3.4 discusses the scenario analysis needed for the input stage more in depth. Section 3.5 provides more information on the data collection needed for the calculations and Section 3.6 shows the used decision framework. Ultimately, Section 3.7 introduces the case study and Section 3.8 explains the use of the transferability theory.

3.3 Sensitivity analysis

After discussing the social cost-benefit framework, this section provides the background information needed to determine for which of the variables characterising the reference and project case, the effect on the project outcome is crucial. De Rus (2010) and Button (2014) argue that it should be examined for which variables a change of their value significantly affects the result of the project. In case a certain variable is not critical in the analysis of a specific project, there is no need to spend a large amount of resources to obtain the exact values of it. In case a certain variable has a large influence on the outcome of the project, it is crucial to obtain a value for it that is as close to reality as possible (Button, 2014). This means that variables with a high impact on the result, but unlikely to change, as well as variables with a low impact on the result and a high chance to change, are excluded from the uncertainty and risk analysis (de Rus, 2010). In Section 3.3.1, sensitivity analyses performed in the urban rail freight literature are discussed. In Sections 3.3.2 and 3.3.3 respectively, a distinction is made between cost- and benefit-related variables. Section 3.3.4 provides an intermediate conclusion.

3.3.1 Sensitivity analyses in the urban rail freight literature

As the starting point of this analysis, it is most interesting to investigate which variables are evaluated in sensitivity analyses in existing studies on urban rail freight. Table 20 provides an overview of two studies in which sensitivity analyses are carried out. In other existing studies on the potential of rail for urban freight distribution, no sensitivity analyses are done. Delaître & De Barbeyrac (2012) conduct a sensitivity analysis with respect to the cost of rail transport. Regué & Bristow (2013) investigate the effect of more variables in their sensitivity analyses, being the capital investment, handling cost, inventory space benefit, sharing resources and timing of the transport.

Table 20 – Variables subjected to sensitivity analyses in the urban rail freight literature

Rail type	Author(s) year	Variables					
		Capital investment	Handling cost	Inventory space benefit	Rail cost	Sharing resources	Timing transport
Light rail	Delaître & De Barbeyrac (2012)				X		
Tramways	Regué & Bristow (2013)	X	X	X		X	X

Source: Own creation

Vadali et al. (2017) do not analyse the potential of rail for urban freight distribution, but provide in their guidelines for cost-benefit analysis an overview of different sources of uncertainty and risk that have to be taken into account. Table 21 shows different sources of uncertainty and risk applicable to this research. These sources are ranked dependent on whether they are cost- or benefit-related, or applicable to the analysis in general.

Table 21 – Uncertainty and risk sources applicable to this research

Costs	Benefits	General
Capital investment cost	Accident rates	Discount rates
Construction delays	Assumed travel times	Optimism bias
Financial difficulties	Energy use models	Spatial resolution of analysis
Labour costs	Externality costs	Temporal scales of analysis
Legal action	Freight traffic growth rate	
Legislative action	Freight values of time	
Maintenance costs	Land use changes	
(Other) construction costs	Rail company operating costs model	
(Other) operating costs	Supply chain structure changes	
Property acquisition costs	Values of time	
Results of contract negotiations		

Source: Own creation based on Vadali et al. (2017, p. 110)

Other literature suggests that sensitivity analyses have to be carried out with respect to the discount rate (Boardman et al., 2018; Comi et al., 2014; Maes & Vanelslander, 2011; Mortimer, 2008; Sartori et al., 2015; Stiglitz, 1994; Verbruggen, 2008). Stiglitz (1994) states that the uncertainty concerning the discount rate is very high, which also confirms the need for some sensitivity analyses. Ortega et al. (2014) also highlight the importance of executing sensitivity analyses, more specifically with the objective of identifying the variables that affect the cost-benefit ratio the most. Sensitivity tests are by these authors i.a. conducted for the social discount rate. From the general variables displayed in Table 21, it is especially the discount rate that is subject to sensitivity analysis. The cost- and benefit-related variables are discussed more in depth in the next sections.

3.3.2 Cost-related variables

Table 21 presents the cost variables that are subject to sensitivity analyses, which are the following: the cost of capital investment, the presence of pre- and post-haulage, the choice for night versus day transport and the operations and maintenance costs (Arvidsson & Browne, 2013; Behrends, 2012b; Boardman et al., 2018; Comi et al., 2014; de Rus, 2010; Mortimer, 2008; Regué & Bristow, 2013; M. Robinson & Mortimer, 2004a; Sartori et al., 2015; Vadali et al., 2017).

Firstly, the cost of the capital investment has to be subjected to sensitivity analyses, including for instance the number of rail vehicles needed (Boardman et al., 2018; de Rus, 2010; Vadali et al., 2017). Rail transport often involves higher investment costs in infrastructure and rolling stock compared to road transport (Arvidsson & Browne, 2013; Bergqvist, 2007; Comi et al., 2014; Dorner, 2001; Marinov et al., 2013; M. Robinson & Mortimer, 2004a; Ruesch, 2001; Strale, 2014). Therefore, it is recommended to make as much as possible use of the existing infrastructure (Cochrane et al., 2017; Marinov et al., 2013; Regué & Bristow, 2013). The high investment costs are one of the reasons why the City Cargo project in Amsterdam (Arvidsson & Browne, 2013) and the GüterBim initiative in Vienna failed (Regué & Bristow, 2013).

Flyvbjerg et al. (2003) refer to a Danish research in which 258 infrastructure projects in 20 countries spread over five continents are studied, comprising bridges, conventional inter-urban rail, freeways, high-speed rail, tunnels and urban rail. All projects were executed between 1927 and 1998. For the rail projects, the study found that the actual costs were on average 45% higher than the estimated costs. The reasons for these cost underestimations are according to van Wee (2007) related to methodological issues and strategic behaviour. In order to deal with strategic behaviour, the author suggests to apply 'reference class forecasting'. This method means that a project under consideration is compared to other comparable projects from the past. It is recommended to construct a database with characteristics of these comparable projects. Moschouli et al. (2019) examine the conditions affecting the performance of European transport infrastructure projects with respect to cost overruns. These authors show that after the global financial crisis of 2008, external factors affect potential cost overruns more than before the crisis.

Secondly, the presence of pre- and post-haulage has to be checked. Adding pre- and/or post-haulage to the rail leg, causes additional out-of-pocket costs, as well as an extra inventory carrying cost, i.e. time cost. It is important to consider the whole supply chain when studying the potential of a rail vehicle (Bergqvist, 2007; Dorner, 2001; Foyer, 2001; Jonction & VerkehrsConsult Dresden-Berlin, 2013; Marinov et al., 2013; Strale, 2014). Following the infrastructure need, rail transport only offers a solution for part of the supply chain, unless both the supplier and the customer possess a rail connection. Thus, often other transport modes such as lorries, electric vehicles or cargo bikes are still needed for the pick-up and delivery of the goods to and from the rail terminal (Comi et al., 2014). Cochrane et al. (2017) suggest to combine a rail freight vehicle with walking or biking couriers, since these can access handling and storage points easily, do not suffer from road congestion, and do not disrupt pedestrian or road traffic.

Thirdly, the choice for night versus day transport can be important. One main failure factor with respect to the target city environment is the interference with passenger transport (Arvidsson & Browne, 2013; Comi et al., 2014; Marinov et al., 2013; M. Robinson & Mortimer, 2004a; Strale, 2014). Some specific points in the urban area have to be chosen where the freight can be loaded and unloaded without disturbing the passenger transport (Comi et al., 2014). A possible way to partly avoid the interaction with passenger transport is by operating the freight activities during the night. However, this causes noise-related issues and may interfere with maintenance activities on the rail lines (Comi et al., 2014; Gorçun, 2014).

Ultimately, the operations and maintenance costs are often altered in sensitivity analyses, including for instance labour costs. It can be beneficial to develop a standard city container that is modular, space- and unload-friendly, secure and that fits for food, clothing, catering and consumer durables (Centre-Ville en Mouvement, 2013; Comi et al., 2014; Foyer, 2001; Muñuzuri, Larrañeta, Onieva, & Cortés, 2005). Ortega et al. (2014) assess the effect of the fuel price and alter this between -30% and +60% of the current price. Hence, the variables construction delays, financial difficulties, legal action, legislative action, property acquisition and results of contract negotiations shown in Table 21 are less considered in existing research on the potential of rail for urban freight distribution.

After having identified the cost-related variables, it is checked which benefits should be taken into account when doing sensitivity analyses.

3.3.3 Benefit-related variables

With respect to the benefits of the project, several variables of Table 21 often tested in sensitivity analyses are the following: the commodities value, the presence of congestion and road measures, the environmental performance of the rail vehicle, ancillary revenue, the assumed travel time and the amount of goods (Arvidsson & Browne, 2013; Cochrane et al., 2017; Comi et al., 2014; Maes & Vanelslander, 2011; Mortimer, 2008; Regué & Bristow, 2013; M. Robinson & Mortimer, 2004a; Sartori et al., 2015; Vadali et al., 2017).

Firstly, the commodities value can affect the project benefits as well as the value of time. Non-time-sensitive, low value commodities are suitable for transport by rail (Dorner, 2001; Maes & Vanelslander, 2011; Marinov et al., 2013; M. Robinson & Mortimer, 2004a). The CargoTram in Zurich for example transports a non-time sensitive, low value commodity, being waste.

Secondly, the presence of congestion and urban freight distribution measures taken by the authorities can affect the SCBA results. Hence, government policy can affect the success or failure of an urban rail freight project. The implementation of a transport solution that does not imply the use of road transport is more favourable in case some road issues are present in the urban area. Increasing congestion is a first example of a condition in which a rail-based solution could bring some benefits (Arvidsson & Browne, 2013; Cochrane et al., 2017; Ruesch, 2001; Strale, 2014). On-time delivery is one of the factors affecting the choice for a certain freight mode (Woodburn, 2017). Moreover, rail-based urban freight initiatives are often more successful when other measures are taken concerning road transport (Comi et al., 2014; Zych, 2014). This makes the use of rail more attractive, since shippers often have to find other transport solutions (Comi et al., 2014).

Thirdly, changes in the environmental performance of the rail and road transport can lead to different results. The better environmental performance of rail transport compared to road transport is a critical factor leading to success of the rail-based transport (Alessandrini et al., 2012; Arvidsson & Browne, 2013; Gorçun, 2014; Marinov et al., 2013; Mortimer, 2008; Regué & Bristow, 2013; M. Robinson & Mortimer, 2004a; Strale, 2014; Zych, 2014).

Fourthly, the effect of the change of ancillary revenue has to be examined, as well as the result of increasing the stockholding surface benefits. Rail initiatives can benefit from additional ancillary revenue. This is for example the case in Dresden, where part of the success of the freight tram of Volkswagen is related to advertisement income. It is beneficial to turn the additional stop in the supply chain, where goods often have to be loaded from a road vehicle to a rail vehicle and vice versa, into an opportunity to offer value added services to the goods. An example of a value added service is to provide inventory space for the shipper to store goods at this handling point (Behrends, 2012b; BESTUFS, 2001).

Fifthly, changes of the assumed travel times also have to be investigated (Arvidsson & Browne, 2013; Comi et al., 2014; Maes & Vanelslander, 2011; Mortimer, 2008; Regué & Bristow, 2013; M. Robinson & Mortimer, 2004a; Sartori et al., 2015; Vadali et al., 2017). Due to increasing congestion in many urban areas, time gains could be obtained by using rail. This can amongst others lead to lower driver costs (Arvidsson & Browne, 2013).

Ultimately, the amount of goods to be transported is often investigated (Boardman et al., 2018; Comi et al., 2014; Maes & Vanelslander, 2011; Mortimer, 2008; Sartori et al., 2015; Stiglitz, 1994; Verbruggen, 2008). Thus, energy use models and land use changes that are displayed in Table 21 are not often taken into account in studies on the use of rail for urban freight distribution.

3.3.4 Intermediate conclusion

Sensitivity analyses are carried out in order to know the critical variables characterising a case. The discount rate is a general variable to be included in sensitivity analyses. Cost-related variables that are checked upon their effect on the SCBA outcome include the capital investment, pre- and post-haulage, the timing of the transport and operational and maintenance costs. Benefit-related variables are the commodities value, congestion and policy measures, the environmental performance of rail and road transport, ancillary revenue, travel time changes and the amount of goods transported.

In order to know the key variables affecting the outcome of the project, the variation in the output is measured when the value of the selected input variables alters. The most important variables are then used as input for the scenario analysis, which is the subject of the next section.

3.4 Scenario analysis

This section discusses the scenario analysis more in depth. In section 3.4.1, scenario analysis in the existing urban rail freight literature is examined. Section 3.4.2 presents the scenario framework used in this research and Section 3.4.3 offers an intermediate conclusion, based on which scenarios are developed in Chapter 6 for the case study used in this research.

3.4.1 Scenarios in the urban rail freight literature

Tsokalis & Naudé (2008) use three scenarios in their policy scenario analysis in order to assess the increase in light freight traffic: the business-as-usual (BAU) scenario, a policy response of new infrastructure plans and a policy response of appropriate pricing signals. Troch et al. (2015, p. 9) develop three scenarios for assessing the future development of intermodal transport in Belgium. These authors state that "*a scenario needs to be plausible, consistent and offer insights into the future, without attempting to forecast its nature*". Several authors provide case-specific insights about rail-based urban freight distribution initiatives. Table 22 gives an overview of studies investigating this topic and shows the scenarios examined in these studies.

Table 22 – Scenarios examined in the urban rail freight literature

Rail type	Author(s) year	Scenarios		
Light rail	Sivakumaran et al. (2010)	Minor versus significant capital investment		
	Alessandrini et al. (2012)	Conventional versus green vehicles		
	Delaître & De Barbeyrac (2012)	Increase the transported amount to saturation level	Shorter train (16 wagons instead of 22)	Bundling of flows
	Gorçun (2014)	Different train routes		
Tramways	Regué & Bristow (2013)	Delivery for shopping centres	Residential waste collection	
	Gorçun (2014)	Different tram routes		

Source: Own creation

With respect to light rail initiatives, four studies apply scenarios. Sivakumaran et al. (2010) make a distinction between minor and significant capital investment. Alessandrini et al. (2012) distinguish among three scenarios: the road-only reference scenario in which diesel lorries are used, a multimodal urban distribution centre combined with conventional diesel lorries and a multimodal urban distribution centre combined with hybrid vehicles. Delaître & De Barbeyrac (2012) apply three different scenarios. These authors proceed with their calculations by increasing the transported amount of goods to the saturation level. Next, the use of shorter trains is investigated, as well as the bundling of flows. Gorçun (2014) defines different scenarios based on the train route that is followed.

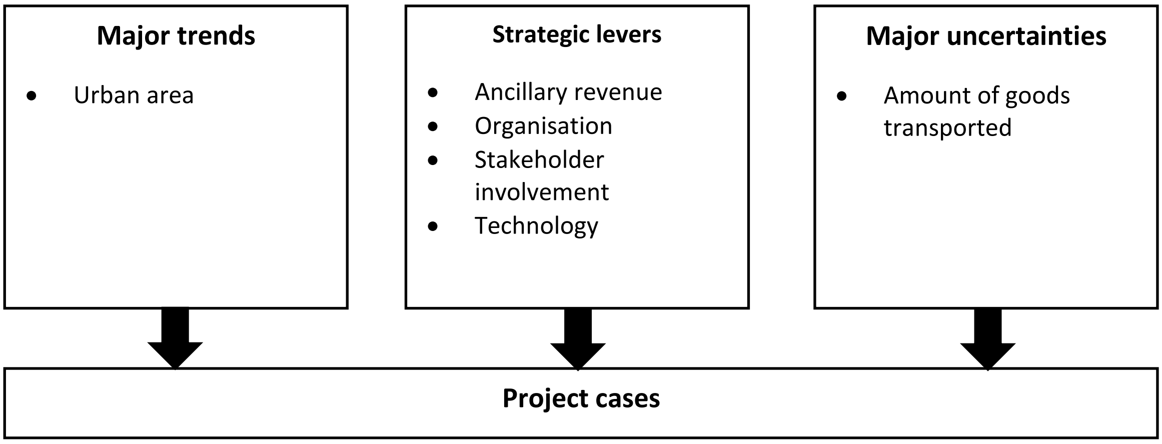
Concerning tramways, Regué & Bristow (2013) elaborate on two freight tram scenarios for Barcelona, being the deliveries to shopping centres in the city centre of Barcelona and the residential waste collection along a tram line. As for the light rail, Gorçun (2014) formulates different tram-based scenarios based on the followed route. The scenarios provided in Table 22 are combined with the variables framework of Crozet (2003) that was presented in Section 3.2. In the following section, the scenario framework for this research is developed.

3.4.2 Scenarios framework

When applying the theory of Crozet (2003) based on Arcade (2003) to the urban rail freight context, Figure 31 displays the three types of variables used in this research. The distinction between major trends, strategic levers and major uncertainties is in Figure 31 applied for the use of rail for urban freight distribution. In the empirical part of this thesis, only the variables in Figure 31 that appear from the sensitivity analysis to be critical, are used for the development of scenarios. In order to be complete, Figure 31 provides here still all the variables, whether they are critical or not.

The major trends are the starting point of the analysis, including the characteristics of the urban area. This variable is known by the project leader, i.e. there is low uncertainty about it, and it is out of his span of control. The strategic levers comprise the ancillary revenue, the organisation of the supply chain, the stakeholder involvement and the technology used. These variables are modifiable by the project leader and thus, are part of his strategy. Ultimately, the major uncertainties include the variables that are not modifiable by the project leader and they are very uncertain. The project leader does not know the amount of goods, i.e. the flows of goods. Based on these three types of variables, different scenarios of project cases are identified and compared to the reference case, being urban freight distribution by road. Vadali et al. (2017) suggest to calculate between 4 and 15 named scenarios.

Figure 31 – Classification of input variables when dealing with uncertainty and risk



Source: Own creation based on Arcade (2003) & Crozet (2003)

In the next sections, the three types of variables presented in Figure 31 are discussed more in depth. Firstly, the major trends are analysed. Secondly, the strategic levers are examined and thirdly, the major uncertainties are discussed. The combination of these variables leads to the development of scenarios, which consist of the most critical variables characterising urban rail freight initiatives. Hence, the scenarios provide a framework that can be transferred to any urban rail freight project.

3.4.2.1 Major trends

The major trends are developed based on the weakly controllable, low uncertainty variables. These variables can hardly be modified by the project leader. This means that the project leader has to consider these variables as given. Table 23 shows the (sub-)variables that belong to this category for the three types of rail traffic for urban freight distribution. These (sub)-variables are identified based on existing and past rail-based initiatives. The main variable is the urban area, as is made clear in Chapter 2. The sub-variables defined in Chapter 2 are the environmental state, freight flows, geography, population density, regulatory framework and transport infrastructure. The next paragraphs discuss all sub-variables in detail.

The first sub-variable is the environmental aspects present in the urban area. An urban area is characterised by for instance a certain air quality performance and congestion level. Emissions that are often measured are NOx, PM10, CO, CO_2. The environmental state of the urban area is also given to the project leader. The air quality in the urban area influences the success chances of a rail-based urban freight solution, as stated in Chapter 2. If the urban area does not suffer from congestion, no benefits of the rail solution can be gained concerning this variable. If on the other hand time losses are experienced by logistics and transport operators due to congestion, time savings can be obtained by using rail instead of road transport for all three types of rail transport shown in Table 23.

Secondly, freight flows are given to the project leader. As pointed out in Chapter 2, different freight types are transported in an urban area and can potentially be shifted from road to rail. The project leader can consider the freight flows, owners of the goods and decision makers in the transport chains as given. This is the case for the three types of rail displayed in Table 23.

Thirdly, properties of the geography of the urban area are for example the width of the streets and the presence of canals and hills. The characteristics of a certain urban area are in the short run fixed for any potential project leader.

Table 23 – Major trends variables with respect to different rail types

Variable	Sub-variable	Rail type		
		Dedicated freight vehicle	Freight wagon attached to passenger vehicle	Parcels in passenger vehicle
Urban area	Environmental state	Air quality, congestion		
	Freight flows	Freight types, owner of the goods, responsible actor, decision makers		
	Geography	Width of streets, hills, presence of canals		
	Population density	Potential demand, exposure to externalities		
	Regulatory framework	Liability, restrictions, measures		
	Transport infrastructure	Availability of rail lines, free rail paths	Availability of rail lines, free space behind rail vehicles	Availability of rail lines, free space in rail vehicles

Source: Own creation based on existing cases, interviews with experts in the field and insights from Comi et al. (2014)

Fourthly, the population density of the urban area is important. Depending on this density, a certain amount of people is affected by for instance air pollution and noise. This determines the external costs of rail versus road transport in the urban area.

Fifthly, the regulatory framework in the urban area plays a role. Regulations consist of the legal aspects in the urban freight supply chain, and measures taken by authorities. Legal aspects include liability issues, legal restrictions and safety limitations. Liability issues comprise amongst others the organisation of alternative transport solutions in case the railway is blocked and rail traffic is suspended for a certain period of time. The actor liable to get the goods at their destination has to be specified. Another liability issue is the owner of the goods at the different stages in the transport process. Legal restrictions include amongst others required certification for the rolling stock and the authorisation to use the existing rail network. The project leader can collect this information beforehand and has to apply the prevalent legal rules.

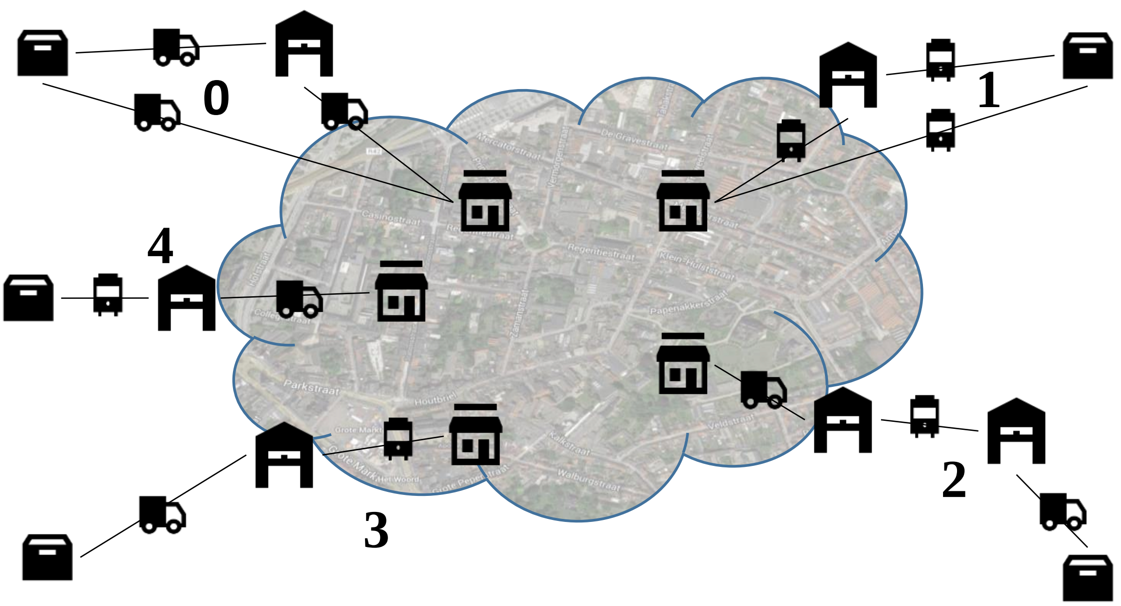
Given a certain rail network, the project leader has to ask for permission to the rail infrastructure owner to use the public railways. In case this is allowed, a next aspect is the part of the network on which a dedicated freight vehicle is allowed to run. This is not always allowed on the whole rail network. Some lines may be dedicated for passenger traffic. When parcels are transported alongside passengers, the full available public rail network can be used. Safety limitations are another important aspect of the legal context, since rail-specific safety rules apply. Depending on the type of goods, different safety rules have to be taken into account. Safety instructions also apply to the railways. For example, on certain railways no freight vehicles are allowed due to safety reasons.

Measures taken by authorities comprise initiatives such as the introduction of low emission zones, pedestrian zones and time windows, congestion charging and road pricing. These regulations cannot easily be modified by a project leader in the short run and are a crucial part of the reference context in which a rail-based initiative is applied. Therefore, these initiatives can be altered in the social-cost benefit model in order to measure the potential effect of them on using rail for urban freight distribution. With respect to a low emission zone, logistics and transport operators may not be allowed to enter the urban area in which their customers are located. If at least one of the customers to be served is located in a low emission zone, the operator might have to pay a fee to enter the low emission zone. This fee is either expressed in euro per entry of the vehicle, euro per day or euro per year.

Concerning a pedestrian zone, logistics and transport operators may not be able to drive to their customers, or they may be constrained to some time windows. In case no customer is located in a pedestrian zone, no related difficulties are present for the use of road transport. If at least one of the customers is located in a pedestrian zone, additional handling may take place to enter the pedestrian zone by for instance a trolley to reach the customer. In case time windows are present, the logistics and transport operators may experience additional costs in the supply chain compared to delivering without time windows. With regard to congestion charging, logistics and transport operators may have to pay a toll to enter the urban area in order to reach their customer. If toll has to be paid, the congestion charging fee to enter the urban area is added to the costs of the logistics or transport operator. This fee is expressed in euro per entry or exit of the vehicle, or in euro per year. Ultimately, concerning road pricing, the number of kilometres for which road pricing has to be paid, is an additional cost for road transport.

Sixthly, the transport infrastructure in the urban area is important in the sense of the availability of rail lines and free capacity on them for the transport of goods. The available rail transport infrastructure in an urban area is fixed in the short run and hence, the choice for rail transport depends on the presence of rail infrastructure. Figure 32 displays the five possible rail configurations. The reference case, configuration 0, corresponds to the current road transport from the supplier to the customer, possibly through a handling and storage point. Configurations 1-4 are the possible rail-based cases, which are compared in this research to the reference case.

Figure 32 – Possible rail configurations

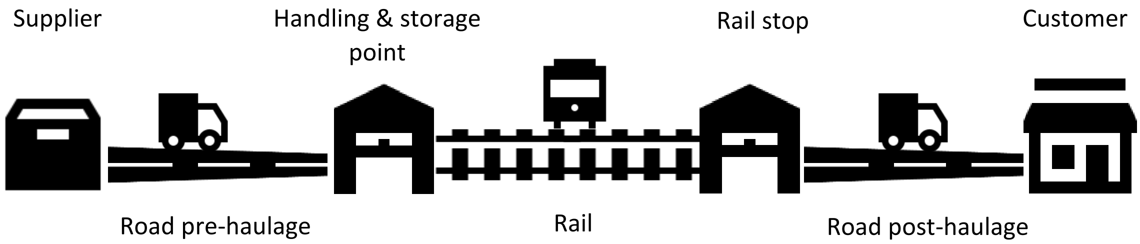


Source: Own creation

Configuration 1 corresponds to the use of only rail transport to bring the goods from the supplier to the customer. This means that no additional handling and storage of the goods happens before or after the rail transport leg. The goods are transported from the rail vehicle to the customer by means of a trolley, forklift or roll cage. Depending on the available rail configuration, additional branching and switches are needed. In configurations 2-4, a combination of road and rail transport is made. Road transport is defined here as the transport of goods over the road network by any type of vehicle, reaching from a traditional lorry to a cargo bike. When the supplier and/or customer do not possess a rail connection, additional road transport is used for a part of the supply chain. In configuration 2, a combination of road, rail and road transport is used. In configuration 3, the goods are transported by road from the supplier to a handling and storage point at the edge of the urban area and by rail between this point and the customer. Ultimately, in configuration 4, rail transport is used between the supplier and the handling and storage point, while the leg between this point and the customer is executed by road transport. These combinations are considered to be given to the project leader, since the presence of the rail infrastructure is fixed in the short run. In the long run, the rail infrastructure is changeable. In some cases, branching to the rail network is needed at the supplier and/or customer. This need affects the costs in further steps of the model and causes the need to define in a later stage which stakeholder finances which part of the branching.

The available rail configuration determines to a large extent which inputs, and thus, costs and benefits, are included in the SCBA supply chain. Figure 33 provides a summary of all possible rail configurations, in which road pre- and post-haulage are potentially needed to connect the supplier and the customer by rail transport. With respect to a dedicated freight vehicle, a rail stop is defined as a location where the freight vehicle is allowed to stop for the time needed to fulfil the (un)loading process. Concerning the use of a freight wagon attached to a passenger vehicle, or the transport of parcels alongside passengers, a rail stop is a stop of the passenger vehicle where the parcels or freight wagon can also be (un)loaded. For each leg of the supply chain, the costs and benefits need to be calculated.

Figure 33 – Urban rail freight supply chain



Source: Own creation

The loading and unloading possibilities are related to the handling and storage point and the rail stop. This aspect is important when a dedicated freight vehicle or a freight wagon attached to a passenger vehicle is used. Free loading and unloading space is either space in the open air that can be used for loading and/or unloading the rail vehicle and for storing the goods for a while, or a building in which the goods can be temporarily stored. When parcels are transported alongside passengers, no loading and unloading issues are present.

Next to the rail configuration, free capacity on the rail network is crucial. Capacity is expressed in a different way for the three rail traffic types. In case of a dedicated freight vehicle, capacity is measured in terms of a free path on the rail network for the freight vehicle. Some railways may already be fully saturated by the passenger traffic. As a result, freight transport might not be allowed on these lines, since rail freight transport in Europe is disadvantaged in terms of priority on the tracks (European Court of Auditors, 2016). In case of freight transport in a wagon attached to a passenger vehicle, the capacity is related to the available free space behind the passenger vehicle. No separate freight slot has to be obtained. When parcels are transported alongside passengers, no separate slot for the freight has to be acquired. The passenger vehicles have their slot and the parcels are transported alongside the passengers. The capacity here concerns the space within the rail vehicles. During peak hours, no free space might be available.

The previous paragraphs clarify the impact of the characteristics of the urban area on the costs and benefits related to urban road and rail freight transport. Six sub-variables exist that are weakly modifiable by the project leader in the short run, but about which low uncertainty exists: environmental state, freight flows, geography, population density, regulatory framework and transport infrastructure. These sub-variables can be used to develop scenarios, if the variables prove to be critical after conducting the sensitivity analyses.

3.4.2.2 Strategic levers

The strategic levers are the second category of variables and they are developed based on strongly modifiable variables. These variables can be used by the project leader to optimise the rail-based solution. This section gives an overview of all strategic levers that can be used if they prove to be critical after conducting the sensitivity analyses as explained in Section 3.3. Four strategic levers are distinguished among here based on the literature review in Chapter 2 and discussed more in depth in the next paragraphs (see Table 24): ancillary revenue, organisation, stakeholder involvement and technology. Different choices for all of these variables lead to different costs and benefits, but the focus of the next paragraphs is on the differences in operations rather than in costs. The cost difference is accounted for in the social cost-benefit model.

The first strategic lever concerns the ancillary revenue. This variable includes analogously with the air transport sector, earnings from sources that do not directly come from the transport of goods as such (Schaar & Sherry, 2010). A main example of ancillary revenue here is the revenue related to selling advertisement space. Previous rail-based initiatives have proven that ancillary revenue benefits can lead to a higher probability of success (Comi et al., 2014). Therefore, using the rail unit (dedicated freight vehicle), freight wagon (wagon attached to a passenger vehicle), or backpack (parcels alongside passengers) for marketing reasons is sometimes a strategic choice. Using rail transport is associated with thinking sustainably, and this may attract customers.

The second lever is related to the organisation of the supply chain. Five organisational aspects can be used as strategic levers, being the number of rail trips, the number of rail transport units, the operating hours, storage and waste and reverse logistics. With respect to the number of rail trips, the frequency has to be decided on. For a freight wagon and the transport of parcels alongside passengers, this is directly related to the passenger transport schedule. Different rail trips are defined as different Origin-Destination-Origin (ODO) combinations. The number of rail trips in a certain period of time depends for a dedicated freight vehicle on the frequency chosen by the project leader. The latter can choose for example to only have the dedicated freight vehicle run once per day, or to have a higher frequency. The choice for a certain rotation is part of the strategy of the project leader. For a freight wagon attached to a passenger vehicle, both the passenger transport schedule and the frequency chosen by the project leader determine the number of rotations. For the transport of parcels alongside passengers, the passenger transport schedule is decisive.

Related to the number of rail trips, the number of transport units is selected. The maximum number of rotations depends on the number of rail vehicle units available. The unit depends on the rail type. Concerning a dedicated freight vehicle, the unit is a complete freight vehicle. With respect to a wagon attached to a passenger vehicle, the unit is a freight wagon and with regard to the transport of parcels alongside passengers, the unit is a backpack.

The operating hours during which the freight is transported are another strategic aspect with respect to the organisation (Bous, 2001). A large difference exists between day and night time, or peak versus off-peak time. A dedicated freight vehicle has to fit in the schedule of passenger vehicles that are using the same rail line. This is not always possible, since many lines are used at full capacity by the passenger transport. In case the freight vehicle is allowed to use the rail network, it still has to run on the times that it will not disturb the passenger traffic (see Chapter 2). This is in most cases during the off-peak hours during daytime, or during the night.

Table 24 – Strategic levers variables with respect to different rail types

Variable	Sub-variable	Rail type		
		Dedicated freight vehicle	Freight wagon attached to passenger vehicle	Parcels in passenger vehicle
Ancillary revenue	Advertisement	On rail vehicle	On freight wagon	On backpack
Organisation	Number of rail trips	Frequency choice	Frequency choice, passenger schedule	Passenger schedule
	Number of transport units	Freight vehicle	Freight wagon	Backpack
	Operating hours (night/day)	Day (off-peak), night	Day	Day (mainly off-peak)
	Storage	Storage infrastructure		
	Waste & reverse logistics	Separate waste/ reverse logistics vehicle or combined with other goods	Waste/ reverse logistics wagon	Waste and reverse logistics unlikely
Stakeholder involvement	Actors	Authorities, customers, logistics service providers, rail operators, suppliers, rail infrastructure managers		Authorities, customers, logistics service providers, rail operators, suppliers
Technology	Handling	At certain freight stops, by a courier, space requirements	At passenger stops, by a courier, space requirements	At passenger stops, by a courier
	IT-system	ETA, track & trace of goods		
	Standard unit	Freight boxes		Backpack
	Vehicle (capacity, dimensions, type)	Freight vehicle, maximum vehicle load, height, length and width	Wagon length	Passenger door dimensions, low/high floor tram

Source: Own creation based on existing cases, interviews with experts in the field and insights from Comi et al. (2014)

In case a freight vehicle operates during the night, less competition for the slots from the passenger traffic exists. However, competition for the use of the lines from maintenance is still present. Many rail lines are maintained during the night, leading to the temporary closing of the line. Maintenance is not executed every night at all the lines and thus, the night slot still leaves some possibilities for the freight vehicles (Fierens & Nuytemans, 2014). The main disadvantage of operating during the night is that the goods have to be received by someone at the destination. This is not always possible, or wanted by the suppliers or customers. Moreover, the urban rail dispatching centre has to be opened during the night, causing additional operating costs (Fierens, Nuytemans, & van Hemelen, 2019). With respect to a freight wagon attached to a passenger vehicle and the transport of parcels alongside passengers, the operating hours of the passenger vehicles are the first condition that has to be met. As a result, no night time freight transport can be carried out if there is no night time passenger transport. Another constraint with respect to transporting parcels in a passenger vehicle is the high utilisation rate of passenger vehicles during peak hours.

With respect to storage, it has to be decided whether goods unloaded from the rail vehicle are stored for a while at the rail stop. If this is the case, storage infrastructure has to be foreseen and this may lead to additional costs. An existing warehouse can be used, or a new one can be built for this purpose. Another possibility is the use of receiver boxes at the rail stop, or at the customer's venue.

The choice to incorporate the transport of waste and reverse logistics in the rail-based solution is the last organisational sub-variable. With respect to a dedicated freight vehicle, this choice implies the opportunity to avoid empty flows and to transport goods in both directions. A separate waste or reverse logistics vehicle can be developed, or waste or reverse logistics parts can be loaded on the rail vehicle after the goods for the customer have been unloaded. Concerning a freight wagon attached to a passenger vehicle, a special waste or reverse logistics wagon can be developed to attach to a passenger vehicle. For the transport of parcels alongside passengers, the transport of waste or reverse logistics parts is more difficult. For example, the smell of some waste types is not compatible with passenger transport.

The third strategic lever is the involvement of different stakeholders, amongst others in terms of financing the project. A distinction has to be made here between using a dedicated freight vehicle, attaching a freight wagon to a passenger vehicle and transporting parcels in a passenger vehicle.

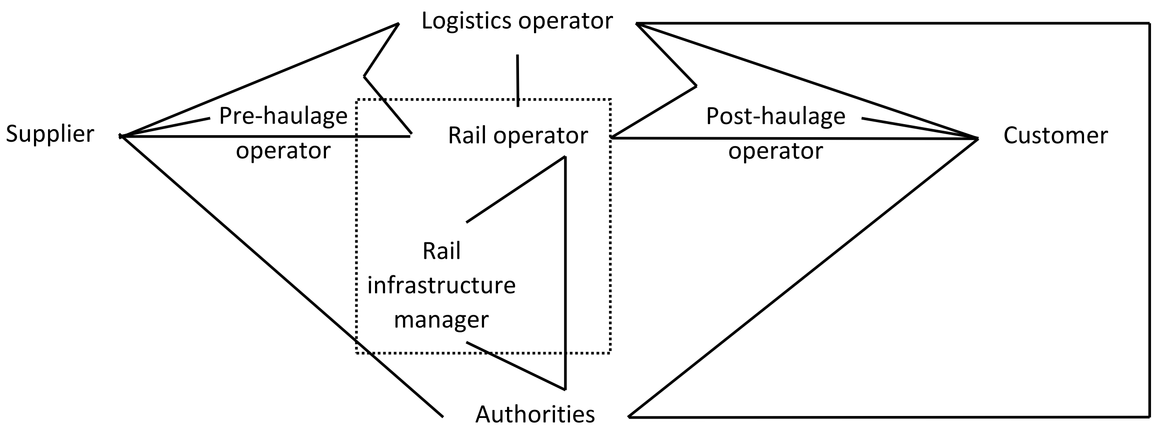
When using rail for urban freight distribution, Figure 34 shows the relationships between the different stakeholders. The supplier can be in touch with a logistics operator, a pre-haulage operator or directly with a rail operator. The customer on the other side of the supply chain has contact with a logistics operator, a post-haulage operator, or a rail operator. The need for a pre- or post-haulage operator depends on the rail configuration. Moreover, the supplier and customer can both be in touch with the authorities, for example with respect to policy measures and subsidies. If a logistics operator is involved, this actor contacts a pre- and/or post-haulage operator if the rail configuration requires this, and a rail operator. The rail operator purchases a rail path from the rail infrastructure manager and these two stakeholders too are in contact with the authorities. The dashed lines around the rail operator and the rail infrastructure manager show that in some urban rail transport areas, these two stakeholders are one and the same body.

The rail operator does not necessarily have to be an existing rail operator. With respect to light rail, it might be a new operator that hires an existing rail operator that is allowed to operate on the rail network. A new operator cannot run a freight train, since only certified railway operators can use the rail network (Monnaerts & Verheyen, 2013a). Concerning tramways, a new operator can be a neutral party, which operates the tram and buys tramway access charges from the tramway infrastructure manager. Before a new tramway operator can buy tramway access charges, a net declaration will have to be developed (Fierens & Nuytemans, 2014).

Depending on the stakeholders involved in the rail-based urban freight solution, other costs and benefits occur and hence, this variable can be considered to be a strategic lever. Moreover, multiple actors can be involved for each type of stakeholder shown in Figure 34. For instance, a couple of suppliers and multiple customers can use the rail-based solution, leading to bundling possibilities.

The fourth strategic lever that determines the strategy of the project leader concerns the technology. The used handling technology determines the time needed to load and unload the rail vehicle and also affects the external noise costs. The time needed may determine the possibility to stop the vehicle at certain stops along the rail network without disturbing the passenger traffic. In a study on using the underground for freight transport in Amsterdam for instance, the maximum approved halting time was 20 seconds (Bous, 2001). In Flanders, a passenger tram stops between 17 and 30 seconds to let passengers alight (Devriendt, 2017a). Hence, in order to unload a dedicated freight tram on the passenger network, or to unload a wagon attached to a passenger tram, the handling technology is of great importance. The external noise cost can be reduced if silent technology is used for the handling. Another consequence of the used technology is the number of personnel needed to carry out the (un)loading, or the possibility of having this done by a courier accompanying the goods during the transport. The handling technology is also influenced by the space available to do the loading and unloading at the rail stops.

Figure 34 – Relationships between stakeholders in an urban rail freight supply chain



Source: Own creation

The use of an information technology (IT) system is also an important issue. An IT system could be developed to which different stakeholders can log in to track their goods and thus, know the estimated time of arrival (ETA) of their goods at a certain stop. This may solve some issues about liability and reliability. An IT-system could offer customers of the rail-based solution for example the possibility to see when their goods will arrive at the rail stop and plan their logistics processes according to this information. This is beneficial for the three types of rail traffic shown in Table 24.

The choice of a certain standard unit to transport the goods is another technological sub-variable. In case a standard unit is used, different types of units exist. Standard units can be developed in such a way that they fit well in the rail vehicle and also on additional road vehicles potentially needed to deliver the goods at their final destination (Rien & Roggenkamp, 1995; van Binsbergen, Konings, & Klein Breteler, 1999). Standard containers of different size can be used as a standard unit.

The last technological sub-variable concerns the vehicle used. For a dedicated freight vehicle, the dimensions of the vehicle are crucial. The length of the vehicle has to be chosen and differs depending on the rail network on which the vehicle will operate, the vehicles that are available on the market and the strategy of the project leader. Other important dimensions to decide upon are the height and width of the vehicle and the door openings, and whether loading and unloading can occur through one or two sides of the vehicle. Factors determining the maximum vehicle load are the number and power of the traction units, the number of loading units, the capacity of one unit and the maximum speed of the vehicle. Subsequently, a decision has to be made whether freight from different owners is bundled in one vehicle, or whether separate vehicles are used for separate freight owners. Another decisive factor here is whether a new freight vehicle is purchased, or whether an old vehicle is adapted to transport urban freight. This old vehicle can be a freight wagon, but also a passenger vehicle modified to transport freight. With respect to a freight wagon attached to a passenger vehicle, the maximum length, width and load have to be determined. Concerning the transport of parcels alongside passengers, the rail vehicle capacity, dimensions and type are of less importance. The dimensions of the doors and the height of the floor (low versus high floor vehicles) affect the loading and unloading possibilities and the maximum parcel size.

In sum, four types of strategic levers are identified, being ancillary revenue, organisation, stakeholder involvement and technology. These strategic levers can be applied by the project leader to the different scenarios that are developed based on the major trends and major uncertainties. The next section discusses the major uncertainties related to urban rail freight distribution.

3.4.2.3 Major uncertainties

The third category of variables is the major uncertainties. These variables cannot easily be modified by the project leader and they are uncertain as well. Table 25 shows the main variable belonging to this category when researching the potential role of rail for urban freight distribution, being the amount of goods transported. In other words, the number of units to be transported is highly uncertain. Therefore, the analysis in this research is reversed in the sense that given the conditions in which the project takes place, the minimum amount of goods to be break-even is calculated. With respect to a dedicated freight vehicle or a freight wagon attached to a passenger vehicle, the unit is a freight box. When transporting parcels in a passenger vehicle, the parcel is the freight unit considered.

Table 25 – Major uncertainties variables with respect to different rail types

Variable	Sub-variable	Rail type		
		Dedicated freight vehicle	Freight wagon attached to passenger vehicle	Parcels in passenger vehicle
Amount of goods	Number of units	Freight boxes		Parcels

Source: Own creation based on existing cases, interviews with experts in the field and insights from Comi et al. (2014)

In brief, the amount of goods to be transported is highly uncertain to the project leader, as already highlighted in Section 3.3.3.

3.4.3 Intermediate conclusion

The scenario framework that is used to investigate the potential of rail for urban freight distribution is developed. Values that appear to be critical after conducting the sensitivity analysis are used as inputs for the scenario framework. In this framework, the critical variables are divided into major trends, strategic levers and major uncertainties. The major trends consist of the characteristics of the urban area. The strategic levers comprise the ancillary revenue, organisation, stakeholder involvement and technology. The major uncertainties include the amount of goods that is transported by urban rail. Depending on which of these variables are critical, scenarios are developed in the case study.

In order to start with the calculations of the SCBA framework that is developed in Section 3.2, data have to be collected. This is the subject of the following section.

3.5 Data collection

As shown in the beginning of this chapter, data collection methods used to assess the potential of rail for urban freight distribution include interviews, monitoring vehicles, origin-destination matrices, secondary data, surveys and traffic or vehicle counts (see Table 10 on page 64). Most authors use secondary data and combine these with data gathered from interviews, surveys and monitoring of vehicles or vehicle counts.

In this research, firstly the availability of urban freight distribution data is examined (Section 3.5.1). Secondly, an expert meeting was held (Section 3.5.2). After the expert meeting, it was decided to conduct several interviews (Section 3.5.3) and to rely on secondary data where possible (Section 3.5.4). In Section 3.5.5 some intermediate conclusions are drawn.

3.5.1 Lack of urban freight distribution data

In order to know which secondary data can be used for this research, a literature study with respect to the availability on urban freight distribution data is carried out. The observations of this review are fourfold.

Firstly, Dablanc (2009) points out that freight transport in general is neglected in many surveys and models. More specifically, Ambrosini, Patier & Routhier (2010) observe that variables such as type of goods, package, delivery frequency, and type of vehicle, which are needed to reflect reality, are not available in common statistics.

Secondly, Newton (2001) indicates that there is a lack of data at the urban level. Moreover, Ambrosini & Routhier (2004) and Crainic, Ricciardi & Storchi (2004) highlight the lack of sufficient representative surveys on urban freight distribution. As a result, these authors state that it is difficult to estimate the importance of urban freight distribution. Allen & Browne (2008) note that national surveys are accomplished in many countries, but they often do not contribute to an extended knowledge on urban freight distribution due to different reasons. A sample in an urban area is small and thus statistically not representative. Moreover, it is difficult to extract data from a general dataset while data in national surveys do not deliver the detail information needed for the analysis of urban freight distribution. McCabe, Roorda & Kwan (2008) argue that most cities around the world do not have enough data available to analyse urban freight distribution in a proper way. In general, Cherrett et al. (2012) notice that there is a lack of public data collection with respect to urban freight distribution. In Flanders too, there is a lack of public available data on urban freight distribution.

In 2006, the BESTUFS-project is accomplished. This project identifies and publishes case studies concerning urban freight distribution. One of the project outputs is an overview of previous data collections per participating country[19]. For Belgium, it appears that no urban freight indicators are collected and the knowledge on urban freight distribution is limited. Most indicators that are collected are general indicators at the national level (Debauche & Decock, 2006). For France, Germany and the Netherlands, which are neighbouring countries of Belgium, it also becomes clear that only a limited amount of data on urban freight distribution is publicly available. Routhier & Patier (2006) give an overview of the main gaps in France, Binnenbruck (2006) lists the main deficiencies for Germany and Vleugel (2006) describes the need for more data in the Netherlands. Moreover, the need for more publicly available data on urban freight distribution is highlighted during several conferences (BESTFACT, 2012; CIVITAS, 2012).

Thirdly, it can be observed that the methodologies used to collect data are not systematic and therefore, different data cannot be compared to each other (Crainic et al., 2004). Data on urban freight distribution are often incompatible with data on freight transport between cities (Ambrosini &

[19] The participating countries in the BESTUFS-project for which this output is available are Belgium, France, Germany, Hungary, Italy, the Netherlands, Portugal, Spain, Sweden, Switzerland and the United Kingdom (http://www.bestufs.net/bestufs2_data.html).

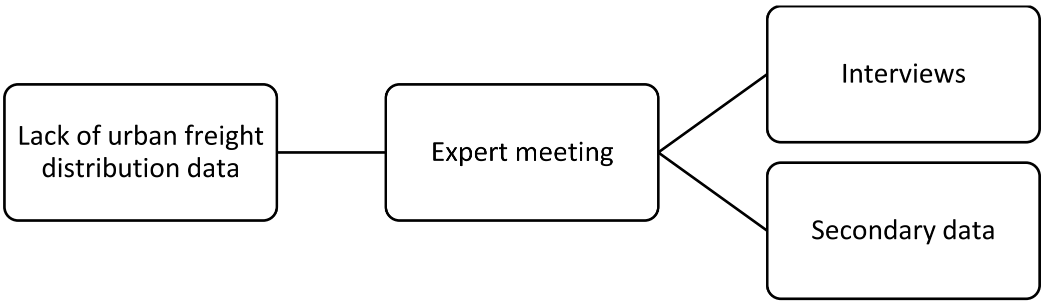
Routhier, 2004). Other reasons for the incompatibility of data are the collection by diverse institutions or authorities (Browne et al., 2007; Newton, 2001) and the fact that different countries employ another definition for 'urban goods movement' (Ambrosini & Routhier, 2004). Browne et al. (2007) and Dablanc (2009) confirm these findings and add that cities do not collect data on a regular basis.

Fourthly, in case data on urban freight distribution are available, they are often not analysed due to the fact that this is an expensive and complex process (Newton, 2001). In addition, Newton (2001) states that the existence of the available data is often unknown. Reasons for this are that data are not all preserved at the same location and that they frequently belong to reports that are formulated in national languages, or that the available data are not made publicly available (Allen & Browne, 2008).

Several authors (Ban, Jaller, Destro, & Marquis, 2010; Browne et al., 2007; J. Holguín-Veras & Jaller, 2012; Patier & Routhier, 2008) list the main gaps in available data. Concerning urban freight distribution, these main gaps appear to be data with respect to empty flows, activities of lorries of less than 3.5 tonnes, speed and (geographic) route data, loading and unloading operations, choice of transport mode and data on other transport modes than road transport.

As a conclusion, only few data on urban freight distribution exist and are publicly available. Specifically for this research, an overview of urban freight flows is lacking, making it difficult to estimate the potential demand for urban rail freight. This leads to the choice to calculate costs and benefits for a given demand for urban rail freight, or to calculate the minimum required demand to be break-even instead of estimating the demand. The next sections provide an overview of the data collection methods used for this research, being the insights of an expert meeting, interviews and the use of secondary data. Figure 35 displays these data collection methods.

Figure 35 – Data collection methods used



Source: Own creation

3.5.2 Expert meeting

On 19 May 2014, an expert meeting was organised among academic and industry experts, on "Tramways, railways and cities – tackling the role of rail in urban freight distribution". The aim of the expert meeting was to validate the first insights from the literature study, to determine the research strategy and to receive insights from local and foreign experts. In total, 18 experts were present. Six academic presentations were held related to the topic of this research. An overview of the presentations and discussants is provided in Appendix 5.

The experts gave examples of experiences they had with rail as a mode for urban freight distribution. Topics include an introduction to a social cost-benefit analysis, some foreign best practices, some methodological aspects concerning the demand for urban rail freight and public policy. These insights resulted in additional knowledge of the main success and failure factors. The outcome of the expert meeting was an overview of different freight types that could be considered, the methodology to be used, and input for the main success and failure factors and the relevant stakeholders. All insights gathered are referred to in the remainder of this research as Comi et al. (2014).

From the expert meeting, it was clear that the SCBA framework has to be complemented by a case study. In order to collect the necessary data to develop the SCBA framework and to apply it based on a case study, interviews are conducted and secondary data are collected. These are the respective topics of the following two sections.

3.5.3 Interviews

In order to collect additional information, a series of interviews has been conducted. Appendix 6 provides the list of interviews. The interviewees consist of different stakeholders along the urban rail freight supply chain, including a supplier (Torfs), rail operators (De Lijn, B Logistics, Lineas), rail infrastructure managers (De Lijn, Infrabel), customers (Grand Bazar Shopping Centre, Waasland Shopping Centre), a tram and train manufacturer (Bombardier) and an authority (City of Antwerp). Moreover, an expert of the former City Cargo pilot in Amsterdam (Hogeschool Amsterdam), and an expert in external costs (VITO) are interviewed.

The interviews are executed with multiple objectives and outcomes. Firstly, by presenting the preliminary results to different urban rail freight stakeholders, the intermediate output of this research is validated. Secondly, missing data are provided by the experts. Thirdly, insights in the actual organisation of the urban rail freight industry are gathered and later on applied to the research. Fourthly, the insights and data from the interviewees allow for the application of the developed SCBA framework to an actual case study.

Next to the data collected during the interviews, and the insights gathered at the expert meeting, secondary data are used in this research.

3.5.4 Secondary data

As a final data source, secondary data are used in order to calculate costs and benefits of using rail for urban freight distribution. The sources of the secondary data are a mix of academic papers, reports and online information. The online information is mainly used for the calculation of the costs and benefits for the case study, since this requires local and specific data. In the next chapters, the data sources used are added when the data are provided.

3.5.5 Intermediate conclusion

Firstly, there is a lack of publicly available urban freight distribution data. An example is the data on urban freight flows. An expert meeting with academic and industry experts was hosted in order to validate the scope of the research and to determine the research approach. Next to the information from the expert meeting, a combination of insights from interviews and secondary data is used to develop the SCBA model and to apply it to a case study. In particular, caution is paid for bias with respect to the data gathered during interviews and found in secondary sources.

As shown in the SCBA framework in Section 3.2.3, the input and calculations part of the SCBA model are developed by respectively the sensitivity and scenario analyses, and the data collection. In order to evaluate the output of the SCBA framework, the decision framework has to be developed. This is the topic of the next section.

3.6 Decision framework

In step 6 of the SCBA (see Section 3.2.2.6), it is discussed how each project case can be evaluated. The resulting outputs to assess the success of the project are the net present value, the internal rate of return and the present value to capital ratio. It is decided that these three outputs are calculated from the project leader's viewpoint and from a socio-economic perspective.

Innovative projects are characterised by many aspects, leading to costs and benefits. In this thesis, the use of rail for urban freight distribution is evaluated in a financial, economic and socio-economic context. The financial perspective can be seen as a part of the economic appraisal here, since it measures the return on capital, which has nothing to do with the socio-economic appraisal. This corresponds to the finding of Arduino et al. (2010, p. 5), who state that a quantification of an innovative project can be made in an economic and socio-economic context.

Hence, two cost and benefit schemes exist (Arduino et al., 2010): the economic and the socio-economic scheme. In the economic scheme, an innovative project case takes place as long as $\Delta R_p - \Delta C_p > 0$, in which ΔR_p equals the change in private revenue as a result of the innovation and ΔC_p is the change in private costs due to the innovation. In the socio-economic scheme, an innovation is present if $\Delta B_s - \Delta C_s > 0$, in which ΔB_s is the change in social benefit as a result of the innovation and ΔC_s is the change in social cost due to the innovation. Depending on the innovator, i.e. the project leader, and the values of ΔR_p, ΔC_p, ΔB_s and ΔC_s, different outcomes are possible. Table 26 displays the possible outcomes for each project leader.

Table 26 – Decision framework for different project leaders

Project leader	Outcome 1	Outcome 2	Outcome 3	Outcome 4
Public authorities	$\Delta B_s - \Delta C_s < y$ Failure	$\Delta B_s - \Delta C_s > y$ Success		
Public authorities+ rail operator consortium	$\Delta R_p - \Delta C_p > x$ $\Delta B_s - \Delta C_s < y$ No consensus	$\Delta R_p - \Delta C_p < x$ $\Delta B_s - \Delta C_s < y$ Failure	$\Delta R_p - \Delta C_p < x$ $\Delta B_s - \Delta C_s > y$ Success likely	$\Delta R_p - \Delta C_p > x$ $\Delta B_s - \Delta C_s > y$ Success
Rail operator	$\Delta R_p - \Delta C_p > x$ $\Delta B_s - \Delta C_s < y$ Success likely	$\Delta R_p - \Delta C_p < x$ $\Delta B_s - \Delta C_s < y$ Failure	$\Delta R_p - \Delta C_p < x$ $\Delta B_s - \Delta C_s > y$ Failure likely	$\Delta R_p - \Delta C_p > x$ $\Delta B_s - \Delta C_s > y$ Success

Source: Own creation based on Arduino et al. (2010) and Aronietis (2013)

The public authorities as a project leader should consider the social costs and benefits. In case the social benefits do not compensate for the social costs by reaching a certain threshold *y*, no socio-economic benefits are present (outcome 1). As a result, the innovation fails and should not be put into practice. In case the social benefits exceed a certain threshold *y*, after subtracting the social costs, socio-economic benefits exist (outcome 2). Hence, the public authorities should go on with the innovation.

When public authorities and a rail operator bundle forces and act together as the project leader, both private and social costs and benefits are considered. The first outcome reveals that the public authorities should not continue with the innovation, since the socio-economic benefits do not reach a threshold *y*. The rail operator on the other hand, wants to apply the innovation, since its net private revenue exceeds a threshold *x*. Thus, no consensus is reached. The second outcome shows that both the economic and socio-economic benefits do not reach their respective threshold *x* and *y*. There is no incentive to continue with the innovation. In the third outcome, no economic benefits are obtained by proceeding with the innovation, but socio-economic benefits are present. A solution here could be the introduction of subsidies S_p by the public authorities to compensate for the missing private benefits. An important remark here is that the public authorities have to balance the net benefits of this innovation with other possible innovation initiatives. The fourth outcome shows that the economic and socio-economic benefits reach their respective threshold *x* and *y*. Thus, the public authorities and the rail operator want to continue the innovation.

The rail operator can also be the project leader. The same outcomes emerge as when the public authorities and the rail operator act together as project leaders. However, the interpretation of the outcomes is different. Given the first outcome, the operator wants to continue the innovation, since economic benefits are present. However, no socio-economic benefits exist. The public authorities either want to reject the innovation, or ask the rail operator a compensation for the socio-economic costs. The second outcome leads to failure, since no economic neither socio-economic benefits exist. In case of the third outcome, no economic benefits are present for the rail operator. However, socio-economic benefits exist. If the public authorities assess the innovation as valuable to the society, compensation S_s can be given to the rail operator and the innovation can continue. This idea of granting subsidies is suggested by Dinwoodie (2006). The fourth outcome leads to a successful innovation, since economic and socio-economic benefits are present.

An important remark with respect to Table 26 concerns the success of the innovation. Even if the (social) cost-benefit calculation reveals that the innovation is successful, the innovation may fail. This is due to the potential presence of hurdles. Aronietis (2013, p. 49) defines hurdles as "*non-monetary obstacles that an innovation can face*". These obstacles can for example be of policy nature.

As a general rule, Aronietis (2013) states that the following relations have to be true for an innovation to be successful:

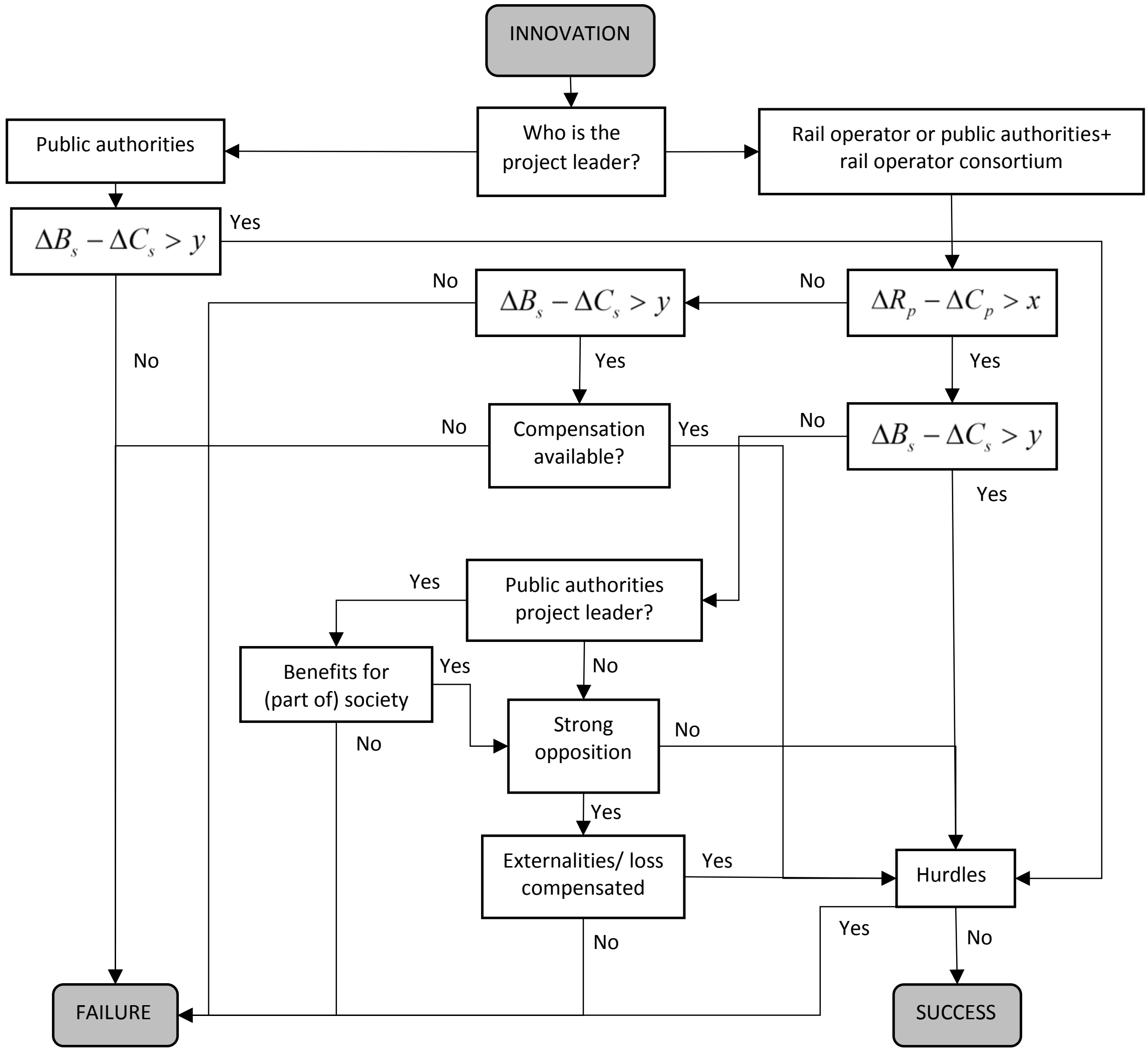
$$\Delta R_p - \Delta C_p + S_p > x \tag{11}$$

$$\Delta B_s - \Delta C_s + S_s > y \tag{12}$$

in which *x* and *y* are the threshold values that a rail operator and public authorities respectively want to obtain by applying the innovation and S_p and S_s are respectively the subsidies and compensation granted to the rail operator. Accordingly, Figure 36 shows the different paths followed when the use of rail for urban freight distribution is introduced. Firstly, the project leader has to be known. Depending on whether this is a public authority, a rail operator, or a consortium of public authorities and a rail operator, different costs and benefits occur. Next to these costs and benefits, the presence of incentives such as compensation, benefits for certain groups of the society, strong opposition and/or the compensation of externalities or loss affect the success or failure of the innovation of using rail for urban freight distribution.

It is now clear how the inputs to the SCBA framework are determined. Data are collected to do the necessary calculations and it is clear how the output of the framework can be assessed. The whole SCBA framework can now be applied to a case study. In this research, a case study is done for the use of a tram for urban freight distribution in the Antwerp urban area. As demonstrated before, the characteristics of the urban area affect the SCBA framework. Therefore, the next section provides more background information on this urban area.

Figure 36 – Success algorithm of rail-based urban freight distribution



Source: Own creation based on Aronietis (2013)

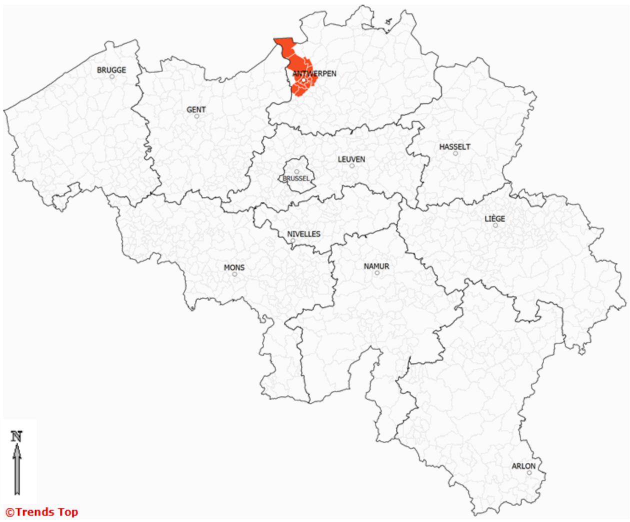
3.7 Case study

As the next part of the research strategy, a case study is conducted in order to illustrate the SCBA framework for a specific case. Belgium possesses one of the densest rail networks in the world with 3,602 km of rail lines, or 117 km of rail lines per 1,000 km² (Infrabel, 2019c). This figure only includes the rail lines used by trains. On top of this, 332 km of tram lines in Flanders can be added, of which 126 km are in Antwerp, 62 km in Ghent and 143 km along the Belgian coast. In Brussels, another 180 km of tram and metro lines are present (MIVB, 2019). In Wallonia, the city of Charleroi possesses 33 km of tram lines (TEC, 2019) and in Liège, a tram net of 12 km is under construction and is foreseen to be operational end 2022 (City of Liège, 2019).

In order to investigate the potential role of rail for urban freight distribution in Flanders, the urban area of Antwerp is chosen as the case study environment. Therefore, it is necessary to define this urban area first in order to understand why this area can serve as a good case study environment. The city of Antwerp is located in the province of Antwerp, in the north of Flanders, Belgium. This is shown in Figure

37. It is the largest Flemish city in terms of number of inhabitants (Statbel, 2018) and it is next to Ghent the only Flemish city that possesses tramway infrastructure[20].

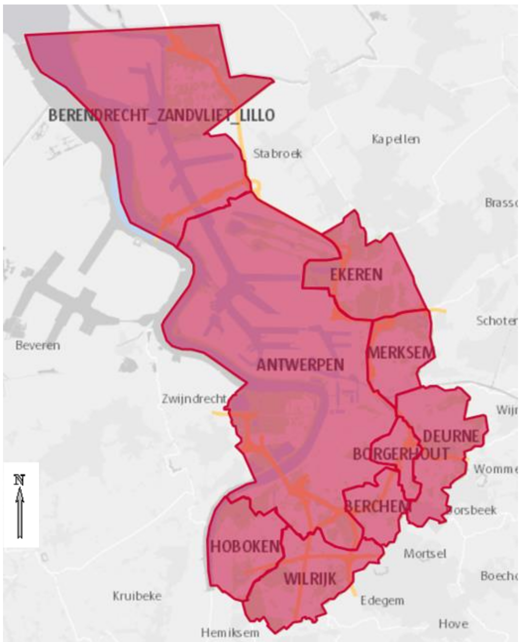
Figure 37 – Location of Antwerp within Belgium



Source: TrendsTop (2014)

The legal boundaries of the city of Antwerp are shown in Figure 37. At a lower level, the city of Antwerp consists of nine districts, being Antwerp, Berchem, Berendrecht-Zandvliet-Lillo, Borgerhout, Deurne, Ekeren, Hoboken, Merksem and Wilrijk (see Figure 38). The name Antwerp thus refers both to the city as to the district. In this research, the city of Antwerp is meant when referring to Antwerp.

Figure 38 – The districts of the city of Antwerp



Source: City of Antwerp (2019d)

[20] Along the Belgian North Sea coast, a tram is serving different cities. However, this is a point-to-point tramway infrastructure that passes through some cities, but does not offer a tramway network within an urban area.

The different characteristics of the urban area of Antwerp are now discussed in the next sections and include the environmental state (3.7.1), freight flows (3.7.2), geography (3.7.3), population density (3.7.4), regulatory framework (3.7.5) and transport infrastructure (3.7.6).

3.7.1 Environmental state

An important environmental aspect in Antwerp is the presence of congestion. In the TomTom Traffic Index of 2018, the city of Antwerp reaches a 92nd place on the ranking of 403 cities of 56 countries in the world with a congestion level of 31%. The congestion level is defined as the increase in overall travel times compared to an uncongested situation. The congestion level of Antwerp fits in the row of the congestion level of cities in which rail-based urban freight distribution initiatives have been taken place: a congestion level of 36% in Paris, 27% in Vienna and 24% in Amsterdam (TomTom, 2019). As shown in Figure 39, most of the delay hotspots are located on the main motorways leading to Antwerp and especially on the ring road around Antwerp, which makes it challenging to enter the Antwerp urban area by road.

Figure 39 – Delay hotspots in Antwerp in 2016

Source: TomTom (2017)

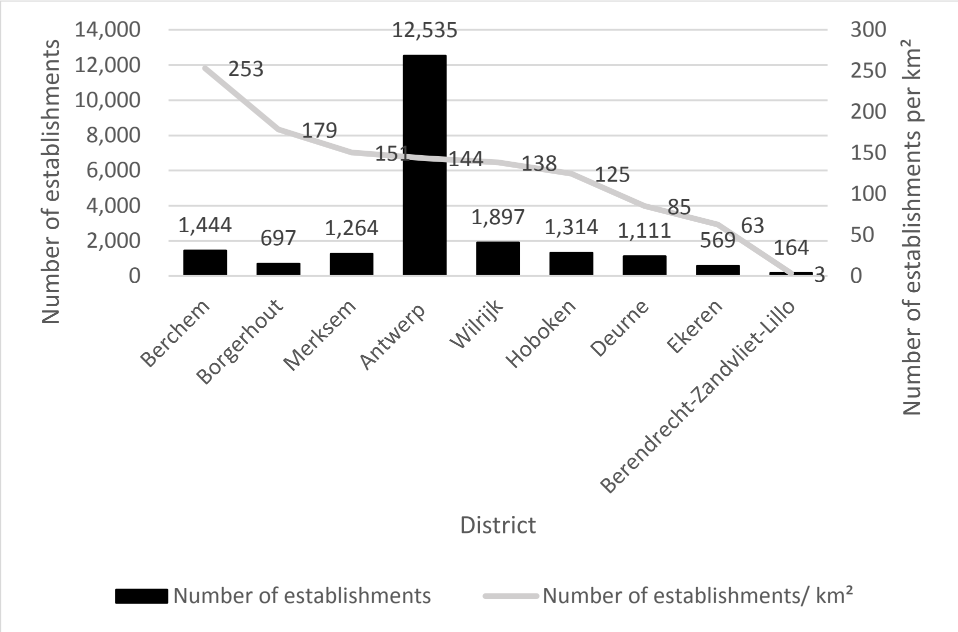
Concerning air pollution, 16.3% of all inhabitants of the city of Antwerp were in 2017 exposed to NO_2 levels higher than the EU standard of 40µg/m³. With respect to noise, 40.7% of all inhabitants experience noise levels of more than 60 dB (City of Antwerp, 2019c). On weekdays, considered to be 180 days a year, a total of 754 accidents happened on the Antwerp ring road R1 in 2018 (Vlaams Verkeerscentrum, 2019).

In sum, a couple of environmental issues are present in the urban area of Antwerp, mainly related to congestion, air pollution, noise and accidents.

3.7.2 Freight flows

The second characteristic of the urban area to be examined is the freight flows. Figure 40 gives an overview of the number of establishments for the category ‘wholesale, retail and repair of small cars’ for each district of the city of Antwerp. The total number of establishments per district is indicated in black and the number of establishments per square kilometre is shown by means of the grey line. The districts are ranked according to a decreasing number of establishments per square kilometre.

Figure 40 – Number of establishments in wholesale, retail and repair of small cars in 2018



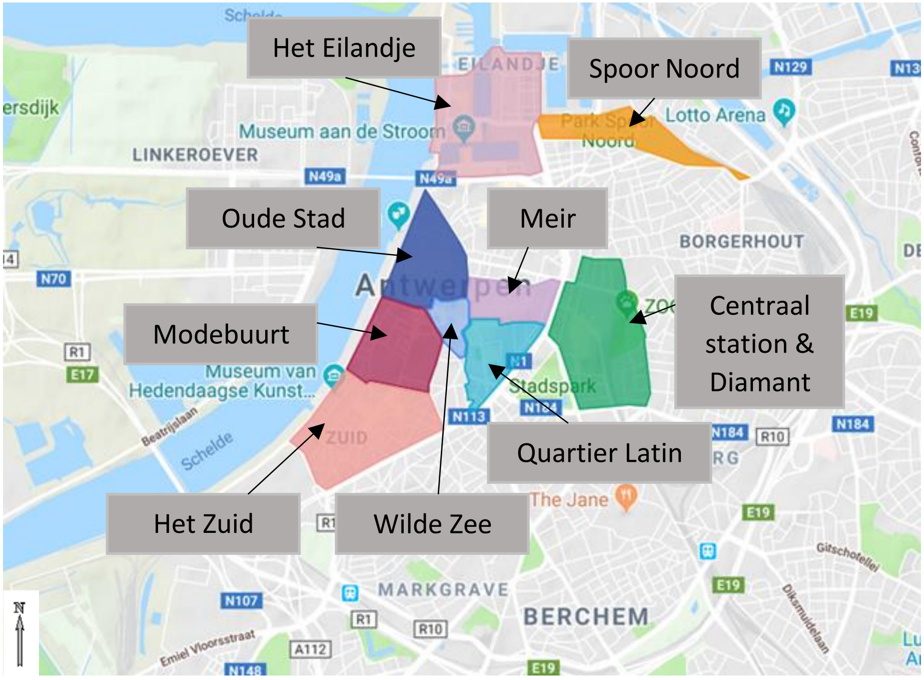
Source: Own creation based on City of Antwerp (2019c)

Figure 40 shows that the district Antwerp has by far the highest number of establishments. When taking into account the surface of each area, the district Berchem shows the highest number of establishments per square kilometre. The district of Berendrecht – Zandvliet – Lillo scores in both cases the lowest. The reason is that in this district with a large surface, the port of Antwerp is located.

Based on Figure 40, it can be concluded that the districts of Berchem, Borgerhout, Merksem and Antwerp are characterised by the most establishments per square kilometre. The district of Antwerp has the highest absolute number of establishments, but only the fourthest highest density. As shown in Figure 38, the surface of this district is much larger than the one of the other districts. Therefore, it is most interesting to have a more detailed look at this district.

When only considering the city centre of Antwerp, nine shopping zones are distinguished. These zones are displayed in Figure 41 and are Centraal station & Diamant, Het Eilandje, Het Zuid, Meir, Modebuurt, Oude Stad, Quartier Latin, Spoor Noord and Wilde Zee. For each of these zones, and for specific areas within these zones, data on the number of commercial establishments are collected every three years (City of Antwerp, 2016). Based on these more detailed data, specific areas with a potential high number of freight flows can be identified and next, freight flows could be measured. For these freight flows, it could be examined which share could be transported by rail instead of by road. Since data on the existing freight flows are not publicly available, the demand for urban rail freight distribution is not analysed in this research.

Figure 41 – Nine retail zones in Antwerp



Source: City of Antwerp (2019b)

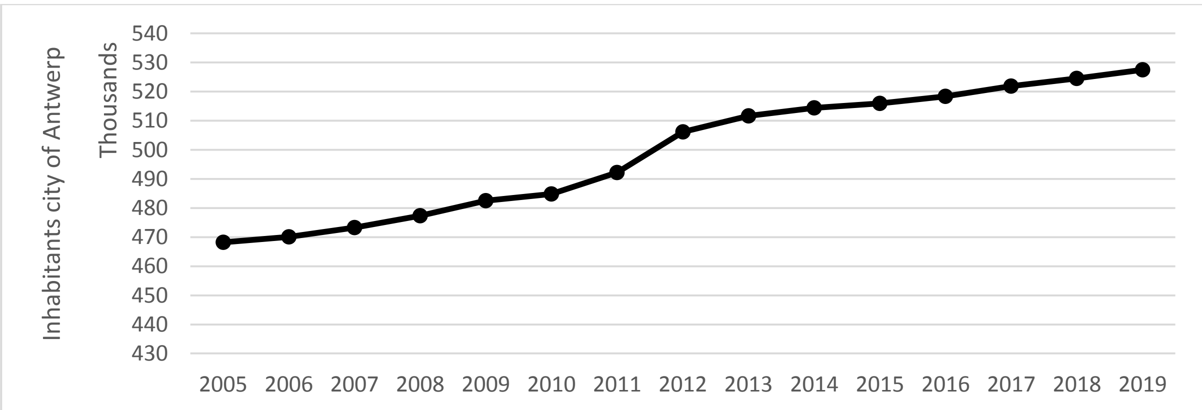
3.7.3 Geography

Thirdly, the geography of the urban area is described. The city of Antwerp consists of a historical inner city centre, characterised by narrow streets. These streets make it challenging to supply shops by lorries. On the other hand, the city is flat and the river Scheldt only divides the city in two parts, being the left bank and the right bank.

3.7.4 Population density

In January 2019, 527,461 people were living in the city of Antwerp (City of Antwerp, 2019b), which leads to a population density of 2,582 people per square kilometre on average. Figure 42 shows the evolution of the population in Antwerp between 2005 and 2019. It is clear that the population is growing. This corresponds with the worldwide growing population and urbanisation trend.

Figure 42 – Evolution of the population in the city of Antwerp, 2005-2019



Source: City of Antwerp (2019a)

Table 27 shows the absolute population and population density of the nine districts in the city of Antwerp. The districts are ranked according to a decreasing population density.

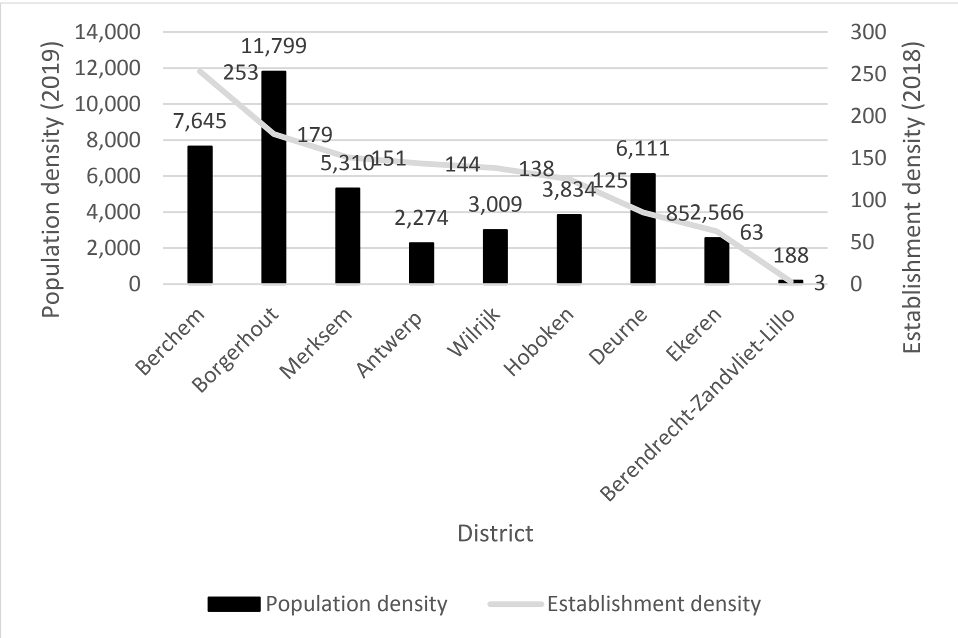
Table 27 – Population and population density in the districts of Antwerp

District	Surface (km²)	Population (01/01/19)	Population density (inh/km²)
Borgerhout	3.90	46,018	11,799
Berchem	5.70	43,577	7,645
Deurne	13.03	79,627	6,111
Merksem	8.39	44,549	5,310
Hoboken	10.52	40,333	3,834
Wilrijk	13.71	41,251	3,009
Ekeren	9.06	23,252	2,566
Antwerp	87.31	198,520	2,274
Berendrecht-Zandvliet-Lillo	52.63	9,893	188

Source: City of Antwerp (2019c)

The three most densely populated areas within the city of Antwerp are in descending order Borgerhout, Berchem and Deurne. The least densely populated areas are in ascending order Berendrecht-Zandvliet-Lillo, Antwerp and Ekeren. When comparing the population densities of the disctricts to the establishment densities in Figure 43, it is clear that these two do not have the same relation for all districts. The districts are ranked according to a decreasing establishment density (see grey line), but the population density is not decreasing over the districts (black bars). For the district Antwerp for instance, the establishment density is the fourth highest of all districts, whereas this district has the second lowest population density.

Figure 43 – Population and establishment density in Antwerp



Source: Own creation based on City of Antwerp (2019c)

Areas with a high establishment density are particularly interesting for this research. These areas do not necessarily correspond to densely populated areas. Therefore, the focus of the analysis does not need to be on the densely populated areas as such. However, the population density of a certain area is important to take into account since the more people are living in a certain area, the more people are exposed to the external costs caused by rail and road transport.

3.7.5 Regulatory framework

With respect to the regulatory framework, three main regulations in the urban area are interesting to mention here. Firstly, the city of Antwerp introduced a low emission zone on the 1st of February 2017, covering the area enclosed by the ring road, as well as a part of the left bank of the river Scheldt. Certain types of road vehicles cannot enter the city any longer. Anno 2019, petrol vehicles with a euro standard 3 and lower and diesel vehicles with a euro standard 4 and lower can only enter the city after purchasing a permission (Slim naar Antwerpen, 2019). Secondly, road pricing for lorries of more than 3.5 tonnes was implemented in Belgium on the 1st of April 2016 (Viapass, 2019b). Thirdly, time windows and pedestrian zones exist in Antwerp, with for example in the shopping street Meir time windows between 6 am and 11 am (Maes, Sys, & Vanelslander, 2012). These policy measures make it more challenging and more costly to supply shops in the urban area by road transport.

3.7.6 Transport infrastructure

The last aspect that has to be taken into account when describing the characteristics of the urban area of Antwerp, is the transport infrastructure. In this research, the focus is on the rail infrastructure, being the tram network and the train network. Firstly, the tramway network of Antwerp is displayed. Figure 44 shows that this network extends for example to the left bank of the river Scheldt. A tram transporting freight towards the city centre could have its starting point at the left bank (e.g. P+R Melsele) and from there transport goods towards the city centre. The scope of the tram infrastructure is an important factor affecting the viability of the use of rail for urban freight distribution. Before the extensions of the tram network shown in Figure 44, the potential of using a tram may have been lower than after the extensions. The reason is that the need for road pre- and/or post-haulage may disappear when the tram network is more extended, leading to lower operational and time costs.

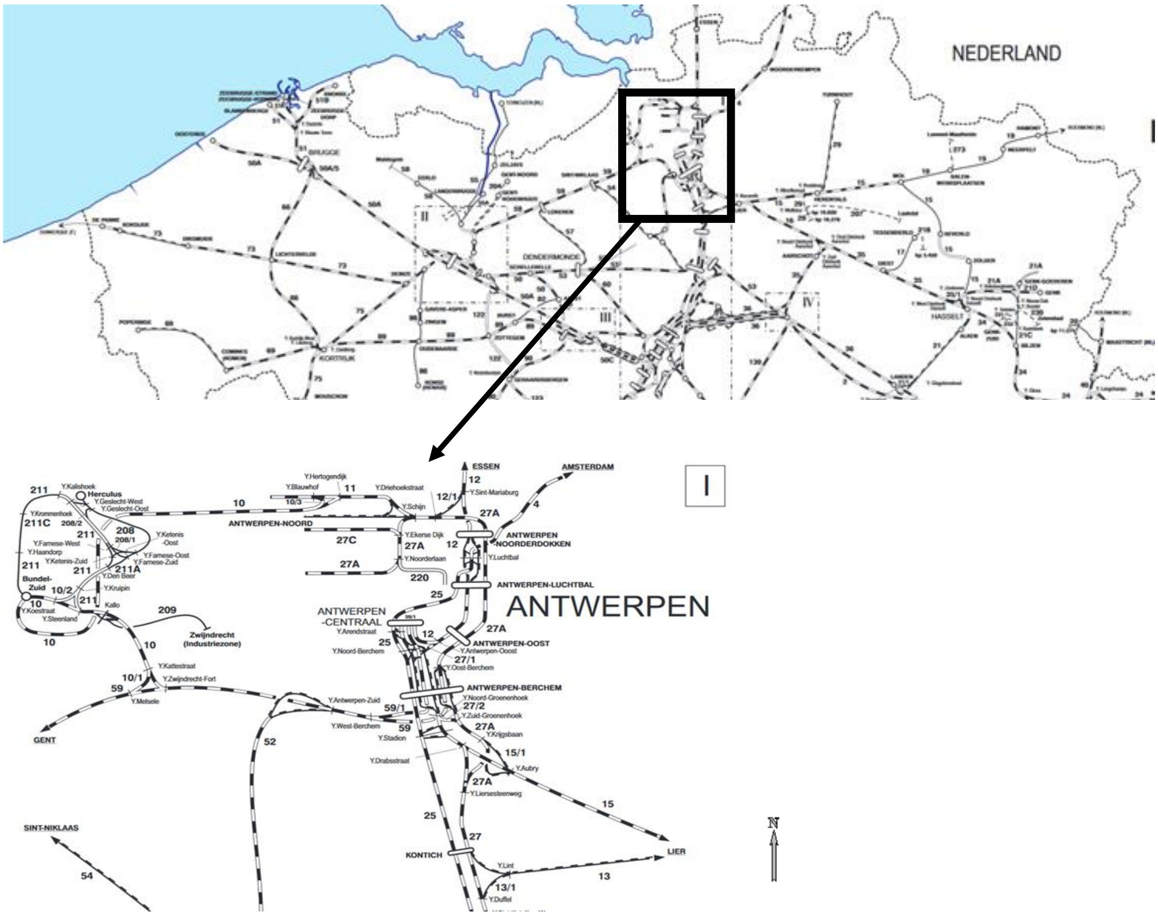
The tramway infrastructure in Antwerp is present and could be used for freight purposes. Interviews with the Flemish tramway company, De Lijn, have revealed that the insertion of a freight tram is possible on the tram network in Antwerp under certain conditions, the main one being that the passenger transport should not be disturbed. At the ground level sections of the rail network, freight trams can just follow a passenger tram in “follower-mode”, keeping a visually safe distance. On the underground sections of the tram network, freight operations could only take place between 1h30 am and 4h30 am, since freight trams cannot just follow passenger trams in the underground and the capacity is already fully used by the passenger trams. An obstacle during these hours could still be the maintenance of the lines, also carried out at night. With respect to the loading and unloading operations, the freight tram may need special junctions, since the passenger transport should not be disturbed by freight operations. Turning loops that are currenlty not used by the passenger trams could be used by freight trams for loading and unloading purposes (Fierens & Nuytemans, 2014).

Figure 44 – Tram network of Antwerp (status 22 December 2018)

Source: De Lijn (2019c)

Secondly, the position of Antwerp in the train network of Belgium is displayed in Figure 45. It is clear that rail infrastructure is available in Antwerp and it could be further examined whether freight could be transported by light rail from different locations in Belgium to the city of Antwerp.

Figure 45 – Position of Antwerp in the Belgian rail network



Source: Infrabel (2019a)

3.7.7 Intermediate conclusion

The urban area of Antwerp is characterised by seven main aspects. Firstly, accidents, air pollution, congestion and noise are examples of externalities to which large parts of the Antwerp population are exposed. Secondly, no data on freight flows in Antwerp are publicly available, but a distinction can be made between districts with high and low establishment densities. Thirdly, the narrow streets in the historical centre of Antwerp make it challenging to supply shops by lorries. Fourthly, the population density of different districts is known and is compared to the establishment densities. It is clear that these two measures are not always related to each other. Fifthly, some regulatory measures such as the introduction of a low emission zone in 2017, the implementation of road pricing in 2016 and the presence of time windows and pedestrian zones make it challenging to deliver goods in Antwerp by road transport. Ultimately, tram and train infrastructure is present in Antwerp.

The total of these seven characteristics make Antwerp a good case study environment. Firstly, there are issues related to urban freight distribution by road, such as congestion and air pollution. Secondly, it is getting more challenging for road operators to supply shops in the urban area due to restrictive policy measures. Thirdly, rail infrastructure is present in the urban area and some areas have high establishment densities and therefore, generate freight flows.

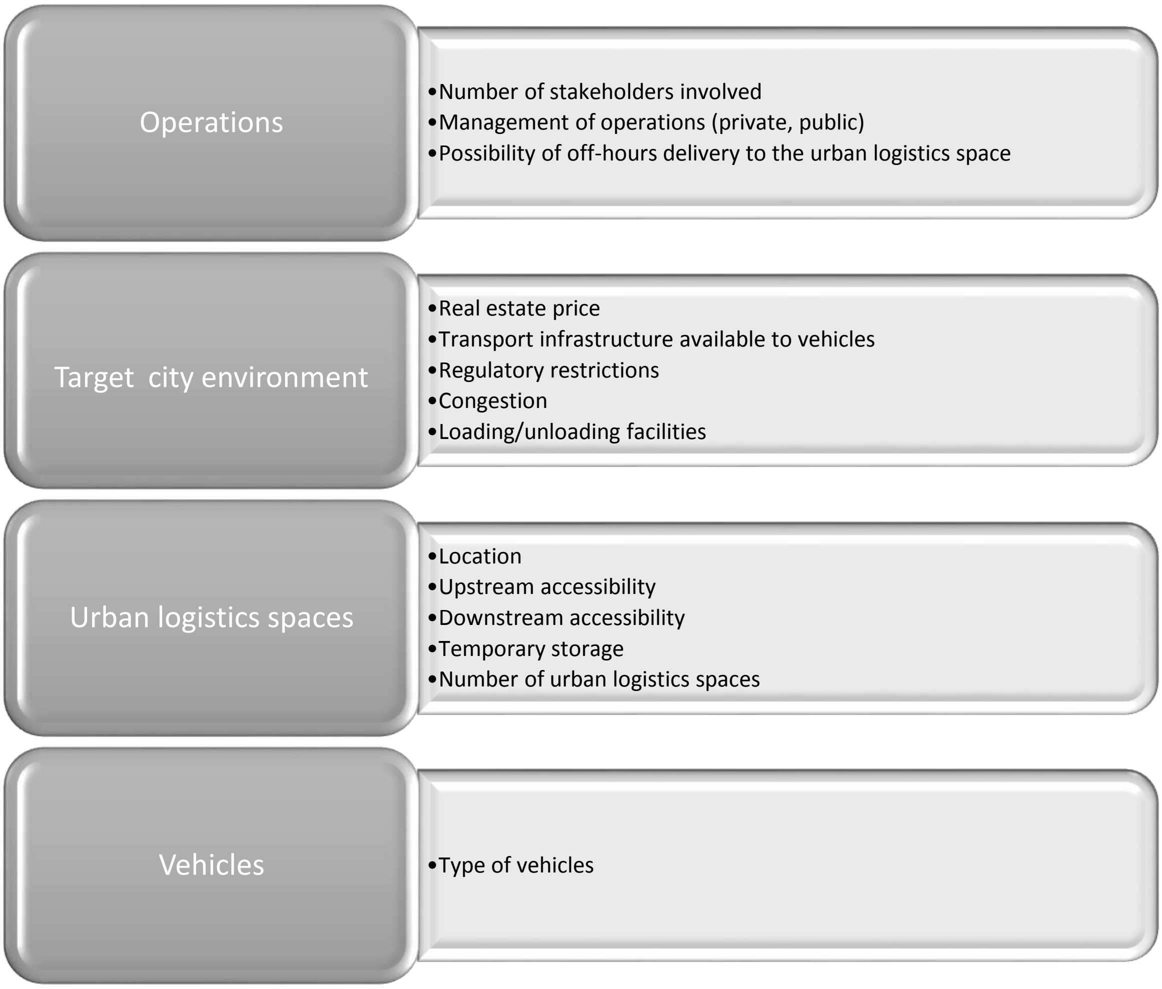
The application of the developed framework to a case study for Antwerp offers some interesting insights. In the next section, it is explained how these insights can be transferred to another case study environment and to the use of trains for urban freight distribution.

3.8 Transferability theory

In order to transfer the insights developed in this research to other urban areas, the transferability theory is used. The starting point of this theory is defined by Macário & Marques (2008) as the fact that "*if a measure or package of measures has been successfully implemented within a given geographical, demographic, socio-economic, cultural, technologic, institutional and organisational setting, then comparable results in terms of the degree of attainment of the measure or package of measures objectives can be achieved in areas characterised by a similar setting*". This theory is discussed in several European projects, such as CIVITAS, TURBLOG, SUGAR, NICHE, TIDE and BESTFACT (Barrera, 2013) and applied by amongst others Janjevic et al. (2013) to replicate micro-consolidation initiatives.

Janjevic et al. (2013) suggest to examine the project both in its original environment and the new environment. Figure 46 shows the different features relevant for this research that characterise the original and new environment in which an urban rail freight project can be applied.

Figure 46 – Features of the original and new environment



Source: Janjevic et al. (2013)

In order to apply the social cost-benefit framework to another urban area, the following additional data specifically have to be collected to compare the features of the original and new environment as shown in Figure 46. Firstly, with respect to the operations, the involvement of the relevant stakeholders, such as authorities, rail operators and retailers has to be determined. Secondly, concerning the target city environment, the real estate price, labour cost, distances to be covered on the rail network, external cost figures, locations for handling and storage points, and urban freight distribution measures such as pedestrian zones, low emission zones, road pricing, congestion charging and time windows have to be specified. Thirdly, regarding the urban logistics spaces, the location and number of customers has to be made clear, as well as the way these customers are currently supplied and their storage policy. Ultimately, the type of road and rail vehicles has to be specified.

Next to transferring the developed tool to another case study environment, it can also be transferred to other types of rail transport. Some differences between tram and train that have to be taken into account are the following.

Firstly, the connection to the train network differs from the connection to the tram network. The tram network is more finely-meshed in the urban area than the train network. Hence, it is more likely that the customers in the urban area are directly connected to a tram network than to the train infrastructure. Concerning the connection at the side of the supplier, the rail infrastructure manager has to examine whether establishing a connection to the train network is possible. If this is possible, the infrastructure manager in Belgium provides the connecting switch and 18 metres of track. All additional distance that has to be covered has to be provided by the private stakeholder that wants to be connected (Monnaerts & Verheyen, 2013b).

Secondly, loading and unloading the goods on the train network is different than for a tram. Passenger trams have a maximum dwell-time at tram stops of 30 seconds, whereas passenger trains stop longer in passenger stations. Depending on the station and the number of people alighting, this can be up to even 15 minutes in terminal stations such as Antwerp Central Station (Monnaerts & Verheyen, 2013b). Hence, the technology needed to unload the goods has other requirements than the one needed to quickly unload the goods at a tram stop. Moreover, track bundles on the train network have to be identified where goods can be loaded and unloaded. In the area of the port of Antwerp, some rail bundles are available. However, this areas is subject to the Major Law, meaning that port labour is used, which is more expensive than labour outside the port area.

By applying the adaptations discussed in this section, the developed social cost-benefit tool can be applied to other case study environments and to the use of trains for urban freight distribution.

3.9 Conclusion

In order to investigate under which conditions using rail for urban freight distribution can be successful, an appropriate research approach and data collection methods are selected. Based on the existing literature, developing a social cost-benefit framework and applying it to a case study seems to be the most appropriate research strategy. The demand for urban rail freight distribution has to be estimated based on stated preference techniques. However, given the high uncertainty about estimating this demand, it is chosen to either investigate the costs and benefits of a given case with a certain demand, or to calculate the minimum required demand to be break-even. Eight steps in developing the SCBA framework are followed. An overview of these steps is provided in Table 28.

Firstly, the set of project cases and the reference case are selected. The reference case is the current urban freight distribution by road. The project cases are urban freight distribution by rail, being the use of tramways and light rail. In both cases, a dedicated freight vehicle, a freight wagon attached to a passenger vehicle, or parcels alongside passengers can be used.

Table 28 – Steps to follow for the development of the SCBA framework

Step	Explanation	Step in this research
1	Specify the set of project cases and reference case	Reference case: urban road freight distribution; Project case: urban rail freight distribution: • Tramways • Light rail In both cases for a dedicated freight vehicle, freight wagon attached to a passenger vehicle and parcels alongside passengers
2	Decide whose benefits and costs count	The benefits and costs of all actors along the urban rail and road freight supply chain count; The project leader = one or more public authorities
3	Identify the impacts and select measurement indicators (units)	Positive and negative impacts are identified for all stakeholders; costs are investment and operational expenses; Benefits are consumer surplus and operational income; A distinction is made between financial, economic and socio-economic analysis; Measurement unit = euro (per parcel)
4	Quantify and monetise all impacts	Use of consumer price index (CPI) and purchasing power index (PPI) to obtain all values for the base year 2018; Time horizon of 30 years, inflation rate of 2.3%
5	Discount costs and benefits to obtain present values	Present values of 2018; Financial and social discount rate of 4%
6	Evaluate each project case	Use of NPV, IRR, present value to capital ratio; Projects ranked according to a decreasing present value to capital ratio and a certain yield required
7	Deal with uncertainty and risk	Variables classified based on modifiability and uncertainty; Distinction between major trends, strategic levers and major uncertainties; Sensitivity tests and scenarios needed
8	Make recommendations based on the previous steps	Recommendations per scenario and case

Source: Own creation

In the second step, it has to be decided whose benefits and costs count. In this research, all costs and benefits related to all actors along the urban freight supply chain are taken into account. The project leader is considered to be one or more public authorities.

Thirdly, the impacts are identified and measurement indicators are selected. From the literature review it is clear that not all authors measure all cost and benefit components related to an urban rail-freight initiative. The positive and negative impacts on all different stakeholders are identified. Costs are divided into investment and operational expenses, whereas benefits include operational income and consumer surplus. The analysis is done from a financial, economic and socio-economic perspective. The measurement unit chosen is euro (per parcel).

In the fourth step, all values are converted to the base year 2018 by means of the consumer price index and the purchasing power index. The time horizon of the analysis is 30 years and an inflation rate of 2.3% is used.

Fifthly, all costs and benefits are discounted to obtain present values for 2018. A financial and a social discount rate of 4% is used. The discounted free cash flow is calculated.

Sixthly, each project case is appraised by means of the net present value, internal rate of return and the present value to capital ratio. Different project cases are ranked according to a decreasing present value to capital ratio and a certain yield is required.

In the seventh step, uncertainty and risk is dealt with. Variables are classified based on how easy they can be controlled by the project leader and how (un)certain they are. A distinction is made between major trends, strategic levers and major uncertainties. Sensitivity tests are performed in order to know the critical variables and scenarios are developed with respect to the major trends and the major uncertainties.

Finally, for each scenario, recommendations are made based on the previous steps. It was shown that in these eight steps, other research methods are applied than only an SCBA. Figure 47 shows the application of the different research methods to the SCBA framework, as well as all decisions made for these methods.

For the sensitivity analyses, three categories of variables are distinguished: general, cost-related and benefit-related. The general variable that is subject to sensitivity analyses is the discount rate. The cost-related variables are the cost of capital investment, the presence of pre- and post-haulage by road, the timing of the transport and the operational and maintenance costs. The benefit-related variables comprise the amount of goods to be transported, the commodities value, the presence of congestion and other policy measures, the environmental performance of rail transport, ancillary revenue, and the assumed travel times.

Concerning the scenario analyses, three categories of variables exist: the major trends, the major uncertainties and the strategic levers. The major trends are the characteristics of the urban area, being the environmental state, the freight flows, the geography, the population density, the regulatory framework and the transport infrastructure. The major uncertainty is the amount of goods to be transported. The strategic levers include the ancillary revenue, the organisation, the stakeholders and the technology.

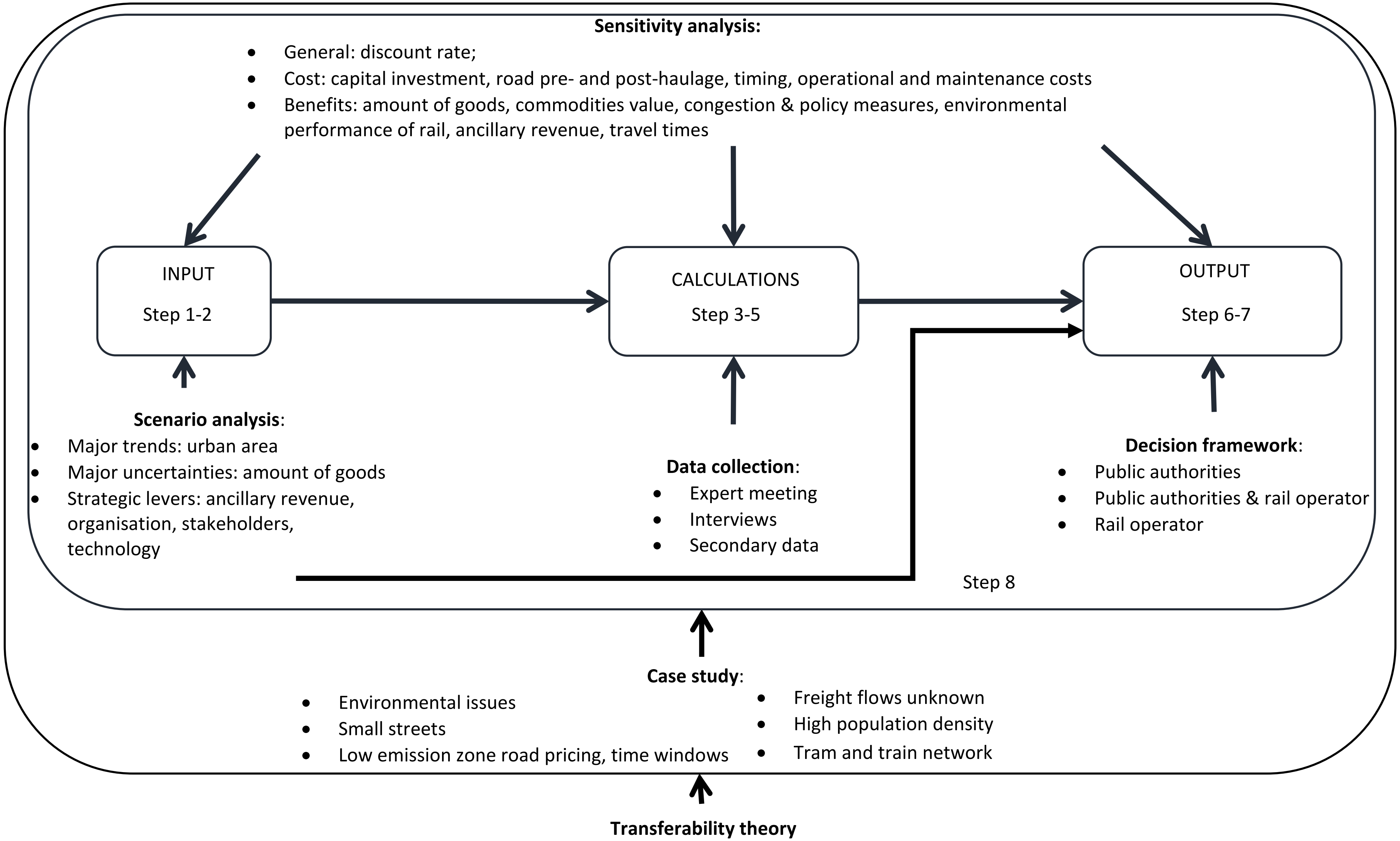
Three data collection techniques have been applied in this research: an expert meeting, interviews and the analyses of secondary data. A decision framework is developed, making a distinction between three types of project leaders: one or more public authorities, a consortium of one or more public authorities and a rail operator, or a rail operator.

Next, a case study environment is selected. The urban area of Antwerp is chosen in this research. The characteristics of the Antwerp urban area are the following. Firstly, there are some environmental issues in Antwerp, including congestion, air pollution, noise and accidents. Secondly, the freight flows are unknown due to a lack of publicly available data. Thirdly, small streets make it challenging to supply shops in certain areas by road transport. Fourthly, population densities in different areas differ, but in general, Antwerp has a high population density. Fifthly, some measures such as a low emission zone, road pricing and time windows provide additional challenges on top of the geographical ones to deliver goods in the city centre. Finally, a tram and train network is available in Antwerp.

Finally, the transferability theory is applied in order to generalise the main findings from the case study to other study environments and other case studies.

Now that the research approach and data collection methods are selected, the potential of rail for urban freight distribution in Antwerp can be examined in the following chapters.

Figure 47 – Applied methods to the SCBA framework



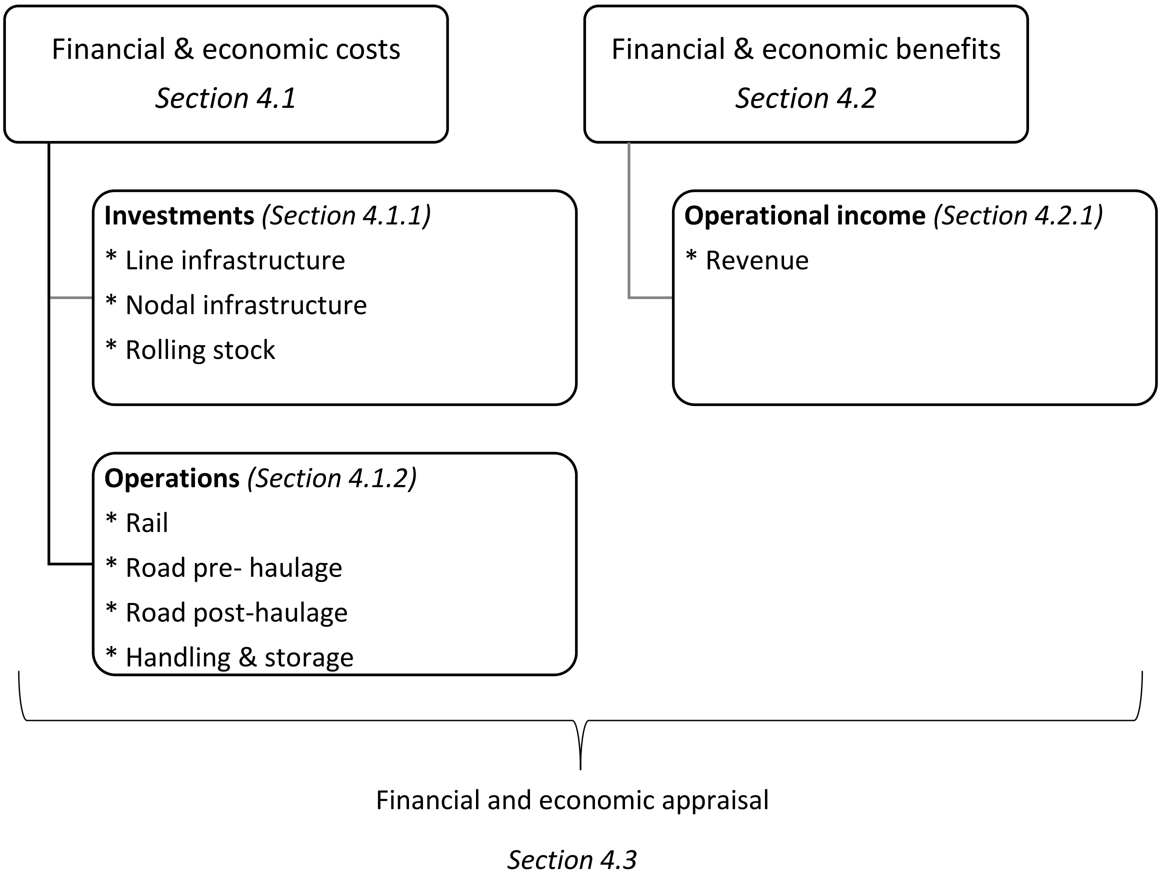
Source: Own creation

4. Financial & economic analysis of urban rail freight

When examining the potential role of rail for urban freight distribution, it is first of all essential to know whether using trains or trams is viable from the perspective of the project leader. As long as using rail transport leads to higher costs than the current transport by road, transport users will not make this modal shift, unless they receive other incentives. In order to know whether the project is viable for the project leader, a financial and economic analysis have to be conducted. In this research, the government is the project leader. The eight steps to follow when examining the potential of rail for urban freight distribution based on an SCBA are presented in the previous chapter. Now, these steps are elaborated on in depth and applied to a case study. In the current chapter, steps 4-6 are executed for the financial and economic analysis.

The financial and economic costs and benefits are following Blauwens & Van de Voorde (1985b) divided as shown in Figure 48. The costs consist of investments and operations. Investments are needed in line infrastructure, nodal infrastructure and rolling stock. Operational costs include all expenses related to rail transport, road pre- and post-haulage and handling and storage. These costs are the subject of Section 4.1. The benefits comprise operational income. The operational income includes the revenue obtained by offering a rail-based urban freight solution. The economic benefits are discussed in Section 4.2. The financial and economic appraisal of an urban rail freight case study, combining costs and benefits, is presented in Section 4.3. In Section 4.4, some conclusions are drawn.

Figure 48 – Financial and economic costs and benefits



Source: Own creation based on Blauwens & Van de Voorde (1985b)

4.1 Financial and economic costs

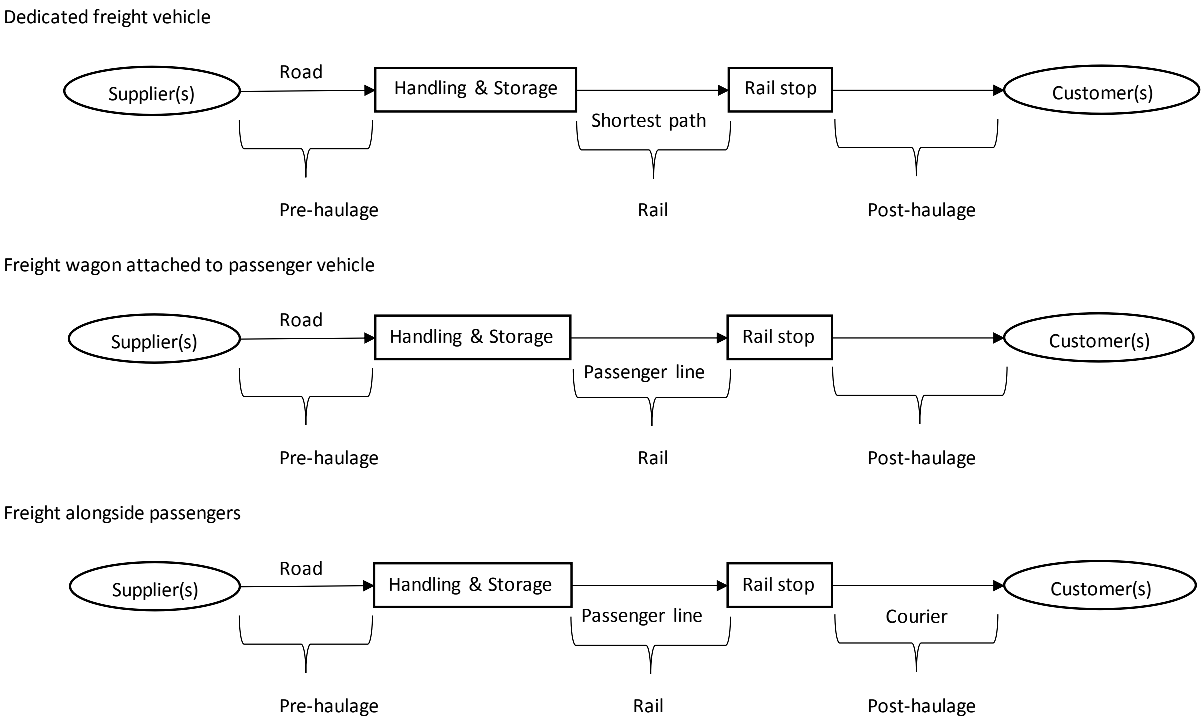
Several authors provide an overview and calculation methods of the financial and economic costs of rail transport, urban road transport or transport in general. Janic (2007), Alessandrini et al. (2012), Regué & Bristow (2013) and Gorçun (2014) offer a case-based analysis of private costs of respectively a multimodal network, a rail shuttle, a freight tram and a transport system in an urban context. However, these authors do not offer a general overview of costs and benefits in an urban rail context. Therefore, the provided cost components can be supplemented by cost information from other sources. With respect to rail costs, Mizutani (2004) provides the variable costs in the rail industry, while Janic (2007) investigates the full costs of a multimodal supply chain and Campos & Hernández (2010) examine the operator costs of a new high-speed rail infrastructure in Spain. Concerning the costs of urban transport, insights from Gevaers (2013) and Cárdenas et al. (2015) about B2C last-mile costs per unit and per stop respectively can be used. This information about the private costs can further be complemented by the time and distance cost concept proposed by Blauwens et al. (2002, 2016).

Following Meersman et al. (2010, p. 219), the costs of using rail for urban freight distribution instead of a lorry or van are the rail-related, cargo-handling, cargo-storage and pre- and post-haulage road-related costs. Figure 49 displays the three types of rail transport considered in this research and highlights the main points of difference between them that are leading to different costs and benefits. For all three types of rail transport, it is assumed that road pre-haulage and road post-haulage could be necessary to complement the rail leg. The rail leg reaches from a handling and storage point at the edge of the urban area to a rail stop in the urban centre. The road pre-haulage takes place between one or more suppliers and the handling and storage point at the edge of the urban area, whereas the road post-haulage occurs between the rail stop in the urban area and the customer(s). The difference between the three types shown in Figure 49 is discussed more in depth in the next paragraphs. It can already be seen at first sight that the main difference between a dedicated freight vehicle and a freight wagon attached to a passenger vehicle lies in the rail route that is followed by the goods. The main difference between these two rail types and the transport of freight alongside passengers lies in the post-haulage leg.

In case of a dedicated freight vehicle, where the supplier(s) and customer(s) do not possess a rail connection, the supply chain is organised as follows. The goods are brought to the handling and storage point and are there transferred to the rail vehicle. The dedicated freight vehicle uses the public rail network and follows the shortest path expressed in distance to reach the appropriate rail stop. At the rail stop, the goods are unloaded and transported to the customer(s) by road post-haulage. The post-haulage can be executed in several ways. A shop employee can pick up the goods at the rail stop, a courier accompanying the rail driver can bring the goods to the customer(s), or a cargo bike service, or a light goods vehicle (LGV) can be used.

When a freight wagon is attached to a passenger vehicle in order to bring goods from the supplier(s) to the customer(s), the main difference with a dedicated freight vehicle lies in the rail leg. A freight wagon attached to a passenger vehicle is bound to the passenger vehicle schedule and has to follow the route taken by this vehicle. This route is not necessarily the shortest rail path and therefore, could take more time. Another issue is that one passenger rail line does not cover the full rail network of an urban area, meaning that not all rail stops are reachable by all rail lines. Moreover, the passenger vehicle only stops at official rail stops, causing the issue that the goods may have to be unloaded at quite some distance from the customer(s). The time available for unloading the freight wagon is limited to the time needed for the passengers to get off and on. In general, a passenger tram stops between 17 and 30 seconds at a tram stop. This includes six seconds for the opening of the doors and six seconds for the closing of the doors (Devriendt, 2017a). Depending on the type of rail and on the type of rail stop, a different amount of time is available for unloading the freight wagon. In the remainder of this research, it is assumed that an unloading technology exists that makes it possible to unload the goods in this short timeframe. All cost and benefit calculations that follow in this research use this assumption.

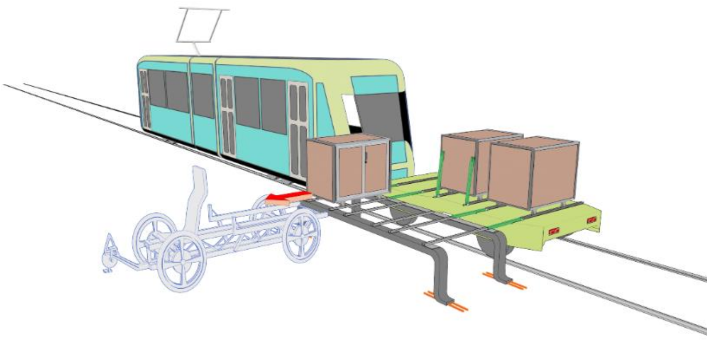
Figure 49 – Rail types and their organisational differences



Source: Own creation

Carette (2018) developed a concept for attaching a freight wagon to a passenger tram. This concept is shown in Figure 50. A low-cost flat wagon is used to transport some freight units. At a passenger tram stop, an unloading platform is installed. The standard units on the wagon have the size of a euro pallet and have wheels at the bottom. On the wagon, rails are added, to make the movement of the freight unit from the wagon to an unloading platform feasible. While passengers are alighting and boarding the tram, the freight units are moved from the flat wagon to the unloading platform. From the unloading platform, the units can for example be transferred to a cargo bike. The bikes are then used to transport the goods within the urban area.

Figure 50 – Freight wagon attached to a passenger tram



Source: Carette (2018)

If freight is transported alongside passengers, the contrast with a dedicated freight vehicle and a freight wagon attached to a passenger vehicle is visible in the rail and post-haulage legs of the supply chain. Small quantities of parcels can be transported alongside passengers. It is assumed that no changes are made to the design of the passenger vehicles for this type of freight transport. In other words, a courier is carrying the parcel(s) in the vehicle. The courier takes the parcels in a backpack on the passenger vehicle at the edge of the urban area, uses the passenger vehicle until the closest stop to the customer(s)'(s) location, and then brings the parcels to the customer(s) by walking. Concerning the rail leg, a lot of differences with a dedicated freight vehicle are present. The courier transports the parcels in a passenger vehicle. This means that the courier has to follow the passenger schedule. As for a freight wagon attached to a passenger vehicle, this means that the transport distance and transport time on the rail network can be longer compared to using a dedicated freight vehicle. The courier can only get out of the vehicle at official stops. With respect to the post-haulage, it is assumed that the courier delivers the parcels at the customer(s) by walking from the stop to the customer(s).

It is clear that the three types of rail transport lead to different investment and operational costs. The route followed by the goods is for instance different for a dedicated freight vehicle and for a passenger vehicle. As a result, the time and distance costs of the rail transport differ among the types of rail transport. Therefore, a distinction between these three types of rail transport is made when analysing the investments (Section 4.1.1) and the operational costs (Section 4.1.2). The effect of the cost and benefit values that are provided in the following sections is evaluated in Chapter 6 by means of sensitivity and scenario analyses.

4.1.1 Investments

Different types of investment relate to line infrastructure, nodal infrastructure and rolling stock. Table 29 shows these three types of investments for the three types of urban rail freight distribution discussed in this research. Firstly, the available line infrastructure towards, away from and within the urban area is a critical variable for the success or failure of a rail-based urban freight project (Comi et al., 2014). Urban areas that do not possess rail infrastructure, face significantly higher infrastructure costs when introducing rail-based transport compared to urban areas in which the rail infrastructure is already present (Centre-Ville en Mouvement, 2013). Important aspects of the line infrastructure are the tracks, including the catenary, and switches. Secondly, in case a combination of rail and road transport is used, at least one additional transfer is needed. This leads to additional nodal infrastructure such as distribution centres and transit platforms. Thirdly, the rolling stock has to be adapted for urban rail freight distribution. For example, passenger vehicles have to be converted before they can be used to transport freight. In some cases, the rolling stock has to be fully acquired (Alessandrini et al., 2012; Dinwoodie, 2006; Nuzzolo & Comi, 2014; Regué & Bristow, 2013).

Table 29 – Investments per type of urban rail freight distribution

Investments	Symbol	Dedicated freight vehicle	Freight wagon attached to passenger vehicle	Freight in passenger vehicle
Line infrastructure	$infra_{line}$			
* Tracks (incl. catenary)	*track*	Yes, if siding needed	/	/
* Switches	*switch*	Yes, if siding needed	/	/
Nodal infrastructure	$infra_{nodal}$			
* Distribution centre (DC)	*dc*	Yes, if chosen	Yes, if chosen	/
* Transit platform	*tp*	Yes, if chosen	Yes, if chosen	/
Rolling stock	*rollingstock*			
* Rail vehicle	*railveh*	Traction unit + wagon	Wagon	/

Source: Own creation based on Alessandrini et al. (2012), Meersman et al. (2006), and Regué & Bristow (2013)

Depending on the type of rail transport, other investments are mandatory. With respect to line infrastructure, investments in tracks and switches are needed if a siding to the existing rail network has to be constructed. When a freight wagon is attached to a passenger vehicle, or freight is transported in a passenger vehicle, no line infrastructure needs to be constructed. Concerning the nodal infrastructure, it is assumed that for a dedicated freight vehicle and for a freight wagon attached to a passenger vehicle, a distribution centre or transit platform may have to be constructed. When a courier takes parcels alongside passengers, it is assumed that no transit platform is needed for handling. A distribution centre may be needed if goods have to be stored at the rail stop. Regarding the rolling stock, a traction unit and wagon are used in case of a dedicated freight vehicle, whereas only a wagon is needed in case of a freight wagon attached to a passenger vehicle. When a courier transports parcels by using rail transport, no rolling stock investment has to be made.

In sum, the total capital investment needed is expressed by Equation (13):

$$investment = \mathrm{infra}_{line} + \mathrm{infra}_{nodal} + rollingstock \tag{13}$$

The next sections explain how the investments in line infrastructure, nodal infrastructure and rolling stock are taken into account in this research.

4.1.1.1 Line infrastructure

Capital investment is sometimes needed in the rail infrastructure, such as sidings to connect to the public rail network (Campos & Hernández, 2010; Gorçun, 2014; Regué & Bristow, 2013). The costs of an infrastructure investment that should be taken into account when doing a cost-benefit analysis are according to Bickel et al. (2006) the capital costs of the infrastructure investment, the residual value, some operations costs with respect to the infrastructure, changes in infrastructure costs on the existing network and optimism bias. The capital costs consist of construction, planning, land and property costs and costs of disruption to the existing users. The user cost of capital has to be taken into account, including amortisation, capital gains, interest and tax advantages. Construction costs include materials, labour, energy, preparation, professional fees and contingencies. Planning costs comprise design costs, planning authority resources and other planning costs. The operations costs related to the infrastructure are administration and maintenance. Due to optimism bias, Bickel et al. (2006) suggest to increase the predicted costs of the rail infrastructure by 34%, since this is the average cost escalation they found for rail infrastructure projects.

The capital cost for tracks and switches, $infra_{line}$, is expressed in Equation (14):

$$\mathrm{infra}_{line} = track + switch \tag{14}$$

In which

track = the length of the rail tracks that has to be constructed for a siding to the rail network, expressed in current metre, multiplied by the unit cost per current metre, expressed in euro;

switch = the cost of the construction of the switches, expressed in euro.

For the capital investment calculation, the life span of the infrastructure is taken into account, as well as the replacement costs and potential residual value. The residual value is derived by linearly amortising the capital investment over the life span of the infrastructure. Furthermore, it is assumed that potential operations costs with respect to the infrastructure, as well as potential changes in the infrastructure costs on the existing network, are incorporated in the track cost. Optimism bias is taken into account in the risk analysis (see Chapter 6).

Available data with respect to the capital investment are presented in Table 30 for trams and trains. The capital investment of constructing a siding to the existing tram infrastructure varies depending on the source between €5,344 per current metre, €10,541 per current metre and €20,845 per current metre. The latter value includes the investment in nodal infrastructure, i.e. a multimodal terminal, as well. This explains why this figure is much higher than the other two figures provided. Switches always have to be constructed in twofold and have a cost of €106,876 per two (Nuytemans & Fierens, 2014b). The track cost of €10,541 per current metre given by Regué & Bristow (2013) includes the cost of switches, which explains why this figure is almost the double of the cost estimated by Nuytemans & Fierens (2014b). In this research, the cost estimation provided by the latter authors is used, making a distinction between the switches and the other investments, since these figures are determined for Flanders. Concerning the capital investment for trains, the cost of tracks is estimated around €3,067 per current metre and the cost of two switches of 30 m amounts to €446,040. The track cost includes the investment in tracks, catenary, track bed works and the recycling of tracks.

Table 30 – Line infrastructure cost values expressed in euro$_{2018}$[21]

Rail type	Variable	Cost	Region	Source
Tram	*track*	5,344 €/current metre	Flanders	Nuytemans & Fierens (2014b)
		10,541 €/current metre	Barcelona	Regué & Bristow (2013)
		20,845 €/current metre[22]	France	Gonzalez-Feliu (2016)
	switch	106,876 €/2 switches[23]	Flanders	Nuytemans & Fierens (2014b)
Train	*track*	3,067 €/current metre	Belgium	Ronda et al. (2011)
	switch	446,040 €/2 switches of 30m	Belgium	Ronda et al. (2011)

Source: Own creation

For a dedicated freight vehicle, three possible ways of loading and unloading can be distinguished among, each of them leading to other siding needs: during the night or very quickly during the day at the public rail network (Figure 51a), on a dedicated track (Figure 51b), or on a siding of the public rail network (Figure 51c). If a dedicated freight vehicle is operational during the night, it can stop and being unloaded and loaded on the public rail network. If this happens during the day, the loading and unloading has to be carried out quickly, in order not to disturb the passenger transport. If the freight is transported during the day and cannot be unloaded and/or loaded quickly, a siding to the public rail network that is not used by the passenger vehicles can be used for loading and unloading. If such a siding is not present, a dedicated track can be constructed for the freight vehicle. In all three cases, the way the goods are loaded and unloaded has to be specified (Devriendt, 2017a).

A freight wagon attached to a passenger vehicle is unloaded on the public rail network and for transporting freight alongside passengers, no sidings are needed. Next to investments in line infrastructure, nodal infrastructure may need to be built. This is discussed in the next section.

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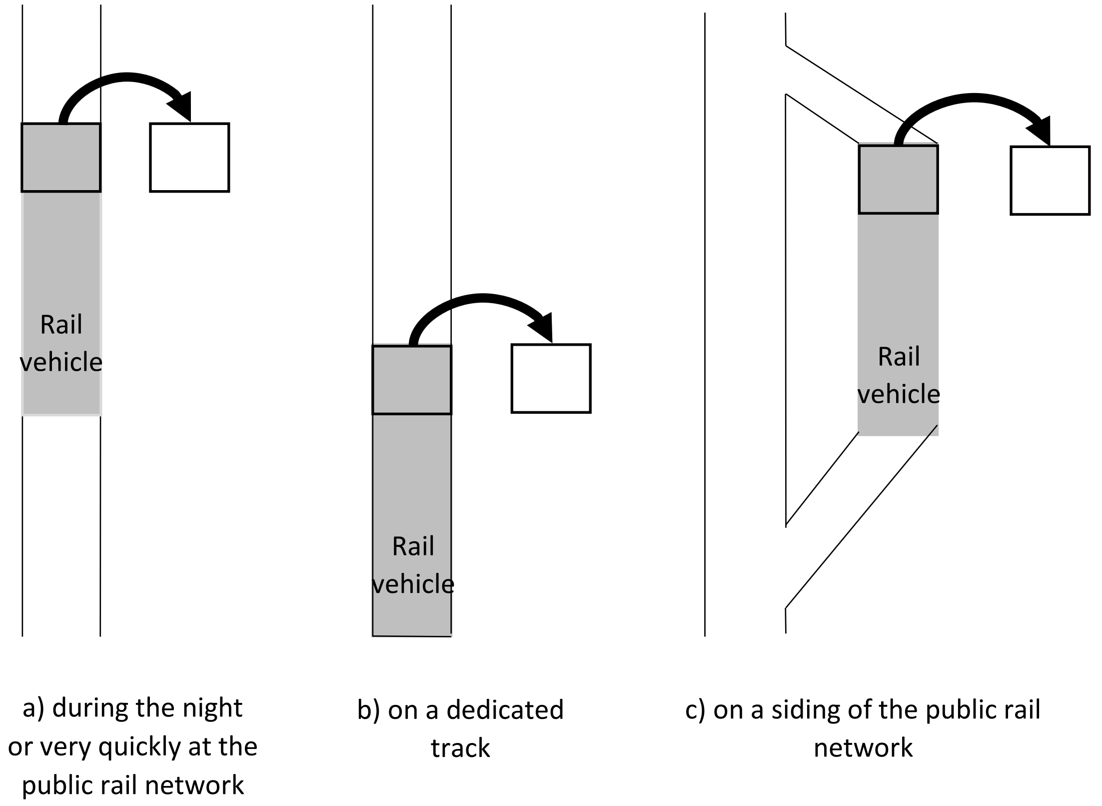
[21] All monetary data in this chapter are discounted to euro$_{2018}$ values by means of Equation (4) in Section 3.2.2.
[22] This figure includes the investment in nodal infrastructure.
[23] Switches are always constructed in pairs.

Figure 51 – Loading and unloading possibilities of a dedicated freight vehicle



Source: Own creation based on Devriendt (2017a)

4.1.1.2 Nodal infrastructure

The second part of the investment when developing a rail-based solution for urban freight distribution, is the construction of nodal infrastructure. If road pre- and/or post-haulage is used in the urban rail freight supply chain, a handling and storage point is needed. The handling and storage space may need some investment in infrastructure. Equation (15) shows how the nodal infrastructure investment cost $infra_{nodal}$ is derived:

$$\text{infra}_{nodal} = \text{infra}_{nodal,pre} + \text{infra}_{nodal,post} \tag{15}$$

in which
$infra_{nodal,pre}$ = the infrastructure investment between the road pre-haulage and the rail leg;
$infra_{nodal,post}$ = the infrastructure investment between the rail and road post-haulage leg.

In order to know the infrastructure investment needed, a subdivision is made by Ayadi (2014) between a distribution centre (*dc*) and a transit platform (*tp*). The main difference is that in a distribution centre, goods can be stored, whereas at a transit platform goods are only moved between the road and rail leg or vice versa. Hence, a distribution centre and transit platform are characterised by other costs.

For each handling and storage point in the urban rail freight supply chain it has to be determined whether the point serves as a transit platform or as a distribution centre. For each used rail stop too, it has to be indicated whether it functions as a transit platform or as a distribution centre. In case transit platforms are used, the life span of the transit platform(s) has to be estimated. In the figures provided by Ayadi (2014), the construction cost of a distribution centre is added in the operational cost of using a distribution centre. Hence, only the construction costs of a transit platform are taken into account as investment cost.

Table 31 gives an overview of the construction cost of a transit platform for different types of retail products. A division is made between cooled, frozen, non-cooled food, and non-food retail products. The figures in Table 31 are derived for urban freight distribution in the neighbourhood of Lyon (France) based on interviews with a real estate company selling commercial real estate.

Table 31 – Construction cost of a transit platform for urban freight distribution in France

Product type	Construction cost (€$_{2018}$/m²)
Cooled retail products	596
Frozen retail products	651
Non-cooled food retail products	488
Non-food retail products	434

Source: Ayadi (2014)

The capital handling costs $infra_{nodal,pre}$ for the nodal infrastructure between the road pre-haulage and the rail leg are expressed by Equation (16):

$$\text{infra}_{nodal,pre} = \beta * \sum_{m=1}^{4} (tp_{const,m} * pallets_{tp,m} * surf_m) \qquad \forall\ 0<m\leq 4 \text{ and } \beta\{0,1\} \qquad (16)$$

In which

β = a dummy variable indicating the use of road pre-haulage (*β*=1 if pre-haulage is used, *β*=0 if no pre-haulage is used);

$tp_{const,m}$ = the construction cost of a transit platform for product type m (1≤m≤4), being cooled or frozen products, non-cooled food, or non-food, expressed in euro per m²;

$pallets_{tp,m}$ = the number of pallets of product type m passing by the transit platform;

$surf_m$ = the surface of one pallet of product type *m*, expressed in m² per pallet.

Likewise, the capital handling cost of the nodal infrastructure between the rail leg and the post-haulage leg is calculated. Equation (17) shows how this capital cost is derived:

$$\text{infra}_{nodal,post} = \sum_{q=1}^{4} (\gamma_q) * \sum_{m=1}^{4} (tp_{const,m} * pallets_{tp,m} * surf_m) \qquad \forall\ 0<q\leq 4,\ 0<m\leq 4 \text{ and } \gamma_q\{0,1\} \qquad (17)$$

In which

γ_q = a dummy variable indicating the use of road post-haulage, with q the type of post-haulage used, being a pick-up by the shop employee (γ_1=1), a delivery by a walking courier (γ_2=1), a delivery by cargo bike (γ_3=1), and the use of an LGV (γ_4=1).

The investment in line and nodal infrastructure is explained. The last investment needed, is the one in rolling stock. This is the subject of the following section.

4.1.1.3 Rolling stock

The rolling stock needed depends on the type of rail transport used, being on the one hand a tram or a train and on the other hand, a dedicated freight vehicle, a freight wagon attached to a passenger vehicle, or a courier transporting parcels alongside passengers. In the latter case, no rolling stock investment is needed. Therefore, this section focuses on the use of a dedicated freight vehicle or a freight wagon. No capital investment costs for the road legs are considered. Road transport is used in the reference case and hence, it is assumed that there is no additional road investment needed for the rail-based project case. In other words, the investment in road vehicles is considered to be a sunk cost in the reference and project case. When applying the model to a certain case study in which investments in road vehicles have to be made either in the reference or in the project case, the investment cost can be added to the model. When the same investment is needed in the reference and in the project case, this cost does not have to be added to the model, since only cost differences between the reference and project case have to be taken into account. The cost of the rail rolling stock is derived in Equation (18):

$$rollingstock = number_{railveh} * railveh \tag{18}$$

In which

$number_{railveh}$ = the number of rail vehicles needed to meet the demand;

railveh = the cost of a rail vehicle in euro.

The rail vehicle in Equation (18) can be a dedicated freight vehicle, or a freight wagon. The number of rail vehicles needed depends on the one hand on the total time needed to execute the daily rail trips and handling activities and on the other hand on the daily amount of goods to be delivered.

Table 32 provides an overview of rolling stock costs for trams and trains. The cost of a tram varies between €2,000 (PCC tram) and €3,076,952 (new passenger tram of 43 m). It is clear that new passenger trams are more expensive than a second-hand tram, or the combination of a traction unit and a flat wagon. Therefore, in this research, the cost of a PCC tram as a traction unit and a flat wagon to transport the goods is used as the rolling stock investment needed. With respect to trains, the purchase as well as the leasing cost of a locomotive and the leasing cost of a wagon are shown in Table 32. In the rail industry, it is common to lease locomotives and wagons. As shown in Table 32, this results in a daily cost. Hence, in this research, no capital investment costs for light rail are considered. The leasing cost is added to the operational cost, which is discussed in Section 4.1.2.

Table 32 – Rolling stock costs

Rail type	Vehicle type	Cost (€$_{2018}$)	Region	Source
Tram	PCC tram	€2,000	Flanders	Fierens et al. (2019)
	Waste tram	€21,686	Zurich	Marinov et al. (2013)
	Traction unit	€510,274	Flanders	Fierens et al. (2019)
	Flat wagon	€510,274	Flanders	Devriendt (2017a), Fierens et al. (2019)
	Second-hand tram	€965,153	France	Centre-Ville en Mouvement (2013)
	Traction unit + flat wagon	€1,020,548	Flanders	Devriendt (2017a)
	Freight tram	€1,563,405	France	Gonzalez-Feliu (2016)
	Freight tram	€2,123,548	Barcelona	Regué & Bristow (2013)
	New passenger tram 32m	€2,250,308	Flanders	Devriendt (2017a)
	New passenger tram 43m	€3,076,952	Flanders	Devriendt (2017a)
Train	Diesel locomotive	€2,902,182	Belgium	Delhaye et al. (2017)
	Electric locomotive	€3,834,184	Belgium	Delhaye et al. (2017)
	Leasing locomotive	2,085 €/day	Belgium	Gemels & Vander Stichele (2016)
	Leasing wagon	24.62 €/day	Belgium	Delhaye et al. (2017)
	Leasing wagon	35.72 €/day	Belgium	Vander Stichele (2017)

Source: Own creation

For transport by train, existing freight wagons can be leased. For tram transport this is not the case, since freight trams are currently not a common transport means in Europe. Therefore, the rolling stock for urban freight transport by tram needs more explanation.

Firstly, a dedicated freight tram can be chosen. When a new freight tram is purchased, it needs to be parked in the workshops of the tram operator at the moment when it is not operating. Anno 2019, the tram workshops in Flanders are becoming saturated, which may lead to additional costs. On the other hand, it is possible to use a second-hand passenger vehicle for this type of transport. However, this may have some organisational and technical consequences. From an organisational viewpoint, the passenger vehicles of tram operators are often all needed to meet the growing passenger transport demand. As a solution, second-hand vehicles could be purchased from a rail operator in another country. This may lead to some technical issues. Attention has to be paid for example to the gauge, voltage and vehicle length. On the tram network of Antwerp for instance, the gauge is 2.30 m and the maximum length of the trams is 30 m on most lines and 45 m on some lines (Fierens & Nuytemans, 2014).

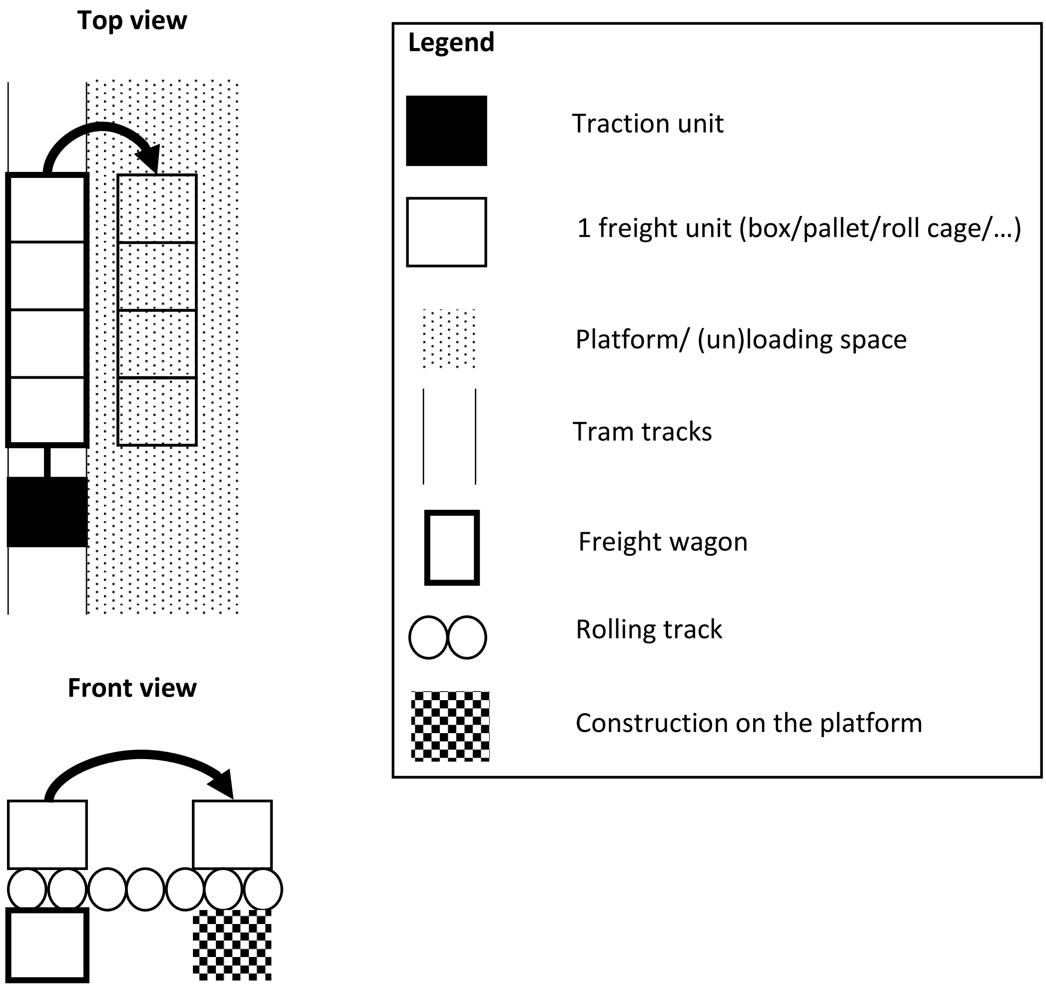
If a passenger vehicle is used for the transport of freight, some other issues have to be considered next to the gauge, voltage and vehicle length. A passenger vehicle has for instance seats inside. This makes the transport of freight more difficult, since the available space in the vehicle cannot be used in an optimal way. Moreover, a concept has to be developed to fix the freight units, for example pallets or roll cages, in the tram, as to prevent them from moving. The inside of the passenger tram may be damaged if goods instead of passengers are transported. This means that the vehicle cannot be used to transport passengers any longer. Hence, the passenger tram has to be transformed into a dedicated freight tram. This brings about high costs (Devriendt, 2017a).

Another important issue is the height of the floor of the freight tram. If the floor is low and thus, close to the ground, it is easier to put roll cages into the tram. This is what happened with the Ultra Low Floor (ULF) freight tram of Siemens that was tested in Vienna in the late 1990s. This tram had a floor of 18 cm high. This height made it easier for the roll cages to be put in the tram (Kortschak, 1995). In Flanders, most of the trams have a floor with a height of 35-36 cm. This makes it more difficult to quickly move roll cages into the tram. Furthermore, the available trams in Flanders that are not used by De Lijn any longer, i.e. the PCC trams, are characterised by a high maintenance cost. In addition, less and less technicians have the knowledge to work on this type of trams, since the trams are running out of operation for the passenger transport (Devriendt, 2017a). If very old trams are used, such as the trams currently used for tourist purposes at the Belgian seaside, an additional problem arises: the safety systems of those trams are not adapted to the current safety standards (Deduytsche, 2017a).

Given the organisational and technical issues related to the use of a passenger vehicle, the concept of freight trains could be applied on the tram network, being the use of a traction unit and a wagon behind it. The main advantage of such a combination of traction unit and wagon is that a concept could be worked out which allows a fast handling of the freight units. (Devriendt, 2017a). Figure 52 shows how freight units on the freight wagon can be quickly unloaded. The upper part of Figure 52 shows the top view, whereas the lower part of this figure displays the front view. The concept works as follows. The traction unit stops at a tram stop. The freight units on the freight wagon, i.e. the boxes, pallets or roll cages, are led to the platform by means of a rolling track. This type of handling can happen in a very short period of time, allowing freight trams to operate in between the passenger trams without disturbing them (Deduytsche, 2017a; Devriendt, 2017a). Bombardier sometimes conducts a test ride on the Flemish tram network and the conclusion is that it is possible to insert an additional tram on the network, but the tram has to proceed quickly (Devriendt, 2017a). Next to the organisational advantage, the relatively low cost of this type of construction is an important asset (Devriendt, 2017a).

Hence, different formations of dedicated freight trams are possible. Table 33 gives an overview of the different options, making a distinction between a PCC tram, a new passenger tram of 32 m length (consisting of five units), a new passenger tram of 43 m length (consisting of seven units), and a flat wagon. For these four types of rolling stock, several characteristics are displayed.

Figure 52 – Unloading concept of a freight wagon



Source: Own creation based on Devriendt (2017a)

The initial investment cost of a passenger tram and a flat wagon is indicated. This cost is highly dependent on the type of tram. A new passenger tram of 32 m costs €2.25 million, whereas a new passenger tram of 43 m has a price tag of €3.08 million (Devriendt, 2017a). The prices mentioned here account for fully equipped passenger trams. Part of the design inside the tram, such as the seats, is not needed to transport freight. As a result, a cost reduction of €30,000 and €35,000 can be given for a 32 m long tram and for a 43 m long tram respectively. This cost reduction includes the placing of hooks to attach the freight in the tram. In order to make loading and unloading more convenient, the tram doors could be replaced by manual roll down shutters. The additional price of these manual shutters is €35,000 for a 32 m tram and €50,000 for a 43 m tram. The cost reduction and the additional price for the shutters only include production and material costs. Administrative and study costs still have to be added on top of this (Deduytsche, 2017b). An old PCC tram that is no longer used for passenger transport has a scrap value of around €2,000. This type of tram could be used as a cheap traction unit for a freight wagon (Devriendt, 2017a; Fierens et al., 2019).

The life span of a passenger tram is on average between 30 and 40 years (Deduytsche, 2017a; Devriendt, 2017a). When the tram is taken out of service for the passenger transport, it can still be used for freight transport for another 15 years (Deduytsche, 2017a).

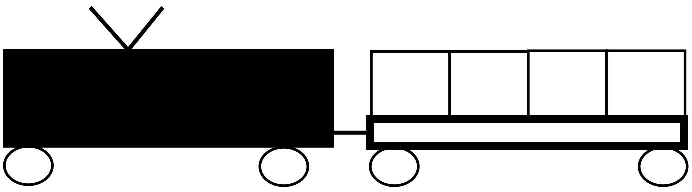
Table 33 – Characteristics of passenger trams in Antwerp (figures for 2018)

Characteristics	PCC tram	Tram 32m	Tram 43m	Flat wagon
Investment cost (in 1000 euro)	2	2,250	3,080	510
Cost reduction if no seats (in euro)	n/a	30,000	35,000	0
Cost of roll down shutter (in euro)	n/a	35,000	50,000	0
Life span passenger tram (in years)	0	30-40	30-40	0
Additional life span tram for freight transport (in years)	15	15	15	30
Dimensions (length * width in m)	11*2.2	25*2.3	36*2.3	11*2.3
Number of axles	2	6	8	2
Maximum load (in tonnes)	/	16	24	16

Source: Own creation based on Deduytsche (2017a), Deduytsche (2017b) and Devriendt (2017a)

The maximum axle load of a tram is between 10.5 tonnes (Flanders) and 12 tonnes (Brussels). A distinction has to be made between the types of tram used. Trams with a length of 43 m possess eight axles and therefore, can carry up to 84 tonnes gross weight. If an average tare weight of the tram vehicle is subtracted, a maximum load of 24 tonnes of passengers and/or freight is left (Devriendt, 2017a). Trams of 32 m in length possess six axles and can therefore carry 16 tonnes of passengers and/or goods (MIVB, 2017). In case a traction unit and freight wagon are used to transport the goods, the maximum load can be calculated. Figure 53 displays the traction unit and freight wagon concept. It is assumed that the flat freight wagon has a tare weight of five tonnes and possesses two axles. In this case, the maximum load capacity of the freight wagon is calculated as 2*10.5 tonnes – 5 tonnes = 16 tonnes (Devriendt, 2017a).

Figure 53 – Traction unit with freight wagon loaded with freight units



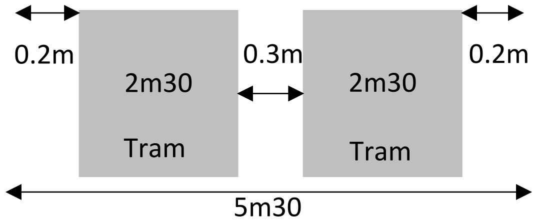
Source: Own creation

Next to the maximum load, the maximum length of the freight wagon needs to be determined. The profile of free space determines with which maximum length the freight wagon can take curves without colliding with another tram in the curve. In Flanders, the maximum length of the freight wagon is limited to 11 m. This is for example also the length of a PCC tram (Devriendt, 2017a).

Moreover, two trams passing each other need to have a certain minimum distance in between in order not to collide. A tram is characterised by a width of 2 m30 in Flanders. To pass another tram, a distance of 30 cm has to be available in between the trams. At the side, a free space of 20 cm is needed. In total, a street width of 5 m30 is needed for two trams to pass one another. This is shown in Figure 54. The free space needed by a tram is less than the space needed to have two buses passing, which equals 7 m80 (2 m40 for each bus, 1 m in between and 1 m at the pavement side) (Devriendt, 2017a).

Secondly, a freight wagon can be attached to a passenger tram. In this case, only a freight wagon has to be purchased, since the passenger tram serves as the traction unit. If some passenger trams are operating at a low utilisation rate at certain times of the day, (part of) these passenger trams could also be used as “freight wagon”. In the latter case, no rolling stock investment is needed to transport freight. However, when using the passenger trams as such for freight distribution, the freight still has to be fixed in the trams. Moreover, putting the goods in the passenger trams is more complicated than putting them on a freight wagon, given the small doors of the passenger trams. The main problem will be that the goods have to be loaded in the passenger tram within a maximum of 30 seconds. This requires more sophisticated technology advancements compared to the ones needed to load a freight wagon within 30 seconds. Thus, it is assumed in the remainder of this research that freight is loaded on a freight wagon and not in a passenger tram.

Figure 54 – Space utilisation of a tram



Source: Own creation based on Devriendt (2017a)

4.1.1.4 Intermediate conclusion

The capital investment when introducing an urban rail freight solution, consists of three main parts: line infrastructure, nodal infrastructure and rolling stock. Depending on the type of rail, other investment costs play an important role. Table 34 provides an overview of all investment cost components and values derived in this section. It is clear that for a dedicated freight vehicle, most investment is needed, whereas no investment is needed for transporting freight in a passenger vehicle. With respect to trains, no capital investment costs are taken into account for the rolling stock, since it is assumed that all rolling stock is leased, leading to an increase of the operational cost.

Table 34 – Rail investment costs in Flanders – non-food retail products (values for 2018)

	Dedicated freight vehicle	Freight wagon attached to passenger vehicle	Freight in passenger vehicle
Line infrastructure tram			
* Tracks (incl. catenary)	5,344 €/current metre	€0	€0
* Switches	106,876 €/2 switches	€0	€0
Line infrastructure train			
* Tracks (incl. catenary)	3,067 €/current metre	€0	€0
* Switches	446,040 €/2 switches of 30m	€0	€0
Nodal infrastructure			
* Pre-haulage	$\sum_{m=1}^{4}(tp_{const,m} * pallets_{tp,m} * surf_m)$		€0
* Post-haulage	$\sum_{q=1}^{4}(\gamma_q) * \sum_{m=1}^{4}(tp_{const,m} * pallets_{tp,m} * surf_m)$		€0
Rolling stock tram			
* Rail vehicle	€512,274 * $number_{railveh}$	€510,274*$number_{railveh}$	€0

Source: Own creation based on Ayadi (2014), Devriendt (2017a), Gemels & Vander Stichele (2016), Nuytemans & Fierens (2014b), and Ronda et al. (2011)

Now that all needed line and nodal infrastructure and rolling stock is provided, the operations can start. The costs related to the operations are discussed in the next section.

4.1.2 Operational costs

The operational costs comprise the costs of operating the rail vehicle, the road pre- and/or post-haulage, and the handling and storage point where the goods are moved from a lorry or van to a rail vehicle or vice versa. The operational costs include energy, fees to third parties, insurance, maintenance, staff and taxes. The energy costs depend on the energy consumption and the energy price (Gorçun, 2014; Regué & Bristow, 2013). The personnel cost is another factor that influences the total operational cost. Different types of handling include extra (un)loading operations that take place due to at least one additional transfer that is associated with using rail transport (Alessandrini et al., 2012; Dinwoodie, 2006; Nuzzolo & Comi, 2014; Regué & Bristow, 2013). A yearly insurance premium also contributes to the costs (Alessandrini et al., 2012; Blauwens et al., 2016) and maintenance of the infrastructure and rolling stock is needed (Campos & Hernández, 2010; Mizutani, 2004).

Table 35 shows the operational costs of each supply chain leg for the three different types of urban rail freight distribution. The operational costs of these legs are divided in time and distance costs. Time costs are related to the duration of the activity, while distance costs are related to the distance covered. Examples of time costs are annual insurance fees and wages of the personnel. Examples of distance costs are fuel consumption, damage liabilities, maintenance costs, road pricing fees and track access charges. Some costs are difficult to add to the category of time or distance costs. Therefore, these costs form a third rest category. Examples of this category are commissions, depreciation and tolls that are not distance-related (Blauwens et al., 2002, 2016). This logic of dividing the costs in three categories is for example followed by Ayadi (2014). In Table 35, only time and distance costs are considered, since it is assumed that for the project case in this research, all costs and benefits can be related to time and distance. With respect to handling and storage, logistics costs are taken into account, including arrival and departure of goods, order processing and storing costs. It is assumed that non-food retail products are transported, so no cold chain costs are added to the operational costs of the transport legs.

Table 35 – Operational costs for each supply chain leg per type of urban rail freight distribution

Operational costs	Symbol	Dedicated freight vehicle	Freight wagon attached to passenger vehicle	Freight in passenger vehicle
Rail	$operation_{rail}$			
* Time	$tcost_{rail}$	Rail driver + courier	Courier	Courier (annual rail ticket)
* Distance	$dcost_{rail}$	Shortest rail path + access charges	Passenger rail path	Passenger rail path
Road pre-haulage	$operation_{pre}$			
* Time	$tcost_{pre}$	Driver		
* Distance	$dcost_{pre}$	Van, road pricing		
Road post-haulage	$operation_{post}$			
* Time	$tcost_{post}$	Four post-haulage possibilities		Courier delivers goods by walking
* Distance	$dcost_{post}$			
Handling & storage	$operation_{handling}$			
* Pre-haulage	$operation_{handling,pre}$	Handling time freight vehicle	Handling time freight wagon	Handling time negligible
* Post-haulage	$operation_{handling,post}$			

Source : Own creation based on Meersman et al. (2006), Alessandrini et al. (2012) and Regué and Bristow (2013)

Operational cost differences are present between the three rail types for each supply chain leg. Concerning the rail leg, a rail driver and a courier are involved when transporting goods by a dedicated freight vehicle, whereas for a freight wagon attached to a passenger vehicle and for transporting freight in a passenger vehicle, the rail driver is already present for the passenger transport. Hence, only the operational cost of a courier has to be assigned to the freight transport. With respect to the distance costs, the dedicated freight vehicle covers the shortest rail path possible and pays rail access charges to the rail infrastructure manager. For a freight wagon attached to a passenger vehicle and the transport of freight alongside passengers, no additional traction is used and hence, no rail access charges have to be paid (Fierens et al., 2019). The path followed is the one of the passenger vehicle, which may be longer than the shortest rail path.

The costs of road pre-haulage are similar for the three rail types and consist of the labour costs of the driver and distance-related costs of the lorry or van. The road post-haulage costs also consist of time and distance costs. The cost difference between the three rail types comes from the way the road post-haulage is carried out. When a dedicated freight vehicle or freight wagon is used, post-haulage can be done by the courier in the rail vehicle, a shop employee, a cargo bike service, or an LGV service. Depending on the choice for a certain post-haulage mode, other operational costs are present. In case of a freight wagon attached to a passenger vehicle, the courier doing the post-haulage is not on board of the vehicle, but picks up the goods at the rail stop. When freight is transported alongside passengers, is it assumed that the post-haulage leg is always executed by the courier.

The operational costs of the handling and storage are mainly determined by the handling time of the dedicated freight vehicle and the freight wagon. In case of the transport of parcels alongside passengers, no additional handling time is assumed.

In sum, the total operational cost, $operation_{total}$, is derived by summing $operation_{rail}$, $operation_{pre}$, $operation_{post}$, and $operation_{handling}$. This is summarised by Equation (19):

$$operation_{total} = operation_{rail} + operation_{pre} + operation_{post} + operation_{handling} \tag{19}$$

The operational costs are present in all legs of the urban freight supply chain, being the rail, road pre-haulage, road post-haulage and handling and storage leg. By adding all the operational costs in Equation (19) for all legs of the supply chain, the total operational cost of using rail for urban freight distribution can be determined. The calculation of the operational cost of the different supply chain legs is discussed more in depth in the next sections.

4.1.2.1 Rail

The rail operational cost $operation_{rail}$ is the sum of the distance cost of the rail transport $dcost_{rail}$ and the time cost of the rail transport $tcost_{rail}$. This cost is shown in Equation (20):

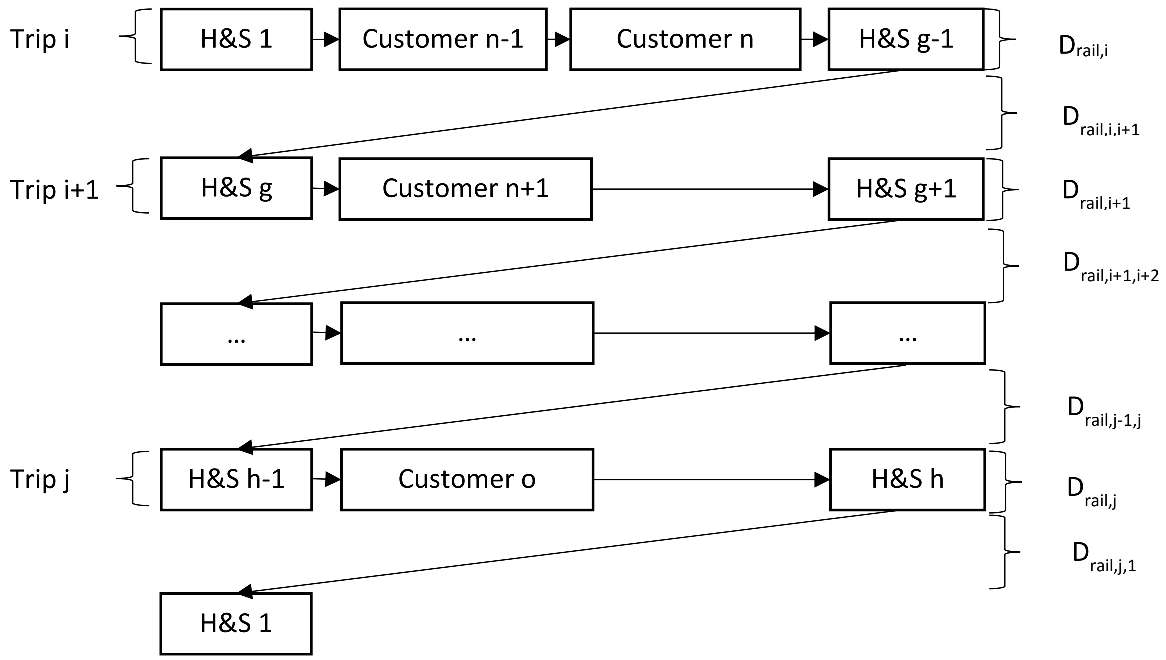
$$operation_{rail} = \mathrm{dcost}_{rail} + t\mathrm{cost}_{rail} \tag{20}$$

Hence, in order to know the operational cost of the rail leg, the distance and time cost of the rail transport have to be determined. Firstly, the distance cost $dcost_{rail}$ is derived. This cost depends on the total distance covered by rail (D_{rail}), expressed in kilometres, and the unit cost per distance (d_{rail}), expressed in euro per kilometre. This relation is shown in Equation (21):

$$\mathrm{dcost}_{rail} = D_{rail} * d_{rail} \tag{21}$$

In order to know the distance cost, the total distance covered and the unit cost per kilometre need to be determined. Figure 55 shows the distance covered if two rail trips, trip i and trip i+1 ($0<i\leq j$ and $j>0$), are executed. In rail trip i, goods are transported from handling and storage point H&S 1 to customer n-1 and customer n ($0<n\leq o$ and $o>0$). The rail trip ends at handling and storage point H&S g-1 ($0<g\leq h$ and $h>0$) and covers a distance $D_{rail,i}$. The rail vehicle can now be repositioned to handling and storage point H&S g over a distance $D_{rail,i,i+1}$. From this point, rail trip i+1 is carried out and goods are delivered at customer n+1. The rail trip ends in handling and storage point H&S g+1, covering a distance $D_{rail,i+1}$. All following rail trips are carried out in the same way, including the last rail trip of the day, trip j. From the last handling and storage point h where the vehicle stops that day, the vehicle needs to be repositioned again, covering a distance $D_{rail,j,1}$, to the starting point of the first rail trip of the next day, in Figure 55 equal to the starting point of trip i.

Figure 55 – Total rail distance covered in all rail trips



Source: Own creation

Thus, the total daily distance covered by rail D_{rail} is calculated by summing up the total distance of all rail trips i ($D_{rail,i}$), the distance between the rail trips ($D_{rail,i,i+1}$) and the distance between the last handling and storage point of the day and the first one of the next day ($D_{rail,j,1}$). This is expressed by Equation (22):

$$D_{rail} = \sum_{i=1}^{j} (D_{rail,i} + D_{rail,i,i+1} + D_{rail,j,1}) \qquad \forall\ 0<i\leq j \text{ and } j>0 \qquad (22)$$

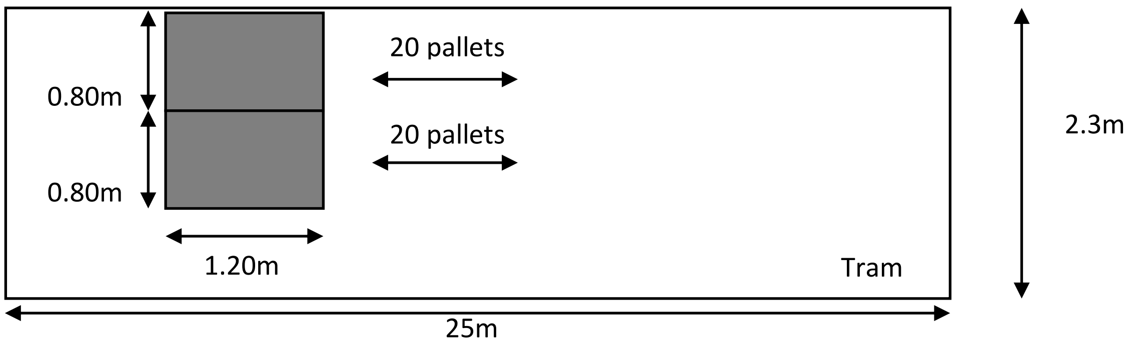
Depending on the amount of goods transported on a daily basis, it is possible that a certain rail trip i needs to be executed more than once. The number of rail trips needed to deliver the daily amount for a certain rail tip i depends on some technical ($railtrips_{technical}$) and organisational ($railtrips_{organisational}$) characteristics. With respect to the technical features, the capacity of the rail vehicle restricts the maximum load that can be transported in one rail trip. This capacity is determined by weight and volume limitations related to the rail type chosen. These restrictions are different for a dedicated freight vehicle, freight wagon and a backpack of a courier.

Concerning the weight-related limitations, the weight of the total daily amount of goods to be transported and the maximum loading capacity of the freight vehicle, freight wagon or backpack have to be compared in terms of weight. If the total daily amount, measured in kilogram, is lower than or equal to the net rail vehicle/wagon/backpack capacity, only one rail trip is needed to deliver all goods at all customers. If the amount in kilogram exceeds the net rail vehicle/wagon/backpack capacity, multiple rail trips are needed. The total daily amount in terms of weight is counted by summing up the amount required by all customers expressed in kilogram.

With respect to the volume, the total daily amount of goods to be transported needs to be compared with the capacity of the rail vehicle/wagon/backpack expressed in volume. In case the total amount, measured in volume, is smaller than the maximum volume that can be placed in one rail vehicle/wagon/backpack, one rail trip is needed. In case the total volume is larger than the rail vehicle/wagon/backpack volume, multiple rail trips have to take place in order to deliver all goods to all customers. Peak load pricing could be used here as a mechanism to obtain a desired division of the demand over different rail trips from an organisational perspective.

In order to determine the maximum amount of transport units a rail vehicle can transport, the dimensions of the rail vehicle and of the freight units are compared. Figure 56 shows this comparison for a dedicated freight tram and euro pallets as freight units. These pallets have a length of 1.20 m and a width of 0.80 m and account for 0.4 loading metre. The tram in Figure 56 is considered to have a loading surface of 2.3 m times 25 m. This has as a result that in a tram with these dimensions, maximum 40 euro pallets, or other transport units with similar dimensions such as roll cages, can be transported.

Figure 56 – Lay-out of the load in a tram of 25m length and 2.3m width



Source: Own creation

Hence, the number of rail trips needed from a technical point of view, is the maximum value of the rail trips needed due to the weight and the rail trips needed due to the volume restrictions. This is expressed by Equation (23):

$$railtrips_{technical} = \max(railtrips_{weight}, railtrips_{volume}) \tag{23}$$

However, in order to assign the number of rail trips needed correctly, some organisational aspects have to be taken into account as well. A selection has to be made of the handling and storage points and the rail stops the supplier(s) and retailer(s) want to use. Depending on this choice, the number of rail trips from an organisational viewpoint $railtrips_{organisational}$ can be different from the number of rail trips needed from a purely technical perspective. Based on the combination of $railtrips_{technical}$ and $railtrips_{organisational}$, the number of rail trips to be carried out is given by Equation (24):

$$railtrips = \max(railtrips_{technical}, railtrips_{organisational}) \tag{24}$$

The second variable that needs to be quantified in order to know the distance cost of the rail leg in Equation (21) is the unit cost per distance, d_{rail}. This cost includes all costs related to the distance covered, such as track access charges, maintenance and energy. Table 36 provides some distance cost figures for rail freight distribution by means of a dedicated rail vehicle. The operational cost of a freight tram lies between 10.01 €/tramkm and 11.24 €/tramkm. In this research, the value of 10.01 €/tramkm is used, since Fierens et al. (2019) indicated that the cost of 11.24 €/tramkm is too high. It has to be added there that the cost of 10.01 €/tramkm includes the time costs of the tram driver. The operational cost of a freight train lies between 4.01 €/trainkm and 36.02 €/trainkm. The large difference between these two figures can be explained by the fact that Sartori et al. (2015) take into account only operational costs such as energy and maintenance, whereas the other sources provide the full operational cost of a train. This full operational cost includes the leasing cost of a locomotive, insurance, administration, overhead, an operating margin, energy, access charges and personnel costs. Depending on whether the transport takes place over a long or a short distance, a cost between 15.81 €/trainkm and 20.41 €/trainkm (lower boundary) respectively is found for Belgium.

The distance unit costs of a freight wagon attached to a passenger vehicle can be estimated to be much lower, since no separate traction is provided for the freight transport. It is assumed that half of the cost per distance unit is related to the driver's labour cost and the other half to the actual costs of covering distance. Next, the assumption is made that for a freight wagon, the costs related to moving are half of the costs of a dedicated freight tram. Hence, a cost of ¼*10.01€/tramkm remains. For a train, these costs are proxied here by the daily leasing costs of a wagon. The distance cost of transporting freight in a passenger vehicle are assumed to be zero.

Table 36 – Distance unit costs for dedicated rail vehicles

Rail type	Component	Cost (€2018)	Region	Source
Tram	Operations	10.01 €/tramkm	France	Gonzalez-Feliu (2016)
		11.24 €/tramkm	Barcelona	Regué & Bristow (2013)
Train	Operations	4.01 €/trainkm	Europe	Sartori et al. (2015)
		15.81 €/trainkm	Belgium-Germany	Dillen (2019)
		≥20.41 €/trainkm	Belgium	Vander Stichele (2017)
		36.02 €/trainkm	Belgium	Rebel (2013)
	Access	2.50 €/trainkm	Belgium	Delhaye et al. (2017) and Dillen (2019)
	charges	3.52 €/trainkm	Europe	Sartori et al. (2015)

Source: Own creation

Next to financing the operations, a rail operator has to pay rail access charges to the rail infrastructure manager. For tram transport, no such charges exist in Belgium anno 2019, since the infrastructure manager is the same body as the tram operator. Therefore, average freight train access charges are taken as a proxy for the tram access charges. For Belgium, an average value of 2.50 €/trainkm is proposed by Delhaye et al. (2017) and Dillen (2019). Access charges to make use of the public rail network have to be paid for the dedicated freight vehicle. On the contrary, no access charges have to be paid for transporting freight in a wagon attached to a passenger vehicle, or for moving freight in a passenger vehicle.

After having determined the total rail distance covered and the cost per distance unit, the total distance cost can be calculated. The next component to obtain the total operational cost of the rail leg is the time cost. This cost can be estimated analogously to the distance cost, by multiplying the total rail time and the cost per time unit. This is shown in Equation (25):

$$\text{tcost}_{rail} = \sum_{i=1}^{j}\Big(U_{rail,i} * \big(\iota_i * u_{rail,day} + (1-\iota_i) * (u_{rail,night})\big)\Big) + (1-\iota) * 3 * u_{rail,dispatch}) \qquad \forall\ 0<i\leq j,\ j>0,\ \text{and}\ \iota\{0,1\} \tag{25}$$

In which

ι_i	= a dummy variable to control for the timing of the rail transport; ι_i=0 if rail trip i takes place during the night and ι_i=1 if rail trip i is executed during the day;
U_{rail}	= the total rail time expressed in hours;
$u_{rail,\ day}$	= the cost of rail transport per time unit if the transport occurs during the day, expressed in euro per hour;

$u_{rail,\ night}$ = the cost of rail transport per time unit if the transport occurs during the night, expressed in euro per hour;

$3*u_{rail,\ dispatch}$ = the cost of opening the dispatch centre during the night for tram transport. It is assumed that the dispatch centre is closed between 1.30 am and 4.30 am and hence, it has to be opened for three additional hours when transport is taking place during the night. For trains, this term equals zero.

Hence, in order to estimate the time cost of the rail leg, the total rail time and the cost per time unit have to be determined. The total rail time for each rail trip i ($U_{rail,i}$) is derived by dividing the total rail distance by the average speed in kilometre per hour of the rail vehicle ($speed_{rail}$). The total rail time U_{rail} for each rail trip i is derived by Equation (26):

$$U_{rail,i} = \sum_{i=1}^{j} \frac{D_{rail,i} + D_{rail,i,i+1} + D_{rail,j,1}}{speed_{rail}} \qquad \forall\ 0<i\leq j \text{ and } j>0 \qquad (26)$$

The average speed of the rail transport depends on the type of rail transport. For tram transport, a difference has to be made between trams having their own right of way and trams sharing the way with road traffic. According to Devriendt (2017a) and Fierens et al. (2019), trams in Antwerp having their own right of way have an average speed of 18 km/h, whereas trams sharing the way with the road traffic are characterised by an average speed of 15 km/h. Time losses during peak hours are difficult to predict. Therefore, the tram company De Lijn uses the same average speed for transport during peak and off-peak hours. Peak hour on the tram network is considered to be between 7 am and 9 am and between 4 pm and 7 pm. Freight trams would be operational in following-mode between passenger trams and thus, it can be assumed that they would be running at the same average speed as the passenger trams. Given the distance cost used in this research, which includes the time costs of the tram driver, only the time costs of the courier accompanying the goods need to be added to the distance costs.

The average speed of freight trains is following Delhaye et al. (2017) equal to 50 km/h, based on B Logistics (now called Lineas), whereas Daubresse et al. (2019) indicate an average speed of 30km/h for freight trains operating in Belgium. The capacity of the train network depends on many factors, such as the location on the network, the number of tracks, the number of stops, trains blocking other trains and the type of trains on the network. On a rail segment with two tracks, without curves and with trains all having the same speed, the capacity is equal to 20 trains per hour. This means that a time span of three minutes is available between two consecutive trains (Gusbin & Hoornaert, 2016). In this research, the time costs are already incorporated in the distance cost figures provided in Table 36. Hence, no separate time costs are added to this figure with respect to the train driver.

Next to the rail travel time, the average waiting time for a courier at a rail stop before a passenger vehicle arrives has to be estimated in case goods are transported alongside passengers. On the tram network in Antwerp, an average waiting time of five minutes is assumed, since on a weekday, there are on average 9.15 minutes between two consecutive trams passing a tram stop. For trains, this depends much more on the rail line used.

The last component to estimate the time costs of the rail leg, is the cost per time unit for day ($u_{rail,day}$) and night transport ($u_{rail,night}$). The staff operating the rail vehicle is an important cost component (Alessandrini et al., 2012; Blauwens et al., 2016; Campos & Hernández, 2010; Mizutani, 2004; Regué & Bristow, 2013). A difference is made between a dedicated rail vehicle, a freight wagon attached to a passenger vehicle and transporting freight alongside passengers.

A dedicated freight vehicle takes the shortest route on the rail network, but both a driver and a courier have to be present. The assumption is made that a rail driver is not allowed to leave his vehicle or the goods in the vehicle behind. As a result, a second person needs to be present in the vehicle when transporting freight. For this second person, a person with the labour cost characteristics of a courier is taken here. Independent from which type of road post-haulage is chosen, this courier is always present in the dedicated freight vehicle. Therefore, the labour costs of the courier have to be added to the ones of the driver. According to De Jaeger (2019) this cost is around 24 €/h.

When a freight wagon is attached to a passenger vehicle, only the time costs of a courier have to be included, since the cost of the driver is already assigned to the passenger transport. When freight is transported by a courier alongside passengers, the annual time cost of the courier can be estimated by the cost of an annual rail subscription (Devriendt, 2017a). A cost of €324 is considered for a year ticket to use the tram for one year in Flanders (De Lijn, 2019d). A year ticket for the whole light rail network in Belgium has a cost of €3,097 (NMBS, 2019). Table 37 displays the time unit costs for rail transport.

Table 37 – Time unit costs for rail transport

Rail type	Component	Cost ($€_{2018}$)	Region	Source
Tram	Cost during day time	38.9 €/tramh	Flanders	De Lijn (2018)
Train	Cost during day time	67.50 €/trainh	Belgium	Dillen (2019)
		77.07 €/trainh	Belgium	Delhaye et al. (2017)
		93.4 €/trainh	Europe	Sartori et al. (2015)

Source: Own creation

The operational cost of the rail leg can now be calculated by means of Equation (20). If the supplier and/or customer does not possess a connection to the rail network, road pre- and/or post-haulage is needed to transport the goods along the supply chain. Therefore, the operational costs of road pre- and post-haulage also need to be calculated. In Section 4.1.2.2, the road pre-haulage costs are discussed, whereas the road post-haulage costs are elaborated on in Section 4.1.2.3.

4.1.2.2 Road pre-haulage

The operational cost of the road pre-haulage (*$operation_{pre}$*) is displayed in Equation (27):

$$operation_{pre} = \mathrm{dcost}_{pre} + t\mathrm{cost}_{pre} \tag{27}$$

Equation (27) shows that the operational cost of the road pre-haulage is divided in a distance cost (*$dcost_{pre}$*) and a time cost (*$tcost_{pre}$*). These two costs have to be determined in order to know the operational cost of the road pre-haulage. The distance cost can be derived by Equation (28):

$$\mathrm{dcost}_{pre} = \sum_{k=1}^{l} (\beta_k * d_{pre,k} * D_{pre,k}) \qquad \forall\ 0<k\leq l \text{ and } l>0 \text{ and } \beta\{0,1\} \tag{28}$$

In which

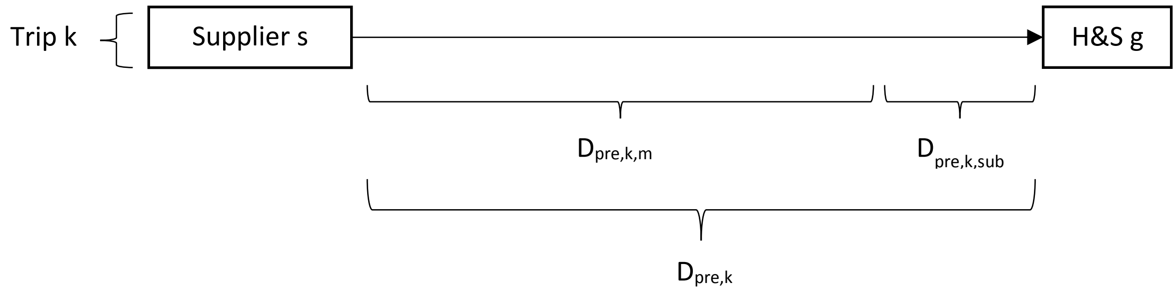
β_k = a dummy variable to correct for the need of road pre-haulage; β_k=0 if no pre-haulage is needed in pre-haulage trip k, whereas β_k=1 if pre-haulage is needed in trip k;

$d_{pre,k}$ = the cost per distance unit for pre-haulage trip k, expressed in euro per kilometre;

$D_{pre,k}$ = the total road pre-haulage distance to be covered for trip k, expressed in kilometre.

In order to know the distance costs of the road pre-haulage, it is necessary to know the total distance covered for the pre-haulage transport complementary to all rail trips, as well as the cost per distance unit for road pre-haulage. The pre-haulage distance ($D_{pre,k}$) includes the distance for each pre-haulage trip *k* (0<*k*≤*l* and *l*>0) between the supplier and the handling and storage point that is used. Figure 57 shows this schematically for pre-haulage trip *k* between supplier *s* (0<*s*≤*t* and *t*>0) and H&S *g* (0<*g*≤*h* and *h*>0).

Figure 57 – Total road pre-haulage distance covered for trip k



Source: Own creation

The total distance covered in Figure 57 between the supplier and the handling and storage point (H&S) is equal to $D_{pre,k}$. This distance is further divided in the distance covered on motorways ($D_{pre,k,m}$) and the distance in suburban areas ($D_{pre,k,sub}$). It is assumed that for the pre-haulage leg, no transport is taking place in the urban area, since the handling and storage point is located at the edge of the urban area. Hence, the total distance for the pre-haulage transport is expressed by Equation (29):

$$D_{pre} = \sum_{k=1}^{l} (D_{pre,k,m} + D_{pre,k,sub}) \qquad \forall\ 0<k\leq l \text{ and } l>0 \qquad (29)$$

Distances are further divided according to the time of the day at which they are covered, being peak hour, off-peak hour or night. The total distance of trip k during peak hour is the sum of all parts of the trip that take place during peak hour. Analogously, the total distance during off-peak hour and during the night are calculated. The total distance of trip *k* on motorways is the sum of all parts of trip *k* that take place on motorways. Similarly, the total distance in suburban areas is calculated.

Depending on the amount of goods that needs to be transported between a supplier and a handling and storage point, a certain amount of road vehicles is needed. The net capacity of the lorry or van used for the road pre-haulage is derived from the gross capacity of the vehicle. A van with a gross capacity of 3.5 tonnes has a net capacity of 1 tonne if no loading bridge is included in the lorry (Ayadi, 2014; Cárdenas, Dewulf, Vanelslander, Smet, & Beckers, 2017) and 0.535 tonnes if a loading bridge is provided in the van (Pittoors, 2019). A lorry with a gross capacity of 12 tonnes has a net capacity of 6 tonnes (Rebel, 2013).

The next component needed to know the road pre-haulage distance cost is the cost per distance unit. In Belgium, road pricing has to be paid by freight vehicles with a gross weight of more than 3.5 tonnes and only on the motorways and the main Belgian roads. The road pricing unit cost needs to be added to the other distance unit costs such as fuel and maintenance. The road pricing fee depends further on the euro standard of the vehicle and on the area in Belgium where the transport takes place. The fee charged in Flanders and Brussels is displayed in Table 38 for the different euro standards for vehicles with a maximum gross weight of 3.5-12 tonnes[24].

[24] As of the 1st of July 2019, the index of the tariffs for road pricing will be adapted. It concerns an adaptation to adjust to the consumer price index (Viapass, 2019a).

Table 38 – Road pricing for vehicles of 3.5t-12t

Euro standard	Price on main Flemish roads and Brussels motorways (€2018/km)	Price on local and regional roads in Brussels (€2018/km)
0	0.151	0.194
1	0.151	0.194
2	0.151	0.194
3	0.130	0.168
4	0.098	0.136
5	0.087	0.123
6	0.076	0.102

Source: Own creation based on Viapass (2019b)

Values for the other distance-related road pre-haulage unit costs are provided at the end of this section, together with the time-related costs. The time-related costs for the road pre-haulage are derived by Equation (30):

$$\text{tcost}_{pre} = \sum_{k=1}^{l} \beta_k * (u_{pre,day,k} * (U_{pre,peak,k} + U_{pre,off-peak,k}) + u_{pre,night,k} * U_{pre,night,k})$$

$$\forall\ 0<k\leq l,\ l>0 \text{ and } \beta\{0,1\} \qquad (30)$$

In which

β_k	= a dummy variable to correct for the need of road pre-haulage; β_k=0 if no pre-haulage is needed in pre-haulage trip k, whereas β_k=1 if pre-haulage is needed in trip *k*;
$u_{pre,day,k}$	= the cost per time unit for pre-haulage trip *k* during the day, expressed in euro per hour;
$u_{pre,night,k}$	= the cost per time unit for pre-haulage trip *k* during the night, expressed in euro per hour;
$U_{pre,peak,k}$	= the total road pre-haulage time during peak hour needed for trip *k*, expressed in hours;
$U_{pre,off\text{-}peak,k}$	= the total road pre-haulage time during off-peak hour needed for trip *k*, expressed in hours;
$U_{pre,night,k}$	= the total road pre-haulage time during the night needed for trip *k*, expressed in hours.

In order to calculate the time needed to complete the road pre-haulage, the pre-haulage distance is divided by the average speed. The average speed is assumed to be 60 km/h, following Delhaye et al. (2017). The road pre-haulage takes mostly place outside the urban areas and these authors state that both vehicles of less than 3.5 tonnes and vehicles until 12 tonnes are characterised by an average speed of 60 km/h. Daubresse et al. (2019) make a distinction between peak hour and off-peak hour and provide a separate average speed for areas sensitive to congestion. These authors indicate an average speed in Belgium of 70.4 km/h during peak hours and 80.4 km/h during off-peak hours in 2015. For areas sensitive to congestion, the average speed equals 53.6 km/h during peak hours and 82.3 during off-peak hours. The total pre-haulage time is in the current research divided into the time during peak hours, off-peak hours and during the night. The sum of the time during peak hour and off-peak hour, is the total time during the day.

Ultimately, time and distance coefficients are derived for the road pre-haulage. Table 39 displays different time and distance coefficients for multiple lorry or van categories based on their gross weight.

Table 39 – Unit costs of urban road transport

Gross weight	Distance cost ($€_{2018}$/km)	Time cost ($€_{2018}$/h)	Daily rest cost ($€_{2018}$/day)	Region	Source
0.5t	0.25	24.42	n/a	Belgium	Blauwens et al. (2016)
3.5t	0.23	19.26	n/a	Flanders	Cárdenas et al. (2015)
	n/a	24.00	n/a	Flanders	De Jaeger (2019)
5t	0.36	26.19	n/a	Belgium	Blauwens et al. (2016)
6 t	0.22	20.43	53.28	Lyon	Ayadi (2014)
8t	0.41	27.50	n/a	Belgium	Blauwens et al. (2016)
<12t	0.28	39.33	n/a	Belgium	Rebel (2013)

Source: Own creation

The advantage of the figures provided by Rebel (2013), Cárdenas et al. (2015), Blauwens et al. (2016) and De Jaeger (2019) is that they are specifically calculated for the Belgian context. The figures provided by Ayadi (2014) can also be used in a Belgian context, under the condition that the factors determining the time and distance coefficients, such as the wages are similar in Lyon and in Belgium. Appendix 7 compares the conditions in Lyon and Antwerp.

Table 39 shows that time and distance coefficients differ depending on the lorry tonnage and the calculation method used by different authors. Rebel (2013) includes wages of drivers, fees paid by drivers, overhead, insurance, vehicle taxes and 50% of the depreciation of the lorry in the time coefficient, while 50% of the depreciation of the lorry, maintenance and fuel are included in the distance coefficient. Ayadi (2014) counts fuel, tires, maintenance and repair as distance costs, while the wages of the drivers, employer contributions and fees paid by the driver are counted as time coefficients. The additional daily cost includes fixed costs of the vehicle, financing and insurance, as well as indirect costs. Rebel (2013) uses the same subdivision as Blauwens et al. (2002, 2016), except for the depreciation rate. The latter authors see the fixed depreciation as a component of the time coefficient, while the variable depreciation is part of the distance coefficient.

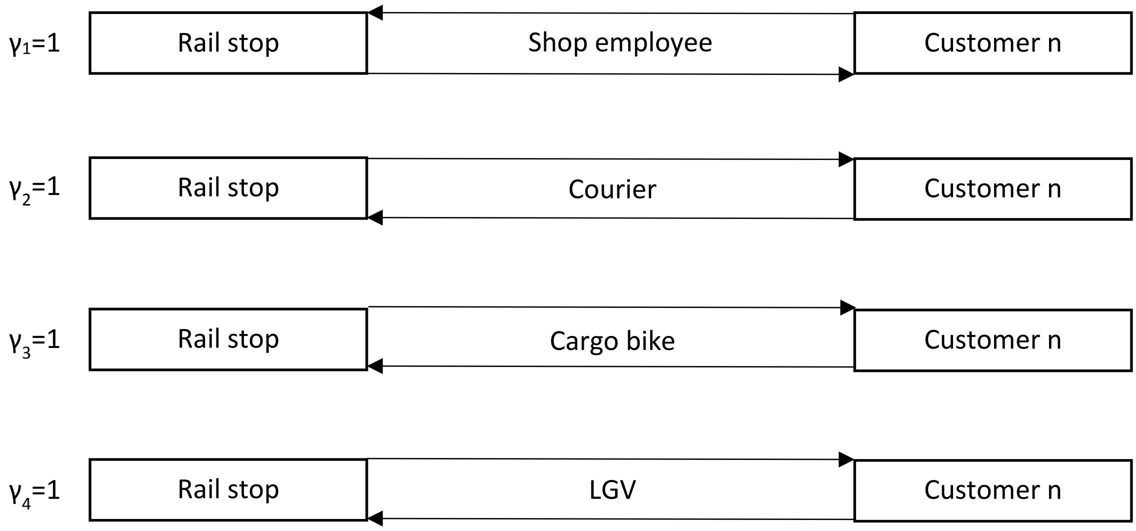
When road post-haulage is needed, other modes than lorries or vans can be used. Therefore, the operational cost of the road post-haulage needs to be calculated as well. This is the subject of the next section.

4.1.2.3 Road post-haulage

Before calculating the operational road post-haulage costs, it has to be clarified for each customer n how the road post-haulage is taking place. If post-haulage is needed, four possible ways are included in this research. Figure 58 displays these four options, being the pick-up of the goods at the rail stop by a shop employee (γ_1), the delivery of the goods by a courier (γ_2), the delivery by a cargo bike service (γ_3), or the delivery by an LGV (γ_4).

Concerning the road post-haulage, the only operational difference between a dedicated freight vehicle and a freight wagon attached to a passenger vehicle is that the courier cannot leave the rail vehicle behind in case of a freight wagon attached to a passenger vehicle. In case of a dedicated freight vehicle this is possible, because the rail driver stays in the vehicle with the remaining goods. Thus, when a freight wagon is used, another courier than the one in the rail vehicle picks up the goods at the rail stop. When goods are transported alongside passengers, it is assumed that the post-haulage transport is carried out by the courier, who walks to the customer(s) to deliver the parcel(s).

Figure 58 – Road post-haulage options



Source: Own creation

In case the rail vehicle stops in front of the customer(s), no road post-haulage is needed. It is assumed that the operational cost is then similar in the reference and project case. Therefore, no differential cost is taken into account. In case road post-haulage is needed, the operational cost of each mode has to be considered in order to obtain the full operational post-haulage cost. This is expressed by Equation (31):

$$operation_{post} = posth_{employee} + posth_{courier} + posth_{bike} + posth_{LGV} \tag{31}$$

in which

$posth_{employee}$	= the operational cost of post-haulage done by a shop employee, expressed in euro;
$posth_{courier}$	= the operational cost of post-haulage executed by a courier, expressed in euro;
$posth_{bike}$	= the operational cost of post-haulage by a cargo bike, expressed in euro;
$posth_{LGV}$	= the operational cost of post-haulage by an LGV, expressed in euro.

The operational cost for all four post-haulage possibilities needs to be determined. For each post-haulage possibility, it has to be determined how many freight units can be transported at once. Thus, the cost of one trip has to be multiplied by the number of trips (*posthtrips*) needed to deliver all goods at the customer(s). Firstly, the operational cost of a shop employee of customer *n* picking up the goods at the rail stop is estimated by Equation (32):

$$posth_{employee,n} = \frac{(D_{post,\gamma1,peak} + D_{post,\gamma1,off-peak}) * u_{post,employee,day} + D_{post,\gamma1,night} * u_{post,employee,night}}{speed_{walk}}$$

$$\forall\ 0<n\leq o \text{ and } o>0 \tag{32}$$

In which

$D_{post,\gamma1,peak}$	= the post-haulage distance covered by the employee during peak hour, expressed in kilometres;
$D_{post,\gamma1,off-peak}$	= the post-haulage distance covered by the employee during off-peak hour, expressed in kilometres;
$D_{post,\gamma1,night}$	= the post-haulage distance covered by the employee during the night, expressed in kilometres;

$u_{post,employee,day}$	= the time coefficient of the employee during the day, expressed in euro per hour;
$u_{post,employee,night}$	= the time coefficient of the employee during the night, expressed in euro per hour;
$speed_{walk}$	= the average walking speed of the employee, expressed in kilometre per hour.

Hence, the operational cost of the pick-up of the goods by the employee consists of the time costs related to the employee. Ayadi (2014) discusses the wear of shoes as the only possible distance-related cost of walking. However, this author argues that this cost is negligible for walking to a shop. Therefore, this cost is not taken into account here. The time costs are obtained by multiplying the total post-haulage time and the costs per time unit. In order to obtain the total post-haulage time, the total post-haulage distance is derived and divided by the average speed. In case a shop employee picks up the goods at the rail stop, the average speed of walking needs to be taken into account. Oja et al. (1998) provide average walking speed figures for the city of Tampere in Finland of 5.8 km/h-6.2 km/h and Soulas et al. (2011) consider an average walking speed of 4.7 km/h. In this research, an average speed of 4 km/h is used ($speed_{walk}$), taking into account the fact that the courier is walking with goods which delays the walking speed.

The time coefficient of an employee picking up the goods ($u_{post,employee}$) comes from the labour cost of a person working in retail (NACE code 47) and equals 30.16 €/h in 2018 (FOD Economie, 2018). The labour cost of the employee differs during day and night time. In case the transport is taking place during the night, a factor of 1.25 is applied to the labour cost during the day (Pittoors, 2019; Van Dooren, 2017). The total post-haulage operational cost is then obtained by adding the costs for all customers *n*.

Secondly, the operational cost of post-haulage to customer n executed by a courier is expressed in Equation (33):

$$posth_{courier,n} = \frac{(D_{post,\gamma 2,peak} + D_{post,\gamma 2,off-peak})*u_{post,courier,day} + D_{post,\gamma 2,night}*u_{post,courier,night}}{speed_{walk}}$$

$$\forall\ 0<n\leq o \text{ and } o>0 \qquad (33)$$

Equation (33) is analogous to Equation (32), though consisting of time costs of the courier instead of the shop employee. The courier brings the goods to the customer(s) by walking. Hence, the average speed of walking needs to be taken into account, which is assumed to be 4 km/h ($speed_{walk}$). The labour cost of a courier is 24 €/h in 2018 (De Jaeger, 2019; Pittoors, 2019). The same factor of 1.25 is applied for night work. In case of a dedicated freight vehicle, an additional cost has to be added when the courier brings the goods to the customer(s). The rail driver has to wait during the unloading time of the goods and during the time needed for the courier to bring the goods to the customer. Therefore, an additional waiting time for the rail driver is added to the cost per time unit.

Thirdly, the operational cost of post-haulage by using a cargo bike service is shown in Equation (34):

$$posth_{bike,n} = \frac{(D_{post,\gamma 3,peak} + D_{post,\gamma 3,off-peak})*u_{post,bike,day} + D_{post,\gamma 3,night}*u_{post,bike,night}}{speed_{bike}} + \mathrm{dcost}_{bike,n}$$

$$\forall\ 0<n\leq o \text{ and } o>0 \qquad (34)$$

The operational cost in Equation (34) consists of two main parts, being the time costs of the bike courier and the distance cost of the bike ($dcost_{bike,n}$) (Maes, Sys, & Vanelslander, 2011a). The distance cost consists of different components. Maes et al. (2011a) estimate the yearly leasing cost of a cargo bike at €92.55 (in $euro_{2018}$ value). In further research, Maes (2017) assumes an average purchase cost of a cargo bike of €8,500, of which €1,000 can be subtracted as the residual value of the bike after four years. Hence, a purchase cost of €7,500 is taken into account (values for 2018). Further, it is assumed that an average cargo bike covers 100 km per day and is operational 260 days in a year. Hence, a cost of 0.07 €/km is obtained. The latter cost is used in this research as the distance cost of the cargo bike. In case an electric cargo bike is used, the energy cost has to be added to the distance cost. Delhaye et al. (2017) provide the net average price of industrial electricity in Belgium. This price equals according to these authors 0.08 €/kWh (value for 2018). Maes (2017) states that cargo bikes need maximum 0.25 kW per day, which equals 0.0025 kWh/km, given the fact that a working day has on average 7.6 h and a cargo bike covers on average 100 km per day. Multiplying the electricity price and the electricity use, a cost of 0.0002 €/km (value for 2018) is added as the energy cost of an electric cargo bike. Equation (35) shows how the distance cost of the post-haulage bike transport $dcost_{bike}$ is calculated:

$$\mathrm{dcost}_{bike} = D_{post,\gamma 3} * (0.07€ / km + \lambda * 0.0002€ / km) \qquad \forall\ \lambda\{0,1\} \qquad (35)$$

In which

λ = a dummy variable to correct for the use of an electric cargo bike; λ=0 if a standard cargo bike is chosen, whereas λ=1 if an electric cargo bike is used.

The time costs of the bike courier depend on the time needed for the post-haulage and the costs per time unit. The labour cost of courier companies is applied, leading to a labour cost of 23 €/h. Here too, a factor of 1.25 is used for night labour. Soulas et al. (2011) state that the average speed of a cargo bike in Europe equals 10 km/h. For electric cargo bikes, Maes (2017) describes a certain type that has a maximum average speed of 16 km/h.

Ultimately, Equation (36) displays the operational cost of post-haulage transport to customer *n* done by an LGV:

$$posth_{LGV,n} = \frac{(D_{post,\gamma 4,peak} + D_{post,\gamma 4,off-peak}) * u_{post,LGV,day} + D_{post,\gamma 4,night} * u_{post,LGV,night}}{speed_{LGV}} + \mathrm{dcost}_{LGV,n}$$

$$\forall\ 0<n\leq o \text{ and } o>0 \qquad (36)$$

The post-haulage cost of an LGV depends on the time and distance costs. The distance costs depend on the characteristics of the LGV. The road post-haulage can be carried out by a diesel, petrol or electric LGV. The distance coefficient of an LGV for the road post-haulage in the urban area ($d_{post,LGV}$) is the one of a van of 3.5 tonnes provided by Cárdenas et al. (2015), being 0.23 €/km (value for 2018). Since road pricing in Belgium is only to be paid on the motorways and on the main Belgian roads, no road pricing is to be paid anno 2019 in Belgium for the road post-haulage leg, since it is assumed that this leg takes place in the urban area.

The time costs are related to the labour costs of a courier and the speed of the transport. The labour cost provided by De Jaeger (2019) of 24 €/h is applied (value for 2018), also multiplied by 1.25 for night labour. The average speed depends on several factors. Soulas et al. (2011) use in their calculations an average speed of a private car in an urban area of 22 km/h. Ayadi (2014) provides the average speed of light goods vehicles of 3.5 tonnes. This author makes a distinction between vehicles delivering B2C goods at home and vehicles delivering goods in pick-up points. The average speed is according to this author respectively 20 km/h and 30 km/h. These figures are derived from an interview with a transport carrier in the region of Lyon (France) and they are valid for April 2012. In Appendix 7, a comparison is made between some characteristics of the road network in Antwerp and in Lyon in order to show that these are similar and hence, figures for the region of Lyon can be applied to Antwerp. In line with Ayadi (2014) the average speed of 30 km/h is applied here. Daubresse et al. (2019) estimate a reduction of the average speed on the Belgian road network of 2.6% during peak hours and 1.9% during off-peak hours between 2015 and 2040. This would be a reduction of the average speed of 30 km/h between 2012 and 2018 of 0.62% and 0.46% respectively, leading to an average speed of 29.81-29.86 km/h. This effect is small and hence, not taken into account in the calculations.

After having determined the operational costs of the rail, road pre-haulage and road post-haulage legs, the handling and storage operational costs still have to be estimated. This is the subject of the following section.

4.1.2.4 Handling & storage

The operational cost of handling and storage has to be considered between the road pre-haulage and rail leg ($operation_{handling,pre}$), as well as between the rail and road post-haulage leg ($operation_{handling,post}$). Equation (37) shows how this cost is quantified:

$$operation_{handling} = operation_{handling,pre} + operation_{handling,post} \tag{37}$$

At the customer(s) too, logistic costs occur. The operational costs comprise the rental costs, the personnel costs, the electricity consumption, the amortisation costs of the investments and other operational costs (Ayadi, 2014). However, it is important to note that only costs that differ between the reference case and the project case are taken into account in this research. It is assumed that most logistics costs at the customer do not change depending on whether goods are delivered by road, rail or road post-haulage. Therefore, the operational costs of handling and storage are limited here to the potential handling activities between road pre-haulage, rail and road post-haulage. The only component of the logistic cost at the customer that is considered to be potentially differential between the reference and project case is the surface needed for in-store stockholding. This component is treated as potential consumer surplus here, and hence, is discussed in Chapter 5.

The operational cost of the handling and storage between the pre-haulage and rail leg is derived by Equation (38):

$$operation_{handling,pre} = \sum_{m=1}^{4}\sum_{k=1}^{l} \beta_k * (operation_{tp,m} * pallets_{tp,m} + operation_{dc,m} * pallets_{dc,m})$$

$$\forall\ 0<k\leq l,\ l>0,\ 0<m\leq 4 \text{ and } \beta\{0,1\} \tag{38}$$

In which

$operation_{tp,m}$	= the throughput cost of a transit platform per pallet and per product type m, expressed in euro per pallet;
$pallets_{tp,m}$	= the number of pallets of product type *m* passing through a transit platform;
$operation_{dc,m}$	= the total operational cost of a distribution centre per pallet and per product type m, expressed in euro per pallet;
$pallets_{dc,m}$	= the number of pallets of product type *m* passing through a distribution centre.

From Equation (38), it is clear that either a transit platform or a distribution centre is used for the handling and potential storage. Both types of handling and storage points lead to different operational costs. Table 40 shows the throughput cost in a transit platform for four different types of retail products, expressed in euro per pallet. The values in Table 40 are derived for urban transport in the neighbourhood of Lyon (France), but it is assumed that the conditions determining the costs, such as the average temperature and labour costs, are similar in Lyon and Antwerp (see Appendix 7). Hence, the figures can also be applied in Antwerp.

Table 40 – Operational cost of a transit platform for urban transport in France

Product type	Throughput cost (€$_{2018}$/pallet)
Cooled food	8.67
Frozen food	9.76
Non-cooled food	6.51
Non-food	5.42

Source: Ayadi (2014)

Ayadi (2014) divides the operational cost of a distribution centre in fixed costs and variable costs. Table 41 gives an overview of the different cost components. Fixed costs include the cost for receiving and sending a pallet and processing orders. Variable costs comprise the storing cost, which is a function of time. It has to be mentioned here that the average storing time can differ between products of the same product type, but also between different types of shop, depending on for instance the shop surface.

Table 41 – Operational cost of a distribution centre (figures for France), in €$_{2018}$/pallet

Product type	Storing time	Daily storing cost	Average storing cost	Receiving cost	Order processing cost	Total cost
Cooled food	0.5 day	0.35	0.18	4.34	14.86	23.70
Frozen food	21 days	0.46	9.66	4.88	17.13	36.45
Non-cooled food	28 days	0.13	3.64	3.25	11.82	21.97
Non-food	42 days	0.11	4.62	2.71	10.30	20.28

Source: Ayadi (2014)

Concerning the storage costs of the goods, a first distinction is made between goods that need to be stored at certain temperatures on the one hand and non-cooled food and non-food goods on the other hand. Cooled and frozen goods are characterised by additional cooling electricity costs compared to the non-cooled food and the non-food goods. Non-cooled food products need some heating in winter so as not to freeze. Therefore, the daily storing cost of frozen food is the highest, followed by the daily storing cost of cooled food. This cost includes electricity, rent and amortisation of the storing racks.

In order to calculate the full operational cost of a distribution centre, the cost of receiving and sending a pallet has to be added. This cost differs per product type and is also displayed in Table 41. It is assumed that the cost of sending a pallet is similar to the cost of receiving a pallet. Therefore, the cost for receiving and sending a pallet equals the double of the receiving costs. This cost includes the cost for unloading a pallet and the handling from the reception to the storing place. The receiving cost includes the personnel cost and the amortisation of the handling equipment. The order processing costs consist of the preparation costs per pallet, the packing costs and the administration costs. The administration cost includes the cost of preparing the delivery slip, office, computers, printers and other office materials (Ayadi, 2014).

As a conclusion, Table 41 gives an overview of the total logistics cost related to an urban distribution centre. The cost of €20.28 per pallet for non-food items for example comes from the addition of the storing costs (€0.11 * 42 = €4.62), the arrival and departure costs (€2.71 * 2 = €5.42), and the order processing costs (€0.098 * 70 parcels per pallet + € 3.47 due to administration = €10.30). Depending on the number of storing days, the storing cost is equal to 0.11 €/day times the number of storing days (values for 2018).

The operational cost of handling and storage between the post-haulage and rail legs is obtained analogously as in Equation (38), with the difference that the time cost of the train driver and/or courier during the unloading and loading has to be added. The time cost is calculated by multiplying the time needed for the post-haulage and the cost per time unit of the actors involved. In case of a dedicated freight vehicle, the actors involved are the train driver and the courier. In case of a freight wagon attached to a passenger vehicle and the transport of freight alongside passengers, only a courier is involved. Since only cost differences between the reference and project case are taken into account in an SCBA, only the differences in time costs are added as a cost. In the reference case, the lorries or vans arriving at the customer also have to be unloaded. As a result, it is assumed here that only the time costs of the rail driver, who is not in charge of the post-haulage, but just has to wait, have to be counted as additional costs. This is only the case for a dedicated freight vehicle and for the post-haulage where the courier brings the goods to the customer(s). This is shown in Equation (39):

$$operation_{handling,post} = \sum_{m=1}^{4}\sum_{q=1}^{4}\sum_{n=1}^{o}(\gamma_{q,n} * (operation_{tp,m} * pallets_{tp,m} + operation_{dc,m} * pallets_{dc,m}) + \mathrm{tcost}_{\gamma 2,n,operation})$$

$$\forall\ 0<n\leq o,\ o>0,\ 0<m\leq 4,\ 0<q\leq 4 \text{ and } \gamma\{0,1\} \qquad (39)$$

In which

$tcost_{\gamma 2,n,operation}$ = the time cost of the rail driver during the post-haulage leg if the post-haulage is executed by the courier and a dedicated freight vehicle is used, expressed in euro.

The time cost to supply all customers can further be expressed by Equation (40):

$$\mathrm{tcost}_{\gamma 2,operation} = \iota * U_{post,\gamma 2,day} * u_{rail,day} + (1-\iota) * U_{post,\gamma 2,night} * u_{rail,night} \qquad \forall\ \iota\{0,1\} \qquad (40)$$

In which

ι = a dummy variable to control for the timing of the post-haulage transport; $\iota=0$ if the post-haulage occurs during the night and $\iota=1$ if the post-haulage takes place during the day;

$U_{post,\gamma 2,day}$ = he total post-haulage time during day time by a courier expressed in hours;

$U_{post,\gamma 2,night}$ = the total post-haulage time during night time by a courier expressed in hours;

$u_{rail,\ day}$ = the cost of the rail driver per time unit if the transport occurs during the day, expressed in euro per hour;

$u_{rail,\ night}$ = the cost of the rail driver per time unit if the transport occurs during the night, expressed in euro per hour.

The time cost is calculated as the waiting time of the rail driver multiplied by the hourly labour cost of the rail driver. A certain amount of time is needed per rail trip *i* to load the vehicle at the handling and storage point and to unload it at the rail stop. This time is calculated based on the number of freight units that has to be transferred per rail trip. Depending on the number of freight units that has to be transferred together, a certain time is needed. CNR (2017a, 2017b, 2017c) provides figures to estimate the loading and unloading time. If the vehicle has maximum 11 tonnes of load, an unloading time of 2h is considered, whereas a vehicle charged with 11-16 tonnes of load is characterised by an unloading time of 2.34h. For non-food products, 11 tonnes of load correspond according to Ayadi (2014) with 25 pallets. Given an unloading time of two hours, an average loading time per pallet of 4.8 minutes is needed. If the load increases to 16 tonnes, an average loading time per pallet of 4.2 minutes is needed. According to Hoekstra Sneek (2017), the maximum time needed to unload for instance three euro pallets is 15 minutes (5 minutes per pallet), 12 euro pallets 30 minutes (2.5 minutes per pallet), 21 euro pallets 45 minutes (2.14 minutes per pallet) and 34 euro pallets 60 minutes (1.76 minutes per pallet).

Combining these two sources, an average unloading time of 5 minutes, or 0.08h, is taken into consideration, which is the upper limit. This is the additional waiting time for the rail driver.

If handling and storage occurs during the night, the additional costs for night labour should be applied to the labour costs of a transit platform and a distribution centre. The operational cost figures for a transit platform and distribution centre used in this research are aggregate figures, not making a distinction between labour costs and other operational costs, such as electricity, amortisation of investments and other factors. It is assumed in the calculations that the labour cost accounts for 50% of the total operational cost of a transit platform and for 30% of the total operational cost of a distribution centre. These shares are validated by Pittoors (2019). The lower share with respect to the distribution centre is explained by the inclusion of the capital cost of the distribution centre in the operational cost figures that are available. Furthermore, based on Van Dooren (2017), it is assumed that night labour is 1.25 times as expensive as day labour. Based on the number of pallets passing through a transit platform and distribution centre, during day and night, a weighted labour cost factor is calculated. This factor is applied to the share of the personnel costs in the total operational costs.

The difference of personnel costs between the reference and project case is now taken into account. Night labour is estimated to be 25% more expensive as day labour. Hence, only 25% of the labour costs are taken into account in order to calculate the cost difference of the shop personnel. For each customer, the timing of the deliveries in the reference case is compared to the timing in the project case. If the delivery in the reference case happens during the day and now during the night, a cost is added in the calculations. If the delivery happens in the reference case during the night and now during the day, a benefit is added. If in the reference and project case, the timing is equal, no cost difference is considered. It is assumed that the cost difference per customer equals 25% times the wage of a shop employee times the time needed for unloading. For the transport of parcels alongside passengers, only handling and storage costs related to a distribution centre are incorporated in the operational cost. If goods are not stored, no handling is performed by the courier, and hence, the handling and storage cost equals zero.

4.1.2.5 Synopsis

Table 42 provides the overview of the operational costs when using trams for urban freight distribution, while Table 43 displays these costs when trains are used. The costs are displayed for each leg in the urban rail freight supply chain and are for rail, road pre-haulage and road post-haulage divided in time and distance costs. Furthermore, a distinction is made between the three types of rail transport taken into account in this research, being a dedicated freight vehicle, a freight wagon attached to a passenger vehicle and freight in a passenger vehicle.

The time costs of the rail leg are obtained by multiplying the quotient of the rail distance and the average speed of the rail transport by the labour cost per hour. For a dedicated rail vehicle, only the cost of a courier is considered, since the labour cost of the rail driver is already included in the provided value for the distance cost. For a dedicated freight tram, a cost to open the dispatching centre is added if the transport takes place during the night. Concerning a freight wagon attached to a passenger vehicle, the labour cost for a tram is the cost of a courier, while the cost for a train includes next to the cost of the courier also the daily leasing cost of a wagon. With respect to the transport of freight in a passenger vehicle, the cost of the courier is taken into account, complemented by the year ticket for tram transport (324 $€_{2018}$/year) and train transport (3,097 $€_{2018}$/year) respectively.

The distance costs of the rail leg for a dedicated freight tram are calculated by multiplying the total distance covered by 12.51 €/km. The latter cost represents the distance cost including energy and maintenance, labour and track access charges. To calculate the distance cost of a freight wagon attached to a passenger vehicle, only half of the distance unit cost that is not related to the labour cost of the driver is taken into account, and no track access charges have to be paid (Fierens et al., 2019). The distance cost of moving freight in a passenger vehicle equals zero. The distance cost for a train is the total operational cost per kilometre for a dedicated freight train. For a freight wagon attached to a passenger train and for the transport of freight in a passenger train, no distance costs are included in the calculations.

The costs of the road pre-haulage are displayed in Table 42 and Table 43. For a dedicated freight vehicle and a freight wagon, the values are shown for the use of a lorry of 3.5-12 tonnes, with a euro standard 5, operating in Flanders. For the transport of parcels in a passenger vehicle, a van of 3.5 tonnes is considered. The time costs are the product of the quotient of the total pre-haulage distance and the average speed, and the labour cost of a driver. The distance costs comprise the product of the total distance and the sum of the costs per distance unit and the road pricing fee. The road pricing fee is only taken into account if applicable on the roads used.

The costs of road post-haulage are the same for the use of a tram or a train, but differ depending on the type of post-haulage and rail vehicle used. Concerning the use of a dedicated freight vehicle and freight wagon, four types of road post-haulage are possible. The cost of an employee picking up the goods at the rail stop are equal to the time costs of the employee. Analogously, the costs of the courier delivering the goods at the customer are equal to the time costs of the courier. For a dedicated freight vehicle, the labour costs of the rail driver are added, since this actor has to wait while the courier is executing the post-haulage leg. When a bike service is used, distance costs are added on top of the time costs and a distinction is further made whether the bike is an electric bike or not. If the cargo bike is electric, energy costs are added to the operational cost. When hiring an LGV, distance costs are added as well. With respect to the use of a freight wagon attached to a passenger vehicle, the costs are the same as for a dedicated freight vehicle. When freight is transported alongside passengers, the only option is that the courier delivers the goods at the customer(s).

The costs of handling and storage are divided in the handling and storage costs related to the need for pre-haulage, and the ones related to the need for post-haulage. The costs related to pre-haulage are the same for tram and train transport and they consist of the operational costs of the number of pallets handled at transit platforms and of the number of pallets handled and stored at distribution centres. This cost is the same for a dedicated freight vehicle, a freight wagon attached to a passenger vehicle and the transport of freight alongside passengers if goods are stored in a distribution centre. If a transit platform is used, no costs have to be included when a courier transports the parcels. The costs related to the post-haulage are for a freight wagon and the transport of freight alongside passengers analogous to the costs related to the pre-haulage and this both for trams and trains. In case a dedicated freight vehicle is used, an additional component is added to the operational cost. This extra cost component comprises the waiting time of the rail driver during the unloading time of the vehicle. For trams and trains, the respective labour costs are taken into account.

By adding all operational costs of using trams and trains for a dedicated freight vehicle, a freight wagon attached to a passenger vehicle and the transport of freight alongside passengers that are displayed in Table 42 and Table 43 respectively, the total operational cost of using trams and trains can be determined. This cost can be added to the investment cost that is derived in Section 4.1.1. Together, these two costs are the financial and economic costs of using rail for urban freight distribution.

Next to financial and economic costs, the benefits have to be determined. This is the subject of the following section.

Table 42 – Tram operational costs in Flanders – non-food retail products (values for 2018)

	Dedicated freight vehicle	Freight wagon attached to passenger vehicle	Freight in passenger vehicle
Tram			
* Time cost	$\frac{D_{rail,peak}+D_{rail,off-peak}}{15km/h}*24\text{€}/tramh+\frac{D_{rail,night}}{15km/h}*1.25*24\text{€}/tramh+(1-\iota)*3*u_{rail,dispatch}$	$\frac{D_{rail,peak}+D_{rail,off-peak}}{15km/h}*24\text{€}/tramh+\frac{D_{rail,night}}{15km/h}*1.25*24\text{€}/tramh$	$\frac{D_{rail,peak}+D_{rail,off-peak}}{15km/h}*24\text{€}/tramh+\frac{D_{rail,night}}{15km/h}*1.25*24\text{€}/tramh+324\text{€}/year$
* Distance cost	D_{rail}*(10.01+2.50) €/tramkm	D_{rail}*(1/4)*10.01€/tramkm	€0
Road pre-haulage			
* Time cost	$\iota*\frac{D_{pre,peak}+D_{pre,off-peak}}{speed_{pre,day}}*30\text{€}/h+(1-\iota)*\frac{D_{pre,night}}{speed_{pre,night}}*1.25*30\text{€}/h$		
* Distance cost	$D_{pre}*0.28\text{€}/km+D_{pre,m}*0.087\text{€}/km$		$D_{pre}*0.23\text{€}/km$
Road post-haulage			
* Employee	$\frac{(D_{post,\gamma1,peak}+D_{post,\gamma1,off-peak})*30.16\text{€}/h+D_{post,\gamma1,night}*1.25*30.16\text{€}/h}{4km/h}*posthtrips$		n/a
* Courier	$\frac{(D_{post,\gamma2,peak}+D_{post,\gamma2,off-peak})*(24+38.9)\text{€}/h+D_{post,\gamma2,night}*1.25*(24+38.9)\text{€}/h}{4km/h}*posthtrips$	$\frac{(D_{post,\gamma2,peak}+D_{post,\gamma2,off-peak})*24\text{€}/h+D_{post,\gamma2,night}*1.25*24\text{€}/h}{4km/h}*posthtrips$	
* Bike	$(\frac{(D_{post,\gamma3,peak}+D_{post,\gamma3,off-peak})*24\text{€}/h+D_{post,\gamma3,night}*1.25*24\text{€}/h}{(1-\lambda)*10km/h+\lambda*16km/h}+D_{post,\gamma3}*(0.07\text{€}/km+\lambda*0.0002\text{€}/km))*posthtrips$		n/a
* LGV	$(\frac{(D_{post,\gamma4,peak}+D_{post,\gamma4,off-peak})*24\text{€}/h+D_{post,\gamma4,night}*1.25*24\text{€}/h}{30km/h}+D_{post,\gamma4}*0.23\text{€}/km)*posthtrips$		n/a
Handling and storage			
* Pre-haulage	$pallets_{tp}*5.42\text{€}/pallet+pallets_{dc}*(15.72+0.11\text{€}/day*U_{storing,pre})\text{€}/pallet$		$pallets_{dc}*(15.72+0.11\text{€}/day*U_{storing,pre})\text{€}/pallet$
* Post-haulage	$(*)+\iota*pallets_{post,\gamma2,day}*0.08h/pallet*38.9\text{€}/h+(1-\iota)*pallets_{post\gamma2,night}*0.08h/pallet*1.25*38.9\text{€}/h$	$pallets_{tp}*5.42\text{€}/pallet+pallets_{dc}*(15.72+0.11\text{€}/day*U_{storing,post})\text{€}/pallet$ (*)	$pallets_{dc}*(15.72+0.11\text{€}/day*U_{storing,post})\text{€}/pallet$

Source: Own creation based on Ayadi (2014), Blauwens et al. (2016), Cárdenas et al. (2015), De Jaeger (2019), Delhaye et al. (2017), De Lijn (2019d), Devriendt (2017a), Fierens et al. (2019), Gonzalez-Feliu (2016), Viapass (2019b)

Table 43 – Train operational costs in Flanders – non-food retail products (values for 2018)

	Dedicated freight vehicle	Freight wagon attached to passenger vehicle	Freight in passenger vehicle
Train			
* Time cost	$\frac{D_{rail,peak}+D_{rail,off-peak}}{30km/h}*24€/trainh+\frac{D_{rail,night}}{30km/h}*1.25*24€/trainh$	$\frac{D_{rail,peak}+D_{rail,off-peak}}{30km/h}*24€/trainh+\frac{D_{rail,night}}{30km/h}*1.25*24€/trainh+35.72€/day$	$\frac{D_{rail,peak}+D_{rail,off-peak}}{30km/h}*24€/trainh+\frac{D_{rail,night}}{30km/h}*1.25*24€/trainh+3{,}097€/year$
* Distance cost	D_{rail}*20.41 €/trainkm	*€0*	€0
Road pre-haulage			
* Time cost	$\iota*\frac{D_{pre,peak}+D_{pre,off-peak}}{speed_{pre,day}}*30€/h+(1-\iota)*\frac{D_{pre,night}}{speed_{pre,night}}*1.25*30€/h$		
* Distance cost	$D_{pre}*0.28€/km+D_{pre,m}*0.087€/km$		$D_{pre}*0.23€/km$
Road post-haulage			
* Employee	$\frac{(D_{post,\gamma1,peak}+D_{post,\gamma1,off-peak})*30.16€/h+D_{post,\gamma1,night}*1.25*30.16€/h}{4km/h}*posthtrips$		n/a
* Courier	$\frac{(D_{post,\gamma2,peak}+D_{post,\gamma2,off-peak})*(24+38.9)€/h+D_{post,\gamma2,night}*1.25*(24+38.9)€/h}{4km/h}*posthtrips$	$\frac{(D_{post,\gamma2,peak}+D_{post,\gamma2,off-peak})*24€/h+D_{post,\gamma2,night}*1.25*24€/h}{4km/h}*posthtrips$	
* Bike	$(\frac{(D_{post,\gamma3,peak}+D_{post,\gamma3,off-peak})*24€/h+D_{post,\gamma3,night}*1.25*24€/h}{(1-\lambda)*10km/h+\lambda*16km/h}+D_{post,\gamma3}*(0.07€/km+\lambda*0.0002€/km))*posthtrips$		n/a
* LGV	$(\frac{(D_{post,\gamma4,peak}+D_{post,\gamma4,off-peak})*24€/h+D_{post,\gamma4,night}*1.25*24€/h}{30km/h}+D_{post,\gamma4}*0.23€/km)*posthtrips$		n/a
Handling and storage			
* Pre-haulage	$pallets_{tp}*5.42€/pallet+pallets_{dc}*(15.72+0.11€/day*U_{storing,pre})€/pallet$		$pallets_{dc}*(15.72+0.11€/day*U_{storing,pre})€/pallet$
* Post-haulage	$(**)+\iota*pallets_{post,\gamma2,day}*0.08h/pallet*67.5€/h+(1-\iota)*pallets_{post\gamma2,night}*0.08h/pallet*1.25*67.5€/h$	$pallets_{dc}*(15.72+0.11€/day*U_{storing,post})€/pallet$ (**)	$pallets_{dc}*(15.72+0.11€/day*U_{storing,post})€/pallet$

Source: Own creation based on Ayadi (2014), Blauwens et al. (2016), Cárdenas et al. (2015), De Jaeger (2019), Delhaye et al. (2017), NMBS (2019), Vander Stichele (2017), Viapass (2019b)

4.2 Financial and economic benefits

Several authors (Alessandrini et al., 2012; Regué & Bristow, 2013) analyse next to the costs also the benefits of rail-based initiatives. Alessandrini et al. (2012) identify the benefits of using a rail-based solution instead of traditional road transport. Regué & Bristow (2013) analyse the benefits of implementing a freight tram in Barcelona. For urban rail freight distribution, the anticipated beneficial impact is the generated operational income.

The operational income for an urban rail freight supply chain consists of the generated revenue. The revenue comprises the user fee paid for the urban rail freight service and the ancillary revenue. Depending on the rail type, the benefits differ. This is shown in Table 44. The user fee is for the three rail types the amount the user, i.e. the shipper or receiver, pays for the offered rail freight service. Ancillary revenue can be obtained by selling advertisement space on the vehicle in case a dedicated freight vehicle is used and on the freight wagon in case of a freight wagon attached to a passenger vehicle. When freight is transported alongside passengers, ancillary revenue could be obtained by selling advertisement space on the backpack of the courier.

Table 44 – Operational income for an urban rail freight supply chain

Operational income	Symbol	Dedicated freight vehicle	Freight wagon attached to passenger vehicle	Freight in passenger vehicle
* User fee	*fee*	Rail freight service	Rail freight service	Rail freight service
* Ancillary revenue	*ancillary*	Freight vehicle	Freight wagon	Backpack

Source: Own creation based on Alessandrini et al. (2012) and Regué & Bristow (2013)

Thus, the operational income, i.e. the revenue, is obtained by Equation (41):

$$income_{oper} = fee + ancillary \tag{41}$$

In the next sections, the user fee (Section 4.2.1) and the ancillary revenue (Section 4.2.2) are discussed more in depth.

4.2.1 User fee

The user fee for the rail freight service is approached here by the willingness-to-pay of potential users, which is in general reflected in the demand curve for the urban rail freight service. However, this demand curve is currently unknown. Therefore, in this research, the user fee is derived for a given quantity of urban rail freight. In other words, one point of the demand curve for urban rail freight distribution is used for the calculations in this research. Moreover, it is assumed that the retailers and suppliers are not willing to pay more for the urban rail freight service than for their current urban road freight distribution. Thus, the willingness-to-pay, i.e. user fee, is proxied here by the saved user costs related to the urban road freight distribution that is not taking place anymore, following other authors (Alessandrini et al., 2012; Campos & Hernández, 2010; Gorçun, 2014; Regué & Bristow, 2013)[25]. As the current urban freight distribution by road is assumed to be a door-to-door service, the willingness-to-pay for the urban rail freight distribution is expressed for a door-to-door service as well. This is why the costs related to the potential road pre- and/or post-haulage leg in the urban rail freight supply

[25] A remark that can be made here is that sometimes the cost of transport is included in the price of the goods, making it more difficult to know the willingness-to-pay for the transport of the goods. A distinction has to be made between the cost of the goods and transport on the one hand, and the price that is asked for the goods, including their transport, on the other hand. The price equals the cost plus a certain mark-up, meaning that even if the cost of transport is included in the price of the goods, the cost of transport can be derived.

chain have to be included in the analysis. The effect of excluding road pre- and/or post-haulage on the viability of the project is evaluated in the scenario analyses in Chapter 6.

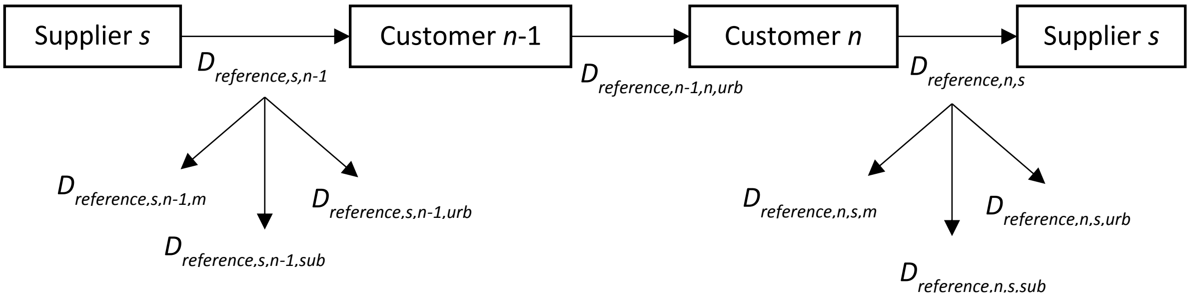
The saved user costs of the current road transport are considered to consist of operational costs only. These costs comprise following Blauwens et al. (2016) the time and distance costs of road freight transport as well as a rest cost, as is shown in Equation (42):

$$fee = \mathrm{dcost}_{reference} + \mathrm{tcost}_{reference} + rest_{reference} \tag{42}$$

The distance cost is calculated in the same way as this is the case for the road pre-haulage in Section 4.1.2. The total distance covered in the reference case is multiplied by the cost per distance unit. The costs per distance unit are considered to be the same as the costs for the road pre-haulage transport by LGV. If the motorways or roads of the main road network are used, the kilometre cost of road pricing has to be added for the appropriate distance.

Figure 59 displays round trip k ($0<k\leq l$ and $l>0$) of supplier s ($0<s\leq t$ and $t>0$), delivering goods at customer n-1 and customer n ($0<n\leq o$, $o>0$). For the leg between supplier s and customer n-1 and the leg between customer n and supplier s, the total distance consists of the distance on the motorways (m), the distance in suburban areas (sub) and the distance in urban areas (urb). Urban areas are areas of at least 1,500 inhabitants per square kilometre. For the leg between two consecutive customers n-1 and n, it is assumed that all transport takes place in an urban area.

Figure 59 – Round trip k in the reference case from supplier s to customer n-1 and customer n



Source: Own creation

The total distance of all round trips ($D_{reference}$) is the sum of the distances of all legs of all round trips, as shown by Equation (43):

$$D_{reference} = \sum_{n=1}^{o}\sum_{k=1}^{l}\sum_{s=1}^{t}(D_{reference,\mathrm{s,n\text{-}1},k} + D_{reference,n-1,n,k} + D_{reference,n,s,k})$$

$$\forall\ 0<k\leq l,\ l>0,\ 0<n\leq o,\ o>0,\ 0<s\leq t,\ t>0 \tag{43}$$

Distances are also classified depending on the time of the day, being peak hour, off-peak hour or night, at which they are covered. The total distance of round trip k during peak hour is the sum of all parts of the round trip that take place during peak hour. Analogously, the total distance during off-peak hour and during the night are calculated. This classification is made because the distance to be covered during peak hours versus off-peak hours and during the night is different, and transport at another timing can lead to other external cost values.

The time cost depends on the time needed for the transport in the reference case and the costs per time unit. The time unit costs are considered to be the same as the ones for the road pre-haulage in the project case. The time needed for the transport is arrived at by dividing the total distance to be covered in all round trips k by the average speed of the LGV. This relation is expressed in Equation (44):

$$U_{reference} = \frac{D_{reference}}{speed_{reference}} \quad (44)$$

Following Blauwens et al. (2016), a rest component can be added to the time and distance costs. In this case, the rest component consists of the congestion charging fee that has to be paid to enter the urban area by road. Anno 2019, no congestion charging fee is imposed in the urban area of Antwerp, so this cost equals zero in the current calculations. However, it might be applicable in other urban areas.

4.2.2 Ancillary revenue

The second component that determines the operational income is the ancillary revenue. This type of revenue can be an important benefit for the rail operator (Comi et al., 2014). Advertisement space on the rail vehicles can be sold to third parties. The potential ancillary revenue generated by selling advertisement space on a rail vehicle (wagon) or courier equipment is calculated based on the advertisement prices for passenger vehicles. Depending on the type of advertisement that is chosen, a different benefit is achieved (De Lijn, 2017).

4.2.3 Intermediate conclusion

The operational income consists of the user fee and the ancillary revenue. Table 45 provides an overview of the equations used to calculate the operational income. The user fee is considered equal to the saved costs because the reference case does not take place anymore. These saved costs consist of distance and time costs. The distance costs equal the distance costs of the road pre-haulage described in Section 4.1.2.2. For the time costs, a distinction is made between day and night transport. The ancillary revenue is the advertisement space on the vehicle, wagon or courier equipment that is sold.

Table 45 – Rail operational income in Flanders – non-food retail products (values for 2018)

	Dedicated freight vehicle	Freight wagon attached to passenger vehicle	Freight in passenger vehicle
* **User fee**	$D_{reference} * 0.28€/km + D_{reference,m} * 0.087€/km$ $+\iota * \frac{D_{reference,peak} + D_{reference,off-peak}}{speed_{reference,day}} * 30€/h + (1-\iota) * \frac{D_{reference,night}}{speed_{reference,night}} * 1.25 * 30€/h$		
* **Ancillary revenue**	*ancillary*		

Source: Own creation

After having determined the costs (Section 4.1) and the benefits (Section 4.2), the financial and economic appraisal is conducted in the next section for a case study in the urban area of Antwerp.

4.3 Financial and economic appraisal: case study

This section discusses the financial and economic appraisal of an urban rail freight case study in Antwerp. The costs and benefits are calculated in order to know whether using rail instead of road provides net benefits for the project leader. More specifically, the use of a tram to transport non-food retail products is examined in this section.

In order to analyse the success or failure of using a tram instead of road transport, the net benefit for the project leader is calculated, being the difference between the changes in private costs ΔC_p measured in euro and the changes in private revenue ΔR_p in euro, as shown in Equation (45):

$$Netbenefit_{tram,private} = \Delta R_p - \Delta C_p \quad (45)$$

If the net private benefits exceed a certain threshold value *x*, using the tram is considered to be a success. If the net benefits are lower than the threshold value *x*, it is considered a failure (see Chapter 3). The value of the threshold *x* depends on the project leader.

The changes in private revenue are calculated by means of Equation (46):

$$\Delta R_p = fee + ancillary \quad (46)$$

The changes in private costs are calculated by means of Equation (47):

$$\Delta C_p = investment + operation_{total} \quad (47)$$

Firstly, the case study is introduced in section 4.3.1. Secondly, the use of a dedicated freight tram is investigated in Section 4.3.2, the use of a freight wagon attached to a passenger tram in Section 4.3.3, and the transport of freight alongside passengers is discussed in Section 4.3.4.

4.3.1 Introduction to the case study

Since no general data on current urban freight distribution flows and costs are publicly available, the calculations are simplified in this research and done for a market in which one user is present, being Torfs, a retailer selling shoes. The fee paid by this user to the project leader is unknown and is proxied by the willingness-to-pay for the urban rail freight service. This willingness-to-pay is assumed to be equal to the saved costs of this user by not executing the reference case anymore. In order to analyse the costs and benefits of the urban rail freight solution, taking into account this project user, the reference case has to be clarified. This is the subject of Section 4.3.1.1. Secondly, the project case is explained in Section 4.3.1.2. All monetary data provided in this chapter are discounted to 2018 values.

4.3.1.1 Reference case

Torfs is a family company founded in 1948. Anno 2019, this retailer owns 75 shops in Flanders and 2 in Wallonia (see Figure 60), as well as a webshop available in Belgium and the Netherlands (Torfs, 2019b). Amongst the 75 shops, two shops are located in the neighbourhood of the tram network in the centre of the Antwerp urban area, making Torfs a potential urban rail freight user.

Figure 60 – Shops of Torfs

Source: Torfs (2019a)

Most of the shops of Torfs are currently supplied twice a week: either on Monday and Wednesday, or on Tuesday and Thursday. Six shops are the exception to this rule, including the shops of Groenplaats, Meir and Wijnegem Shopping Centre, which are located in Antwerp (Pittoors, 2019). Figure 61 shows these three shops.

Figure 61 – Shops of Torfs in Antwerp

Source: Torfs (2019a)

The shops Groenplaats, Meir and Wijnegem Shopping Centre are supplied four times a week, from Monday to Thursday. The reason is that these shops are city shops, which only have a limited storage space. To supply all its shops, Torfs owns three types of vehicles: one tractor-trailer with a maximum loading capacity of 33 roll cages, multiple rigid lorries with a maximum loading capacity of 18 roll cages and several vans of 3.5 tonnes with a maximum loading capacity of three roll cages. The vehicles are using diesel and have a euro standard 5 (Pittoors, 2019).

Some general characteristics of the round trip done by Torfs are displayed in Table 46. In the round trip under consideration, three customers are supplied. Hence, n is equal to three. The freight unit used by Torfs is a roll cage (see Figure 62). The dimensions of the roll cages are the same as for a euro pallet (0.80 m*1.20 m) and have a height of 1.77 m. An average roll cage has a weight of 180 kg and contains 150 articles.

Table 46 – General characteristics of the round trip of Torfs

Characteristics	Round trip considered	Variables model
Customers	Three customers: Meir, Groenplaats, Wijnegem Shopping Centre	n=3
Freight unit	Roll cage of 1.20 m*0.80 m*1.77 m, 150 articles per roll cage, 180 kg per roll cage	Roll cage
Main product type	Non-food retail products	m=4
Round trips	One round trip per day	k=1
Value of the goods	€80 per pair of shoes times 150 pairs of shoes = €12,000 per roll cage	$Value_m$=€12,000
Vehicle	Rigid lorry of 12 tonnes gross vehicle weight, euro 5, diesel, loading capacity of 18 roll cages	/

Source: Own creation based on Pittoors (2019)

The main product type transported is non-food items (m=4). One round trip is carried out per day, four times a week. Thus, k is equal to 1. The average sales value per roll cage is estimated at €80 per pair of shoes. Given an amount of 150 pairs of shoes per roll cage, the value of an average roll cage amounts to €12,000. The vehicle used for this round trip is a diesel lorry of 12 tonnes with euro standard 5.

Figure 62 – Roll cage used by Torfs

Source: Own picture

Moreover, the distinction between peak hour, off-peak hour and night is defined as follows at Torfs (Pittoors, 2019):

- Peak hour: 6 am – 10 am and 3 pm – 7 pm
- Off peak-hour: 10 am – 3 pm and 7 pm-11 pm
- Night: 11 pm – 6 am

When supplying the shops, the drivers follow the route suggested by Google Maps. Hence, the distances to be covered are obtained by Google Maps data. Table 47 shows the round trip that is conducted to supply the three shops. Until 2016, the drivers used to start their round trip at 6.30 am. Because of the increasing congestion problems, the drivers now start their round trips at 5 am. The round trip starts at the DC in Temse. The supplied shops are the shop Meir, then the shop Groenplaats, and then the shop Wijnegem Shopping Centre. After supplying these three shops, the driver goes back to the DC of Torfs in Temse (Pittoors, 2019). The characteristics of the different legs of the round trip are now described.

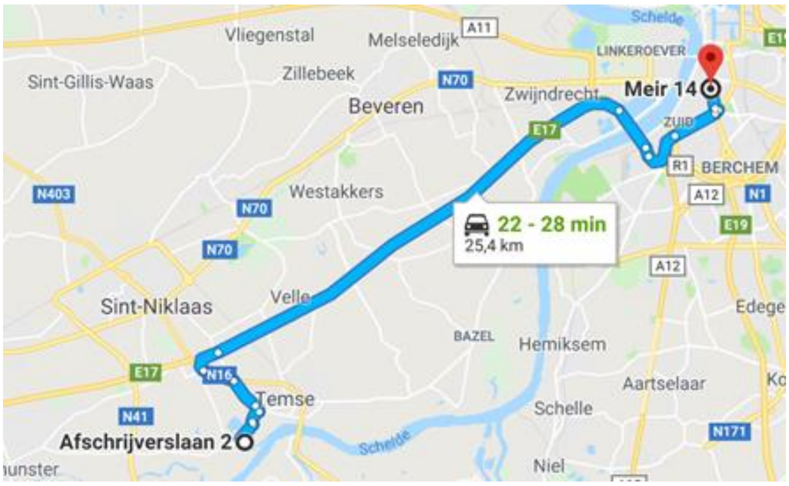
Table 47 – Round trip to supply the shops Meir, Groenplaats & Wijnegem Shopping Centre

Time	Activity	Route	Load
5 am	Drive DC → Shop Meir	Temse - Meir	Max. eight roll cages/day
5.30 am	Unloading goods & loading empty roll cages (several floors in shop → about one hour needed for delivery)	Shop Meir	Max. four roll cages/day
6.30 am	Drive Shop Meir → Shop Groenplaats	Meir – Grand Bazar	Max. four roll cages/day & four empty roll cages
6.30 am	Unloading goods & loading empty roll cages	Shop Groenplaats	Max. two roll cages/day
7 am	Drive Shop Groenplaats → Shop Wijnegem Shopping Centre	Grand Bazar – Wijnegem Shopping Centre	Max. two roll cages/day & six empty roll cages
7.30 am	Unloading goods & loading empty roll cages	Shop Wijnegem Shopping Centre	Max. two roll cages/day
8.30 am	Drive Shop Wijnegem Shopping Centre → DC	Wijnegem Shopping Centre – Temse	Max. eight empty roll cages
9.15 am	Unloading empty roll cages in DC	Temse	Max. eight empty roll cages

Source: Own creation based on Pittoors (2019)

The first leg of the round trip is shown in Figure 63. This leg takes place between the distribution centre in Temse (Afschrijverslaan 2) and the first shop at Meir (Meir 14).

Figure 63 – Leg between DC and shop Meir



Source: Own creation based on Google Maps

The characteristics of this leg are shown in Table 48. Maximum four roll cages are delivered at the shop Meir. The total distance covered is 25.5 km, which is divided over distance in suburban areas (3.5 km), on motorways (18 km) and in urban areas (4 km). The time needed to cover this leg is half an hour. The transport takes place during off-peak hour and the maximum total value of the delivered goods is €48,000.

Table 48 – Characteristics of the leg DC – Shop Meir

Characteristics	Leg DC – shop Meir	Variables model
Amount	Max. four roll cages of 180 kg per day delivered at shop Meir = max. 720 kg	Max. 720 kg
Distance	25.5 km, of which 3.5 km in suburban area, 18 km on motorways and 4 km in the urban area of Antwerp	$D_{reference,s,1,m}$= 18 km, $D_{reference,s,1,sub}$ = 3.5 km, $D_{reference,s,1,urb}$= 4 km
Time	30 min (measured on Tuesday 15 January 2019, leaving at 5 am) – the longest time is taken and rounded up since the transport is done by a lorry that cannot exceed a speed of 90 km/h, whereas a maximum speed of 120 km/h is assumed on the motorways in the calculations of Google Maps.	$U_{reference,s,1}$ = 0.5 h
Timing transport	Off-peak hour (5 am – 5.30 am)	Off-peak hour
Value of goods delivered	Four roll cages times €12,000 per roll cage = €48,000	Max. €48,000

Source: Own creation based on Pittoors (2019)

The second leg of the round trip is the leg between the shop Meir (Meir 14) and the shop Groenplaats (Grand Bazar). Figure 64 displays the route followed for this leg. It is clear from Figure 64 that the two shops are located close to one another.

Figure 64 – Leg between shop Meir and shop Groenplaats

Source: Own creation based on Google Maps

The main characteristics of the second leg of the round trip are shown in Table 49. Maximum two roll cages are delivered per day at the shop Groenplaats. The distance covered between shop Meir and shop Groenplaats is 0.2 km, which takes 0.02h. The transport occurs during off-peak hour and the maximum value of the goods being delivered at shop Groenplaats is €24,000.

Table 49 – Characteristics of the leg shop Meir – shop Groenplaats

Characteristics	Leg shop Meir – shop Groenplaats	Variables model
Amount	Max. two roll cages of 180 kg per day delivered at shop Groenplaats = max. 360 kg	Max. 360 kg
Distance	0.2 km, all in the urban area of Antwerp	$D_{reference,1,2,urb}$= 0.2 km
Time	1 min (measured on Tuesday 15 January 2019, leaving at 6.30 am)	$U_{reference,1,2}$ = 0.02 h
Timing transport	Off-peak hour (6.30 am)	Off-peak hour
Value of goods delivered	Two roll cages times €12,000 per roll cage = €24,000	Max. €24,000

Source: Own creation based on Pittoors (2019)

The third leg of the round trip is the part between the shop at Groenplaats and the shop at Wijnegem Shopping Centre (see Figure 65).

Figure 65 – Leg between shop Groenplaats and shop Wijnegem Shopping Centre

Source: Own creation based on Google Maps

The main characteristics of the third leg are summarised in Table 50. The maximum load delivered at the shop Wijnegem Shopping Centre is two roll cages. The distance to be covered between the shop Groenplaats and the shop Wijnegem Shopping Centre is 9 km, which is all in the Antwerp urban area. The time needed is half an hour. The transport takes place during peak hour and the total value of the delivery is maximum €24,000.

Table 50 – Characteristics of the leg shop Groenplaats – shop Wijnegem Shopping Centre

Characteristics	Leg shop Groenplaats – shop Wijnegem Shopping Centre	Variables model
Amount	Max. two roll cages of 180 kg per day delivered at shop Groenplaats = max. 360 kg	Max. 360 kg
Distance	9 km, all in the urban area of Antwerp	$D_{reference,2,3,urb}$= 9 km
Time	30 min (measured on Tuesday 15 January 2019, leaving at 7 am)	$U_{reference,2,3}$ = 0.5 h
Timing transport	Peak hour (7 am – 7.30 am)	Peak hour
Value of goods delivered	Two roll cages times €12,000 per roll cage = €24,000	Max. €24,000

Source: Own creation based on Pittoors (2019)

The last leg of the round trip consists of the trip from the last customer back to the distribution centre. This last leg is shown in Figure 66.

Figure 66 – Leg between shop Wijnegem Shopping Centre and DC in Temse

Source: Own creation based on Google Maps

The main characteristics of the last leg of the round trip are shown in Table 51. On the way back to the distribution centre, maximum eight empty roll cages are taken. The total distance to be covered is 34 km, which consists of 3.5 km in suburban areas, 26 km on motorways and 4.5 km in the Antwerp urban area. The total time needed to cover the total distance is one hour, since the transport is taking place during peak hour.

Table 51 – Characteristics of the leg shop Wijnegem Shopping Centre – DC Temse

Characteristics	Leg shop Wijnegem Shopping Centre - DC	Variables model
Amount	Max. eight empty roll cages of 30 kg per day transported back to DC, = max. 240 kg	Max. 240 kg
Distance	34 km, of which 3.5 km in suburban area, 26 km on motorways and 4.5 km in the urban area of Antwerp	$D_{reference,3,s,m}$= 26 km, $D_{reference,3,s,sub}$ = 3.5 km, $D_{reference,3,s,urb}$= 4.5 km
Time	60 min (measured on Tuesday 15 January 2019, leaving at 8.30 am)	$U_{reference,3,s}$ = 1 h
Timing transport	Peak hour (8.30 am – 9.30 am)	Peak hour

Source: Own creation based on Pittoors (2019)

The total distance covered in the reference case can now be obtained by adding the distances of all legs:

$D_{reference,m}$ = 18 km + 26 km = 44 km
$D_{reference,sub}$ = 3.5 km + 3.5 km = 7 km
$D_{reference,urb}$ = 4 km + 0.2 km + 9 km + 4.5 km = 17.7 km
$D_{reference}$ = 44 km + 7 km + 17.7 km = 68.7 km

Analogously, the total time needed to cover the distance of 68.7 km can be obtained by adding the time of all legs:

$U_{reference}$ = 0.5h + 0.02h + 0.5h + 1h = 2.02h

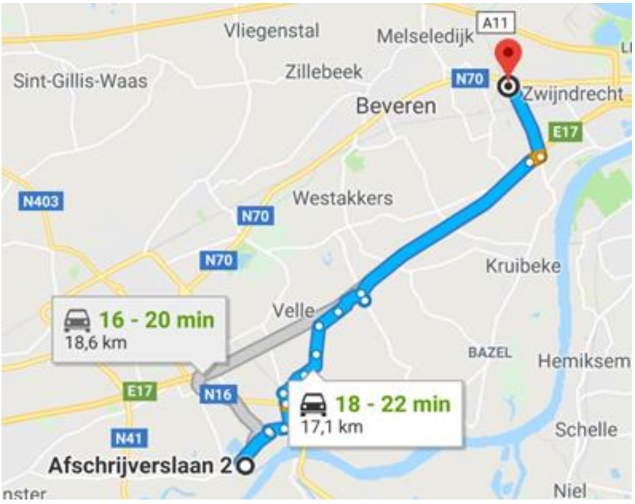
Hence, the average speed during the current road transport is 34.01 km/h. Furthermore, the labour cost of a driver is around 30 €/h (Pittoors, 2019). All legs of the considered round trip have now been discussed. In other words, the current urban freight distribution of Torfs with respect to the supply of three shops in Antwerp is explained. In order to know whether it is beneficial for the project leader, i.e. the government, to implement a rail-based urban freight solution, given this one project user, the project case has to be clarified. This is done in the following section.

4.3.1.2 Project case

The project case of the urban freight distribution of Torfs to three shops in Antwerp consists of the use of tram transport. The urban rail freight supply chain comprises different legs, being the road pre-haulage, the handling and storage, the rail leg and the road post-haulage. The service offered by the government is a door-to-door service, including all legs of the rail freight supply chain, since the reference case also consists of a door-to-door service.

Firstly, the need for road pre-haulage has to be examined. The distribution centre of Torfs is not located next to a tram stop. Hence, road pre-haulage is needed in order to use the tram to bring goods to the shops in Antwerp. The closest tram stop from the viewpoint of the distribution centre of Torfs is P+R Melsele. This means that the road pre-haulage takes place between the distribution centre in Temse and tram stop P+R Melsele. The route that has to be covered by lorry is shown in Figure 67.

Figure 67 – Round trip road pre-haulage



Source: Own creation based on Google Maps

For the road pre-haulage, it is assumed that the same lorry as in the reference case is used. Table 52 describes the main characteristics of the road pre-haulage. The total distance to be covered is 17 km, of which 10 km is covered in suburban area and 7 km on motorways. The time needed for the pre-haulage transport is considered to be around 25 minutes, or 0.42h. The transport takes place during off-peak hours, as in the reference case.

Table 52 – Characteristics of the road pre-haulage

Characteristics	Road pre-haulage	Variables model
Amount	Max. eight roll cages of 180 kg per day = max. 1,440 kg	Max. 1,440 kg
Distance	17 km, of which 10 km in suburban area, 7 km on motorways	$D_{pre,m}$= 7 km, $D_{pre,sub}$ = 10 km
Time	25 min (measured on Tuesday 15 January 2019, leaving at 5 am)	U_{pre} = 0.42 h
Timing transport	Off-peak hour (5 am – 5.25 am)	Off-peak hour

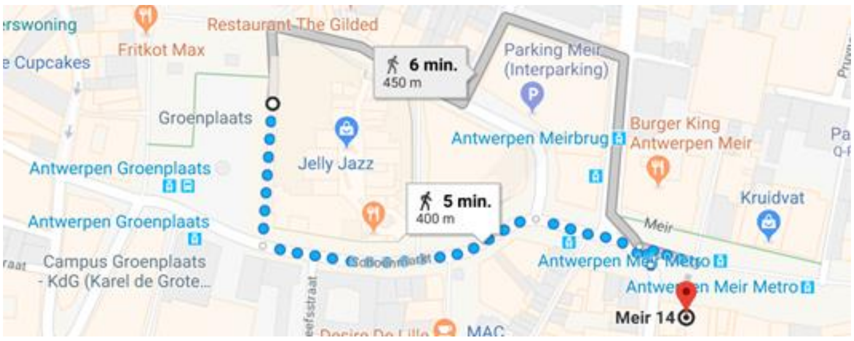
Source: Own creation

Secondly, handling and storage needs to be considered. Torfs declares that it does not want its goods to be stored at the handling and storage points. The company prefers to keep the storage of the goods in own account. All shops already use their shop space as much as possible for sales purposes. Hence, the handling and storage points between the road pre-haulage and the tram leg and between the tram leg and the road post-haulage if applicable, serve as transit platforms and not as distribution centres. If Torfs would decide to outsource storage, the handling and storage point at the edge of the urban area could serve as a distribution centre. This could lead to a reduction of the in-store inventory and hence, a benefit. For the shops Meir and Groenplaats, the tram stop "Groenplaats" (ground level) is chosen to unload the goods. For the shop Wijnegem Shopping Centre, the stop "Wijnegem Shopping Centre" is chosen.

Thirdly, the rail leg has to be discussed. Three types of rail transport are possible, a dedicated freight tram, a freight wagon attached to a passenger tram, or the transport of freight alongside passengers. For all three types, it has to be taken into account that the tram shares its way with road traffic at some parts of the tram network in Antwerp. Hence, the average speed of the tram transport is assumed to be 15 km/h. No ancillary revenue can be obtained for all three types of tram transport. Torfs has advertisement on its own lorries, so it is assumed that no differences in ancillary revenue exist between advertisement on a lorry, or on a tram vehicle, wagon or backpack. The tram transport takes place during off-peak hours at daytime. The other characteristics of the tram transport are described for every type of tram transport separately. This is done in Section 4.3.2 (dedicated freight tram), Section 4.3.3 (freight wagon attached to passenger tram) and Section 4.3.4 (freight alongside passengers).

Fourthly, the road post-haulage is clarified. For each of the three shops considered, it has to be determined whether road post-haulage is needed. With respect to the shop Meir, road post-haulage is needed. Figure 68 shows the distance to be covered between the tram stop "Groenplaats" and the shop at Meir. This distance equals 0.4 km and thus, it is assumed that this is more than the distance that has to be covered between the lorry and the shop in the reference case.

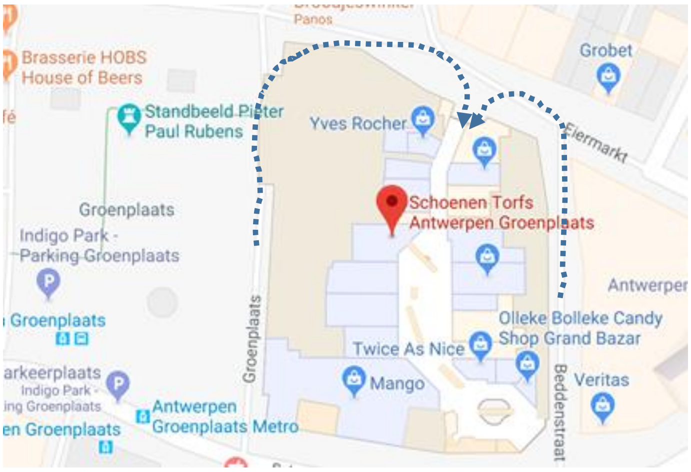
Figure 68 – Leg between tram stop Groenplaats and shop Meir



Source: Own creation based on Google Maps

The shop Groenplaats is located very nearby the tram stop at Groenplaats. Therefore, it is assumed that the distance to be covered coming from the tram stop is more or less the same distance as the one to be covered if the goods arrive by lorry, in which case the goods are unloaded in Beddenstraat (see Figure 69). Hence, no post-haulage is required to supply the shop at Groenplaats, since only differences between the reference and project case are taken into account in the analysis.

Figure 69 – Leg between tram stop Groenplaats and shop at Groenplaats



Source: Own creation based on Google Maps

The shop at Wijnegem shopping Centre is located at 120m from the tram stop Wijnegem Shopping Centre (see Figure 70). This is a bit further than when the goods arrive by lorry. Hence, road post-haulage is needed here.

Figure 70 – Leg between tram stop Wijnegem Shopping Centre and shop Wijnegem Shopping Centre

Source: Own creation based on Google Maps

For the shops where road post-haulage is needed, the way the post-haulage is executed needs to be decided on. The option where a shop employee picks up the goods at the tram stop is very unlikely because of two reasons. Firstly, the employees are in general present in the shops from 9.30 am, which is too late to pick up the goods at the tram stop. Secondly, the policy of Torfs is that the employees are paid to sell goods and to offer service to customers. Thus, the option of employees picking up goods at the tram stop is not preferred by Torfs (Pittoors, 2019).

From an organisational perspective, it is possible that a courier brings the goods from the tram stop to the shops. However, in case of a dedicated freight tram or a freight wagon attached to a passenger tram, roll cages are used as freight units. These roll cages are heavy and difficult to steer over cobble stones and curbs. Therefore, it would be better to unload the shoe boxes from the roll cages at the tram stop and to load them on another transport mode. The drawback of this solution is the additional handling needed, causing extra operational costs. In order to fasten this process, the shoe boxes are tied together per six boxes, see Figure 71. This causes an additional handling cost at the DC of Torfs. However, for deliveries at the shop Meir, this is always done in the reference scenario and hence, no additional cost has to be counted here. Unloading one roll cage with shoe boxes that are tied together takes around 10 minutes. In the calculations in this chapter, it is assumed that a courier can push the roll cage to the shop. Adding extra handling time adds another cost. This could be examined later on, if the urban rail-based system proves to be viable when the courier pushes the roll cages.

Figure 71 – Shoe boxes tight together

Source: Own picture

Furthermore, it is possible that a courier brings the goods to the shop by cargo bike. Given the short distance that has to be covered for the post-haulage leg, the use of an LGV is not considered here.

The reference and project case are explained and can now be compared to each other. For the project case, three types of rail transport are considered. Section 4.3.2 evaluates the use of a dedicated freight tram. Section 4.3.3 analyses the use of a freight wagon attached to a passenger tram and Section 4.3.4 discusses the potential of transporting the goods alongside passengers in a passenger tram. For a dedicated freight tram and a freight wagon attached to a passenger tram, the yearly costs and benefits are provided, and a financial and economic analysis is done. Concerning the transport of parcels alongside passengers, the net benefits per parcel are calculated.

4.3.2 Dedicated freight tram

The first type of rail transport considered is the use of a dedicated freight tram. A financial and economic analysis are carried out here in order to know the return on capital and the return on investment for the project leader respectively. Table 53 shows the values of the inputs used in this analysis, as well as the annual costs and operational income.

With respect to the investment, a PCC-tram is used as a traction unit, which has a remaining lifespan of 15 years. The nodal infrastructure, line infrastructure and wagon are assumed to have a remaining lifespan of 30 years. The total investment needed is the sum of the investment costs for the rolling stock (€512,274), the line infrastructure (€267,189) and the nodal infrastructure (€9,369). The line infrastructure that has to be constructed consists of a siding at the handling and storage point P+R Melsele, since all available tracks are used by the passenger transport. Hence, a freight tram cannot occupy these tracks for a long time. Next, a siding is constructed at tram stop Wijnegem Shopping Centre, where no free space is available for the freight tram as well. The time horizon considered in this analysis is 30 years. Thus, the residual value of the infrastructure and rolling stock is zero and after 15 years, the PCC tram has to be substituted by another one. This is reflected by the replacement cost of €2,000.

Table 53 – Inputs and annual costs and revenue for a dedicated freight tram (values for 2018)

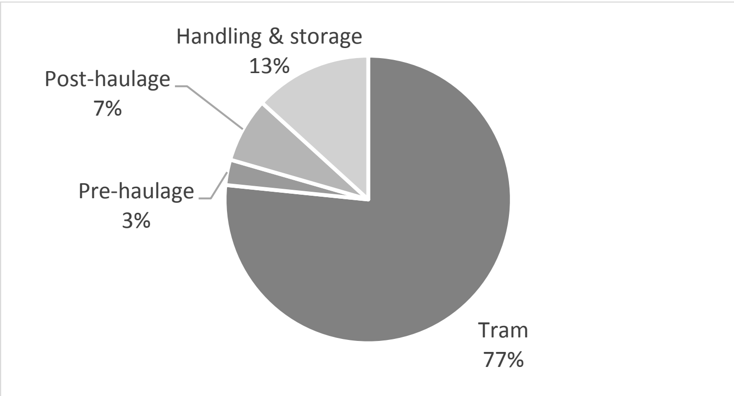
Variable	Unit	Value
Investment		
Lifespan of the nodal infrastructure	years	30
Lifespan of the rolling stock: traction unit	years	15
Lifespan of the rolling stock: flat wagon	years	30
Lifespan of the line infrastructure	years	30
Rolling stock (1)	€/lifespan	512,274
Line infrastructure (2)	€/lifespan	267,189
Nodal infrastructure (3)	€/lifespan	9,369
Total investment (1+2+3)	€/lifespan	788,832
Residual value of the rolling stock	€	0
Replacement costs rolling stock	€	2,000
Loan	%	50%
Lifespan loan	years	30
Interest loan	%	1.35%
Inflation, discounting and taxes		
Inflation	%	2.30%
Taxes on profit	%	33.99%
Financial discount rate	%	4%
Operational costs		
Tram (4)	€/year	126,749
Road pre-haulage (5)	€/year	4,730
Road post-haulage (6)	€/year	12,044
Handling & storage (7)	€/year	21,931
Total operational cost (4+5+6+7)	€/year	165,454
Operational income		
User fee (8)	€/year	17,405
Ancillary revenue (9)	€/year	0
Total operational income (8+9)	€/year	17,405

Source: Own creation

Furthermore, it is assumed that the investment is for 50% financed by public equity and for 50% by a loan. The loan is paid back over 30 years and the interest rate is 1.35% (NBB, 2019d). The inflation is assumed to be 2.30% (NBB, 2019c), taxes on profit are 33.99% (Belgische Federale Overheidsdiensten, 2019) and a financial discount rate of 4% is applied.

The operational costs consist of the costs occurring in all legs of the urban rail freight supply chain. Figure 72 shows the share of the urban rail freight supply chain legs in the total operational costs. The operational costs of the tram leg are the highest (77%), followed by the ones of handling and storage (13%), post-haulage (7%) and pre-haulage (3%). The operational income of the project leader consists only of the user fee for the urban rail freight service, which equals in this case the savings in the operational cost of the urban freight distribution in the reference case.

Figure 72 – Share of the supply chain legs in the operational cost of a dedicated freight tram



Source: Own creation

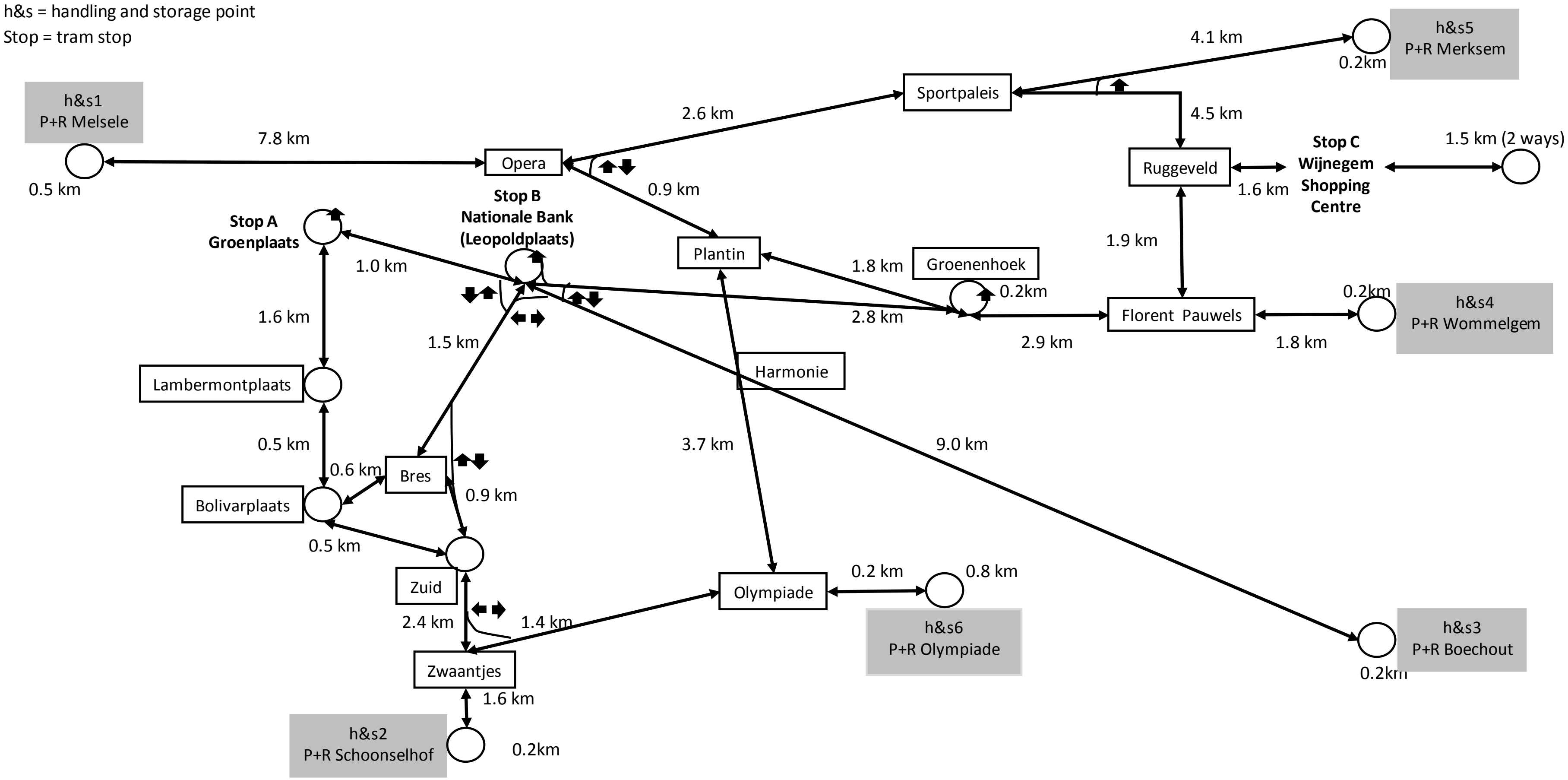
When leaving the investment costs out of the analysis and only considering the operational costs of the project case (€165,454) and the operational costs of the reference case (€17,405), it is clear that the reference case is characterised by lower operational costs than the project case. This is mainly due to the high operational costs of the tram leg. Therefore, these costs are investigated more in depth.

The yearly operational tram costs consist of distance costs (€89,908), time costs (€14,377) and track access charges (€22,464). The distance costs include the maintenance of the tram vehicle, electricity, insurance, and labour costs of the tram driver. The distance to be covered by a dedicated freight tram can be seen in Figure 73. The handling and storage point chosen is P+R Melsele, and the tram stops are Groenplaats and Wijnegem Shopping Centre. The time costs are related to the labour costs of the courier who is accompanying the goods in the dedicated freight tram. The track access charges are the fee paid to the infrastructure owner for using the tram infrastructure.

Given the fact that the tram operational costs are much higher than the current costs by lorry, the costs of road pre- and post-haulage and handling and storage do not have to be analysed further at this moment. The high distance costs of the tram transport are explained by two factors: the distance covered and the unit distance cost. The distance to be covered amounts 43.2 km. This is because coming from P+R Melsele, the tram only passes stop Groenplaats in the underground level (called "Premetro"), where the tram cannot stop to unload goods, since this would disturb the passenger transport. In order to arrive at the ground level stop Groenplaats, the tram has to make a long detour (see Figure 73). The time costs are related to the courier that accompanies the goods during the transport. This additional labour factor also increases the tram operational costs.

The investment in this project is now analysed from a financial and from an economic viewpoint, although it is already clear from Table 53 that it is not viable under the current project case conditions. Therefore, the sensitivity and scenario analyses in Chapter 6 are crucial to find out under which conditions the project would become viable. Given the high operational costs of the tram leg, it is already clear that this variable receives more attention in Chapter 6.

Figure 73 – Tram network Antwerp (status 2017) for a dedicated freight vehicle



Source: Own creation

4.3.2.1 Financial analysis

In the financial analysis, the return on capital is calculated. In order to do this, the revenue and residual value of the infrastructure are calculated and the operational cost and the cost of the financing sources are subtracted.

When doing the financial analysis over a time horizon of 30 years, Table 54 displays the results. The results for years 2-14 and 16-29 are not displayed, but these are analogous to the other years. Year 15 is displayed because after 15 years, the PCC traction unit is replace by another one. This is shown in the replacement costs of €2,000. Appendix 9 provides the full financial analysis over 30 years.

Table 54 – Financial analysis of a dedicated freight tram in Antwerp (values in $€_{2018}$)

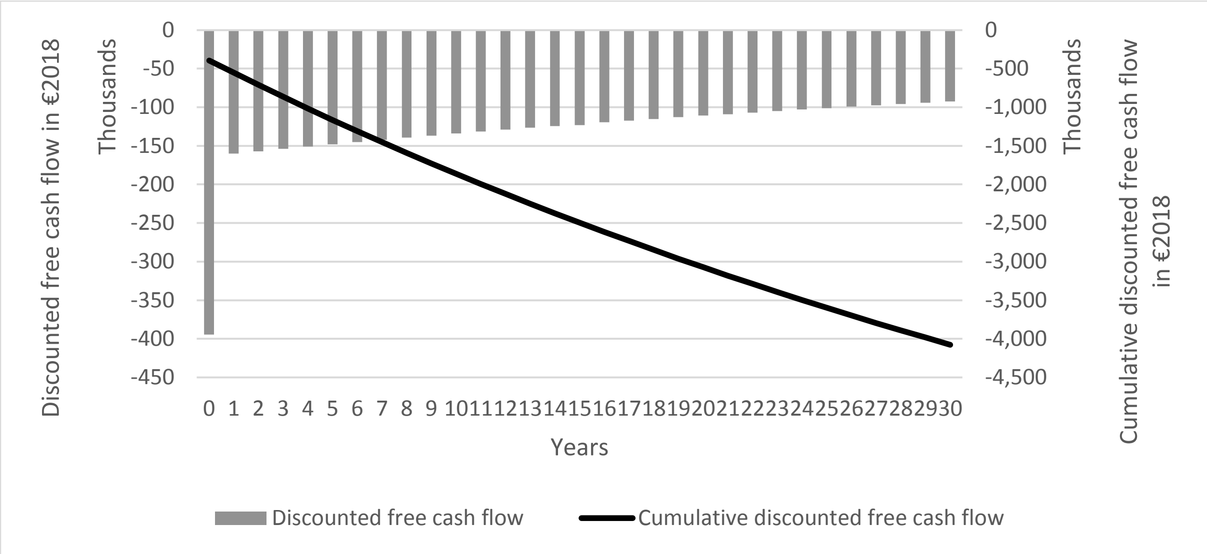
Item	Year					
	0	1	2-14	15	16-29	30
Own public + private equity	394,416					
Loan over 30 years	393,416	380,302	…	196,708	…	0
Loan over 15 years	1,000	933	…	0	…	0
Interest		5,325	…	2,833	…	177
Loan repayment		13,181	…	13,181	…	13,114
Depreciation rolling stock		17,142	…	17,142	…	17,142
Depreciation nodal infrastructure		312	…	312	…	312
Depreciation line infrastructure		8,906	…	8,906	…	8,906
Total financial cost	**394,416**	**18,505**	**…**	**16,014**	**…**	**13,291**
Tram		126,749	…	174,262	…	245,097
Road pre-haulage		4,730	…	6,503	…	9,146
Road post-haulage		12,044	…	16,559	…	23,290
Handling & Storage		21,931	…	30,152	…	42,408
Replacement costs		0	…	2,000	…	0
Total operational + replacement cost		**165,454**	**…**	**229,476**	**…**	**319,941**
Operational income		17,405	…	23,929	…	33,656
Residual value		0	…	0	…	0
Total inflows	**0**	**17,405**	**…**	**23,929**	**…**	**33,656**
EBITDA		-148,049	…	-205,547	…	-286,285
Operational result		-174,410	…	-231,908	…	-312,646
EBT		-179,735	…	-234,741	…	-312,823
TAXES		0	…	0	…	0
Net result after taxes		-179,735	…	-234,741	…	-312,823
Cash flow	-394,416	-153,374	…	-208,380	…	-286,462
Free cash flow		-166,554	…	-221,561	…	-299,576
Discounted free cash flow	-394,416	-160,148	…	-123,025	…	-92,365
Cumulative discounted free cash flow	**-394,416**	**-554,564**	**…**	**-2,496,344**	**…**	**-4,076,528**

Source: Own creation

Figure 74 shows the results of Table 54 graphically by displaying the discounted free cash flow (bars) and the cumulative discounted free cash flow (line). It is clear from Table 54 and Figure 74 that the project should not be executed. This is confirmed by the resulting net present value of -€4,076,528 and a present value to capital ratio of -5.17. The internal rate of return cannot be calculated, since all cash flows are negative over the considered time horizon. This was expected, since it is clear from

Table 53 that the operational income does not compensate for the operational costs, abstracting from the investments needed.

Figure 74 – (Cumulative) discounted free financial cash flow for a dedicated freight tram in Antwerp



Source: Own creation

From a financial viewpoint, introducing the urban rail freight solution with a dedicated freight tram in Antwerp, given the user considered in this research, is not profitable for the project leader. In the next step, the analysis is done from an economic viewpoint, measuring the return on investment.

4.3.2.2 Economic analysis

The results of the economic analysis are displayed in Table 55. The main difference with the financial analysis is that the financing sources are not taken into account in this analysis. The full economic analysis for 30 years is added in Appendix 10.

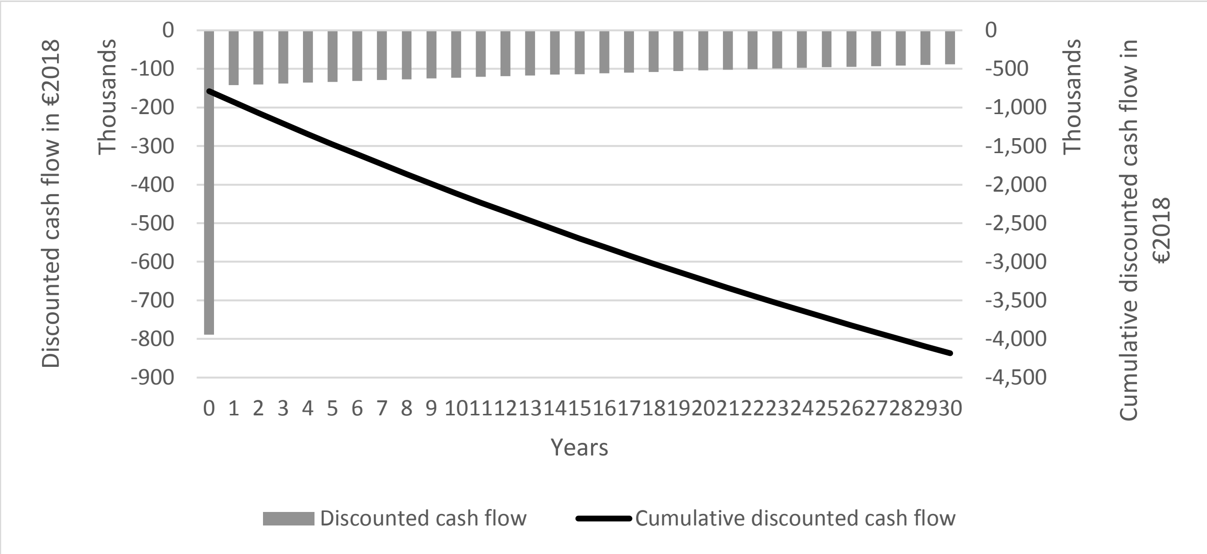
Table 55 – Economic analysis of a dedicated freight tram in Antwerp (values in $€_{2018}$)

Item	Year					
	0	1	2-14	15	16-29	30
Initial investment	**788,832**	**0**	…	**0**	…	**0**
Tram		126,749	…	174,262	…	245,097
Road pre-haulage		4,730	…	6,503	…	9,146
Road post-haulage		12,044	…	16,559	…	23,290
Handling & storage		21,931	…	30,152	…	42,408
Replacement costs		0	…	2,000	…	0
Total operational + replacement cost		**165,454**	…	**229,476**	…	**319,941**
Operational income		17,405	…	23,929	…	33,656
Residual value		0	…	0	…	0
Total inflows		**17,405**	…	**23,929**	…	**33,656**
Net result		-148,049	…	-205,547	…	-286,285
Cash flow	-788,832	-148,049	…	-205,547	…	-286,285
Discounted cash flow	-788,832	-142,355	…	-114,133	…	-88,267
Cumulative discounted cash flow	**-788,832**	**-931,187**	**…**	**-2,697,421**	**…**	**-4,187,105**

Source: Own creation

The discounted cash flow and the cumulative discounted cash flow are for the considered time horizon graphically displayed in Figure 75. The obtained net present value is -€4,187,105 and the present value to capital ratio equals -5.31. The internal rate of return can again not be calculated, since all cash flows are negative.

Figure 75 – (Cumulative) discounted economic cash flow for a dedicated freight tram in Antwerp



Source: Own creation

The financial and economic costs and benefits for 2018 can also be calculated per parcel. This calculation leads to private costs of 0.77 €/parcel and private benefits of 0.07 €/parcel. Combining these two, a net private cost of 0.70 €/parcel has to be paid for. Hence, from an economic viewpoint as well, the use of a dedicated freight tram in Antwerp is not viable for the project leader, given the reference and project case under consideration. The main issue are the elevated operational costs of the tram leg. In the next section, another type of tram transport is investigated, namely the use of a freight wagon attached to a passenger tram.

4.3.3 Freight wagon attached to a passenger tram

For the considered case study, the use of a freight wagon attached to a passenger vehicle is not likely, given the current route schedule of the passenger trams in Antwerp. The reason is that the chosen tram stops for the case study, being Groenplaats (ground level) and Wijnegem Shopping Centre, are anno 2019 not served by one and the same passenger tram line. Moreover, from the chosen handling and store point P+R Melsele, stops Groenplaats[26] and Wijnegem Shopping Centre cannot be reached by passenger trams without changing trams.

The cost-benefit analysis is performed from the viewpoint of the government, including the tram operator. Therefore, it is assumed now that the government changes the passenger tram schedule, which results in one passenger tram line moving people from P+R Melsele via Groenplaats (ground level) to Wijnegem Shopping Centre. The route followed by the passenger tram is then the same as

[26] Stop Groenplaats can be reached in the underground, but goods cannot be unloaded in the underground. The ground level tram stop of Groenplaats is only reached by tram lines 4 and 7. Hence, none of the handling and storage points on Figure 73 serve tram stop Groenplaats at the ground level. Tram stop Wijnegem Shopping Centre can be reached from P+R Schoonselhof (h&s2) only.

the one followed by the dedicated freight tram, which is the shortest route between the handling & storage point and the two chosen tram stops (see Figure 73 on page 177).

Table 56 shows the inputs used, as well as the yearly costs and benefits for the use of a freight wagon attached to a passenger tram in Antwerp for the shoes transport of Torfs.

Table 56 – Inputs and annual costs and revenue for a freight wagon (values for 2018)

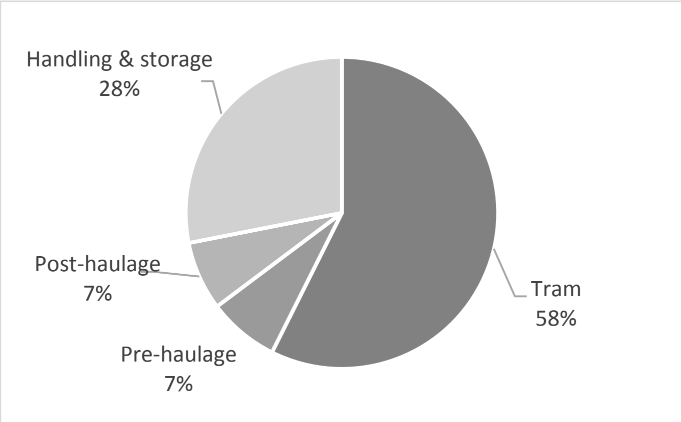
Variable	Unit	Value
Investment		
Lifespan of the nodal infrastructure	years	30
Lifespan of the rolling stock	years	30
Rolling stock (1)	€/lifespan	510,274
Nodal infrastructure (2)	€/lifespan	9,369
Total investment (1+2)	€/lifespan	519,642
Residual value of the rolling stock	€	0
Replacement costs rolling stock	€	0
Loan	%	50%
Lifespan loan	years	30
Interest loan	%	1.35%
Inflation, discounting and taxes		
Inflation	%	2.30%
Taxes on profit	%	33.99%
Financial discount rate	%	4%
Operational costs		
Tram (3)	€/year	36,854
Road pre-haulage (4)	€/year	4,730
Road post-haulage (5)	€/year	4,593
Handling & storage (6)	€/year	18,043
Total operational cost (3+4+5+6)	€/year	64,219
Operational income		
User fee (7)	€/year	17,405
Ancillary revenue (7)	€/year	0
Total operational income (7+8)	€/year	17,405

Source: Own creation

The rolling stock needed to transport goods in a freight wagon attached to a passenger tram is only a flat wagon. The predicted lifespan of this wagon is 30 years, so no replacement costs have to be made in the time horizon of the analysis. The nodal infrastructure investment is the same as for a dedicated freight vehicle. No line infrastructure is needed, since the flat wagon is attached to the passenger tram on the public tram network. This leads to a total investment cost of €519,642.

The annual operating costs are displayed in Table 56 for the different legs in the urban rail freight supply chain. The operational costs of the tram leg are much lower than for a dedicated freight tram. This can be explained by the distance costs of the tram leg. First of all, no track access charges have to be paid, since no separate traction is needed to pull the freight wagon. Secondly, it is assumed that the distance costs of a dedicated freight tram consist for 50% of the labour costs of the tram driver. These costs do not have to be added here, since the tram driver is running the passenger tram. Thus, this cost does not have to be assigned to the freight wagon. Thirdly, it is assumed that the remaining distance costs (half of 10.01 €/km) can again be halved, since only a freight wagon needs to be maintained, insured, etc. instead of a whole freight tram. This leads to a distance cost of 2.50 €/km instead of the one of 10.01 €/km used for the dedicated freight tram. The distance covered and the time needed to do so, are assumed to be identical as for the dedicated freight tram, since the same route is taken here. Figure 76 shows the shares of the supply chain legs in the total operational cost. The tram leg still counts for the highest share (58%), followed by handling and storage (28%), post-haulage (7%) and pre-haulage (7%).

Figure 76 – Share of the supply chain legs in the total operational cost of a freight wagon



Source: Own creation

The road pre-haulage costs amount €4,730 per year and these are identical as the ones for a dedicated freight tram. The road post-haulage costs are €4,593, which is again lower than for a dedicated freight tram. This can be explained by the fact that the tram driver does not need to wait while the courier is delivering the goods at the customers, which is the case for a dedicated freight tram. When using a freight wagon attached to a passenger tram, it is assumed that the goods are unloaded from the wagon while the passengers are boarding. When this action is over, the passenger tram continues its journey. An external courier picks up the goods at the transit platform and delivers the goods at the customer.

The yearly handling and storage costs equal €18,043, which is slightly lower than for a dedicated freight tram. The difference lies in the handling and storage costs between the rail and post-haulage leg. The tram driver does not need to wait while the goods are unloaded from the tram. This explains the cost decrease for the handling and storage.

Hence, the total annual operational cost is €64,219 for the use of a freight wagon attached to a passenger wagon. The operational income remains €17,405, which means that again, without considering the investments needed, the yearly costs are higher than the yearly potential operational income. However, the difference between these two is much lower than for the use of a dedicated freight tram.

In the next sections, the financial and economic analysis is carried out for the use of a freight wagon attached to a passenger tram.

4.3.3.1 Financial analysis

Table 57 displays the results of the financial analysis for the use of a freight wagon attached to a passenger tram in Antwerp. In order to make Table 57 comparable with Table 54, the results for year

15 are displayed, although no rolling stock replacement takes place when a freight wagon is attached to a passenger tram. The full financial analysis over 30 years is added in Appendix 11.

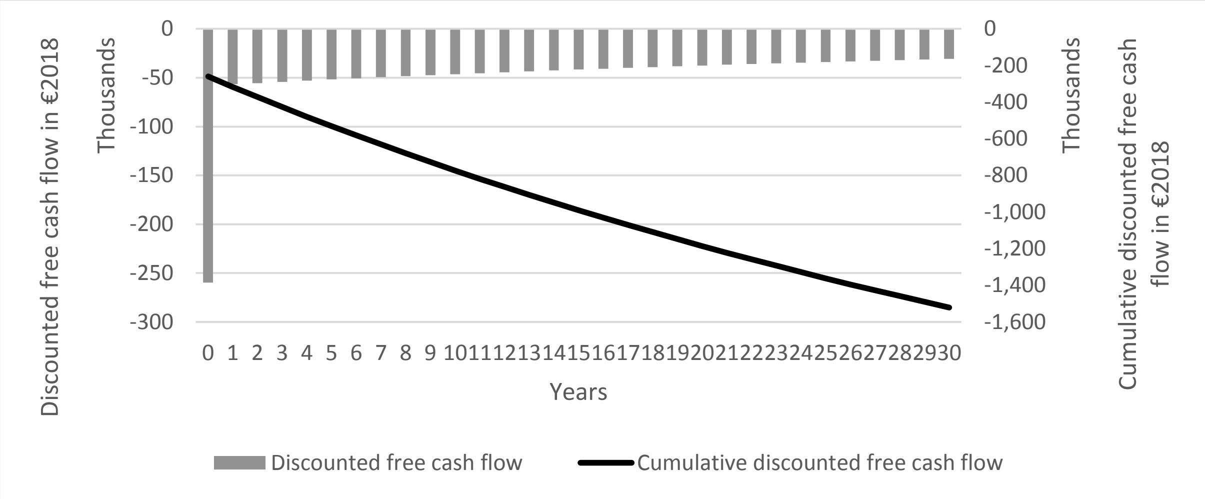
Table 57 – Financial analysis of a freight wagon in Antwerp (values in €$_{2018}$)

Item	Year					
	0	1	2-14	15	16-29	30
Own public + private equity	259,821					
Loan over 30 years	259,821	251,161	…	129,911	…	0
Interest		3,508	…	1,871	…	117
Loan repayment		8,661	…	8,661	…	8,661
Depreciation rolling stock		17,009	…	17,009	…	17,009
Depreciation nodal infrastructure		312	…	312	…	312
Total financial cost	**259,821**	**12,168**	**…**	**10,531**	**…**	**8,778**
Tram		36,854	…	50,669	…	71,265
Road pre-haulage		4,730	…	6,503	…	9,146
Road post-haulage		4,593	…	6,314	…	8,881
Handling & Storage		18,043	…	24,807	…	34,890
Replacement costs		0	…	0	…	0
Total operational + replacement cost		**64,219**	**…**	**88,293**	**…**	**124,182**
Operational income		17,405	…	23,929	…	33,656
Residual value		0	…	0	…	0
Total inflows	**0**	**17,405**	**…**	**23,929**	**…**	**33,656**
EBITDA		-46,815	…	-64,364	…	-90,527
Operational result		-64,136	…	-81,685	…	-107,848
EBT		-67,644	…	-83,556	…	-107,965
TAXES		0	…	0	…	0
Net result after taxes		-67,644	…	-83,556	…	-107,965
Cash flow	-259,821	-50,322	…	-66,235	…	-90,644
Free cash flow		-58,983	…	-74,895	…	-99,304
Discounted free cash flow	-259,821	-56,715	…	-41,587	…	-30,617
Cumulative discounted free cash flow	**-259,821**	**-316,536**	**…**	**-990,127**	**…**	**-1,520,951**

Source: Own creation

Table 57 shows that after a time horizon of 30 years, the cumulative discounted free cash flow is negative. This is also displayed in Figure 77. The resulting net present value equals -€1,520,951 and the present value to capital ratio amounts -2.93. The internal rate of return again cannot be calculated, since all cash flows are negative over the full time horizon.

Figure 77 – (Cumulative) discounted free financial cash flow for a freight wagon in Antwerp



Source: Own creation

In the next section, the economic analysis of using a freight wagon attached to a passenger tram is made.

4.3.3.2 Economic analysis

The outcome of the economic analysis of attaching a freight wagon to a passenger tram in Antwerp is displayed in Table 58. The full economic analysis for the time horizon of 30 years is added in Appendix 12.

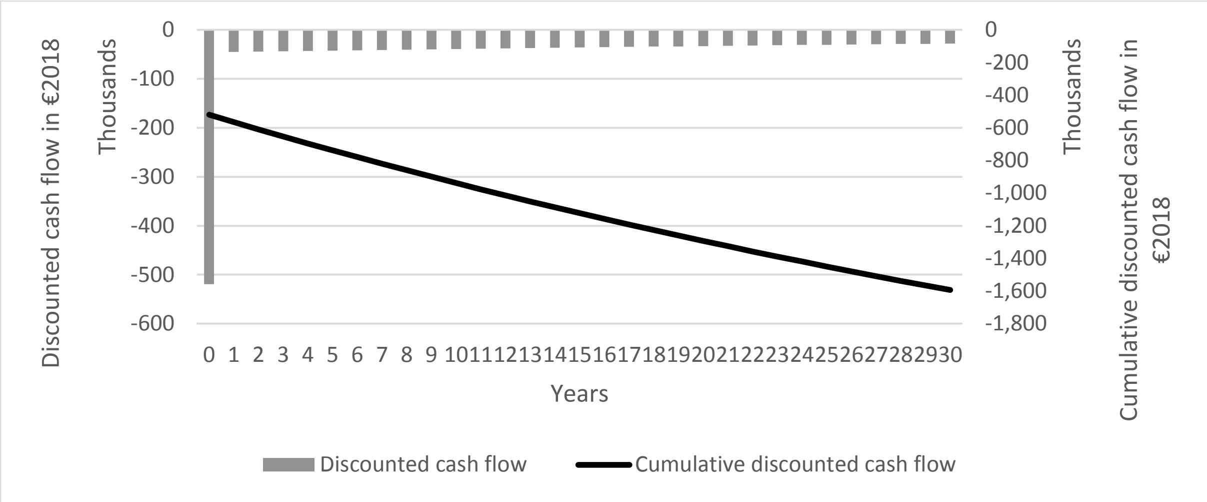
Table 58 – Economic analysis of a freight wagon in Antwerp (values in $€_{2018}$)

Item	Year					
	0	1	2-14	15	16-29	30
Initial investment	**519,642**	**0**	…	**0**	…	**0**
Tram		36,854	…	50,669	…	71,265
Road pre-haulage		4,730	…	6,503	…	9,146
Road post-haulage		4,593	…	6,314	…	8,881
Handling & storage		18,043	**…**	24,807	**…**	34,890
Replacement costs		0	…	0	…	0
Total operational + replacement cost		**64,219**	…	**88,293**	…	**124,182**
Operational income		17,405	…	23,929	…	33,656
Residual value		0	…	0	…	0
Total inflows		**17,405**	…	**23,929**	…	**33,656**
Net result		-46,815	…	-64,364	…	-90,527
Cash flow	-519,642	-46,815	…	-64,364	…	-90,527
Discounted cash flow	-519,642	-45,014	…	-35,739	…	-27,911
Cumulative discounted cash flow	**-519,642**	**-564,657**	**…**	**-1,122,810**	**…**	**-1,593,866**

Source: Own creation

The resulting net present value of the economic analysis equals -€1,593,866 and the present value to capital ratio is -3.07. The internal rate of return cannot be measured, given the fact that all cash flows are negative over the time horizon considered. Figure 78 shows the (cumulative) discounted cash flow graphically.

Figure 78 – (Cumulative) discounted economic cash flow for a freight wagon in Antwerp



Source: Own creation

The financial and economic costs and benefits can also be calculated for 2018 in euro per parcel. A private cost of 0.33 €/parcel has to be borne, while a private benefit of 0.07 €/parcel is obtained. Subtracting the benefit from the cost, a net private cost of 0.26 €/parcel has to be paid when shifting from road to tram. Two types of rail freight distribution for Antwerp are discussed and are not viable given all the chosen input values. In the next section, the third type of urban rail freight distribution, being the transport of parcels alongside passengers, is investigated.

4.3.4 Freight alongside passengers

When transporting freight alongside passengers, a courier carries goods and transports them in a passenger tram. It is assumed that a courier cannot take more than 8 kg of goods on his back per time. Hence, the reference case used in Section 4.3.2 and 4.3.3 is slightly adapted here in the sense that less goods are considered for urban delivery now. It is examined in this section whether using the tram is viable for some express deliveries. More specifically, the express delivery of some pairs of shoes is investigated here. Table 59 displays the new input data used in this analysis. Furthermore, it is assumed that the transport in the reference case, and hence also in the road pre-haulage of the project case, is done by a van of 3.5 tonnes. The other characteristics of the van are similar to the lorry of 12 tonnes used before.

Table 59 – New input data reference case

Shop	Number of pairs of shoes	Total weight	Total value
Meir	4	4kg	€320
Groenplaats	2	2kg	€160
Wijnegem Shopping Centre	2	2kg	€160

Source: Own creation

The other input values used, as well as the corresponding yearly costs and revenue are displayed in Table 60. It is clear from Table 60 that no investment has to be made in nodal infrastructure, line infrastructure or rolling stock. Hence, this type of rail transport is not the subject of a social cost-benefit analysis to evaluate transport investment decisions. Therefore, it is decided to continue with this analysis by calculating the cost difference in euro per parcel of using road (reference case) and rail (project case).

Table 60 – Inputs and annual costs and revenue for freight alongside passengers (values for 2018)

Variable	Unit	Value
Inflation, discounting and taxes		
Inflation	%	2.30%
Taxes on profit	%	33.99%
Financial discount rate	%	4%
Operational costs		
Tram (1)	€/year	9,060
Road pre-haulage (2)	€/year	4,229
Road post-haulage (3)	€/year	1,298
Handling & storage (4)	€/year	0
Total operational cost (1+2+3+4)	€/year	14,587
Operational income		
User fee (5)	€/year	15,853
Ancillary revenue (6)	€/year	0
Total operational income (5+6)	€/year	15,853

Source: Own creation

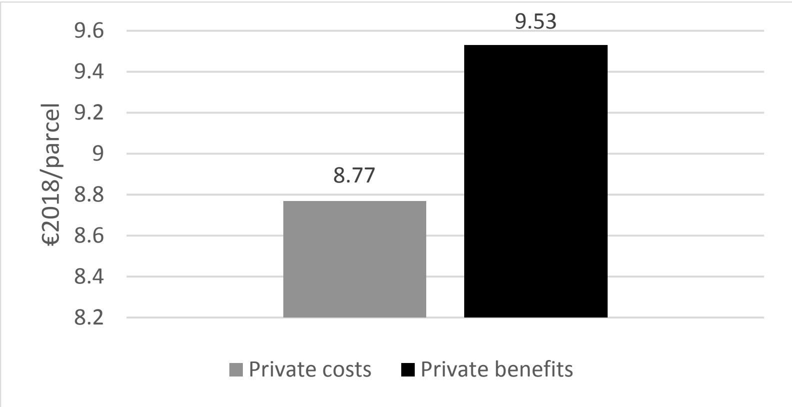
Before calculating the net benefits of using rail instead of road, the annual costs shown in Table 60 are explained. The yearly tram operational costs correspond to a daily cost of €42, given 52 weeks in a year and four days per week in which the shops are supplied. This daily cost comprises the labour costs of the courier. The annual ticket to use the trams in Antwerp (324 €/year) has to be added to this cost. The cost of the annual ticket is a fixed yearly cost, independent from the number of tram trips the courier makes. Hence, it is advantageous to make as many trips as possible, since then this fixed cost can be divided over more parcels, reducing the cost per parcel.

The road pre-haulage costs amount €4,229. These costs consist of a time cost (12.60 €/day) and a distance cost (7.73 €/day). These costs are lower than for the two previous rail types (Section 4.3.2 and Section 4.3.3), because here a van of 3.5 tonnes is used for the pre-haulage leg, which anno 2019 does not have to pay road pricing in Belgium.

The road post-haulage costs relate to the labour costs of the courier. The handling and storage costs are zero, since goods are not handled or stored at the handling and storage point or at the rail stop. In sum, it is clear that almost all operational costs come from the tram transport and more specifically, from the annual ticket that is bought.

Given the eight parcels, i.e. shoe boxes, which are delivered on a daily basis, Figure 79 provides the private costs and benefits of using the tram instead of the van in the reference case in euro per parcel. It is clear from Figure 79 that using rail costs €8.77 per parcel, whereas using the current road transport is characterised by a cost of 9.53 €/parcel. Hence, given all chosen input values, it would be profitable for Torfs to deliver some express pairs of shoes by tram instead of by van.

Figure 79 – Private costs and benefits of transporting parcels alongside passengers



Source: Own creation

Three types of rail transport have now been examined. In the next section, an intermediate conclusion is drawn. Note that the conclusions drawn in this chapter are all based on the case study under consideration. In Chapter 6 and Chapter 7, more generic conclusions are drawn.

4.3.5 Intermediate conclusion

The use of a tram for urban freight deliveries is financially and economically evaluated for three rail types: a dedicated freight tram, a freight wagon attached to a passenger tram, and the transport of parcels in a passenger tram. The appraisal is done for the Antwerp urban area and there is one user present, being the retailer Torfs. Table 61 provides an overview of the results of the financial and economic analysis.

Table 61 – Overview financial and economic analysis (values for 2018)

Aspect	Dedicated freight tram	Freight wagon attached to passenger tram	Freight in passenger tram
Amount of goods	8 roll cages	8 roll cages	8 parcels
Lorry/van in reference case	12 tonnes	12 tonnes	3.5 tonnes
Total investment	€788,832	€519,642	€0
Total annual operational cost	€165,454	€64,219	€14,587
Annual operational income	€17,405	€17,405	€15,853
Financial NPV	-€4,076,528	-€1,520,951	n/a
Financial IRR	n/a	n/a	n/a
Financial present value to capital ratio	-5.17	-2.93	n/a
Economic NPV	-€4,187,105	-€1,593,951	n/a
Economic IRR	n/a	n/a	n/a
Economic present value to capital ratio	-5.03	-3.07	n/a

Source: Own creation

The use of a dedicated freight tram and a freight wagon attached to a passenger tram can be compared, since in both cases, eight roll cages are transported and the lorry used in the reference case is the same. For the transport of parcels in a passenger tram, only eight parcels are transported per day and the van used for the reference case is a van of 3.5 tonnes. Hence, the costs of the reference case, i.e. the operational income of the project case, are different. Moreover, it is clear from Table 61 that no investment is needed to transport parcels in a passenger tram. Hence, this type of transport is not evaluated by a social cost-benefit analysis, but rather by a private cost analysis. For this rail type, the costs of transporting the parcels by van and by rail are compared to each other and expressed in euro per parcel. Under the current conditions of the case study, transporting the parcels by rail is the only of the three tram types that is profitable.

When transporting goods in a dedicated freight tram, or in a freight wagon attached to a passenger tram, different investments are needed. The operational costs between these two types of rail transport differ a lot in the given case study. The main reason for this difference lies in the access charges that have to be paid when using a dedicated freight tram, and the labour costs of the courier accompanying the goods. Moreover, the distance to be covered on the tram network is high for both types of rail transport, since the tram has to make a long detour to reach the chosen tram stops where the goods are unloaded.

For a dedicated freight tram and a freight wagon attached to a passenger tram, the operational costs exceed the operational income. Hence, the project case is not executed. This also becomes clear when considering the financial and economic net present value and the present value to capital ratio. The internal rate of return cannot be calculated, since all cash flows in the considered time horizon are negative.

The case study provides some interesting insights that are used as input for the scenario and sensitivity analyses in Chapter 6. The operational costs of the tram transport are very high in the current project cases. Hence, the effect of a decrease of these costs on the viability of the use of a tram is examined. These costs can be reduced by altering the tram distance to be covered, and by considering a concept in which only the tram driver is present during the tram transport, and no courier. The tram distance could be reduced by allowing the freight tram or wagon to be unloaded at the tram stop Groenplaats in the underground, or by choosing another handling and storage point, from where the tram stop can be accessed more quickly via the public tram network. Furthermore, it is investigated how the results change if more than one user is present in the market. In other words, what is the effect of an increase of the daily amount of goods to be transported and what is the required amount to be break-even?

4.4 Conclusion

This chapter offers the development of the generic cost-benefit model to evaluate the potential of using rail for urban freight distribution. The model provided in this chapter deals with the financial and economic analysis from the viewpoint of the project leader, i.e. the government. The financial and economic costs consist of the investments in line and nodal infrastructure and rolling stock on the one hand and the operational costs in all urban rail freight supply chain legs on the other hand. The financial and economic benefits comprise the operational income, which includes the user fee and the ancillary revenue. The user fee is proxied here by the cost savings related to the fact that the urban freight distribution of the reference case does not take place anymore when using rail.

The use of rail for urban freight distribution is then applied to a case study in Antwerp. One user of the system is considered, being the retailer Torfs. The costs and benefits of this case study are calculated for the use of a dedicated freight tram, a freight wagon attached to a passenger tram and the transport of parcels in a passenger tram. When using a dedicated freight tram or attaching a freight wagon to a passenger tram, it is financially and economically not viable to shift from road to rail, given the current case study conditions. Therefore, it is most interesting to add the consumer surplus and external costs to the analysis by conducting the socio-economic analysis in Chapter 5. Transporting freight alongside passengers is viable under the current conditions. However, further research is needed to know how sensitive the project outcome is to for example changes in the travel times. This is examined by sensitivity analyses in Chapter 6.

5. Socio-economic analysis of urban rail freight

Besides investigating the potential role of rail for urban freight distribution from the viewpoint of the project leader, the perspective of society can be applied. When using this perspective, the effects of the project case on project users and impactees are added to the analysis. The latter are measured by several authors as follows. Campos & Hernández (2010) define the social benefits of the construction of a new high-speed rail line in Spain as the changes in consumer and producer surplus. Sartori et al. (2015) and Blauwens et al. (2016) add next to changes in consumer and producer surplus savings in external costs to the socio-economic effects. In the current research, the supply curve is assumed to be horizontal, following for instance Jonkeren (2009) and Blauwens et al. (2016). The reasoning behind this is that input prices hardly increase when more inputs are purchased. Consequently, no producer surplus is present. This means that only changes in the consumer surplus and external cost savings are taken into account here. If the market supply curve is not horizontal, changes in producer surplus have to be added to the benefits.

The case study in Chapter 4 also shows that the use of a dedicated freight tram or a freight wagon attached to a passenger tram is not profitable from a financial and economic viewpoint, given the chosen input values. Hence, it is most interesting to examine whether adding changes in travel time and external costs to the calculations can lead to socio-economic benefits. These two effects are discussed in Section 5.1 and Section 5.2 respectively. All monetary data used in this chapter are valid for 2018.

5.1 Consumer surplus change

The first effect of the use of rail for urban freight distribution that is considered is the one on the project users. Shippers and receivers making use of the urban rail freight system can potentially benefit from time savings and hence, a decrease of their logistical costs. These benefits are expressed by the increase of consumer surplus of the project users (Blauwens et al., 2016).

The potential time savings are related to the shipped goods and they are present as the reduced in-transit inventory and hence, reduced logistical costs for the shipper or receiver of the goods (Blauwens et al., 2016; Campos & Hernández, 2010). When shifting from road to rail, the transport time, the shipment size and the number of replenishments can change. The shipment size and the number of replenishments have an effect on the cycle stock, safety stock and stock-out costs, and thus, the in-store stockholding surface, whereas the transport time affects the in-transit inventory.

5.1.1 In-store stockholding surface

When goods are delivered by rail in smaller and more frequent quantities, the cycle stock decreases. Hence, the customer needs less storage space and can use more of its shop surface as sales space. The goods can be stored in the handling and storage point at the edge of the urban area and transported to the customer just in time (Regué & Bristow, 2013). The holding cost of the goods depends amongst others on the land cost of the storage place. The difference in rent between the customer located in the urban area and a handling and storage point at the edge of the urban area, or the supplier located outside the urban area, is used to calculate the in-store stockholding surface reduction benefit. However, in the short term, customers cannot use their storage space in their shop in a flexible way. In the long run, customers could restructure their shop floor and assign more space to selling instead of storage purposes. Vice versa, less frequent deliveries lead to more in-store stockholding. This factor then becomes a cost instead of a benefit.

It is assumed in this research that most shops in the urban area do not alter their delivery and inventory policy when shifting from road to rail and hence, the change of the cycle stock, safety stock and stock-out costs equals zero. As a result, only the change of the inventory during transit due to a change of travel time remains as potential consumer surplus.

5.1.2 In-transit inventory

The reduced inventory carrying cost accounts for the benefits obtained because the inventory is for a shorter period of time in transit. Blauwens et al. (2016) measure the inventory costs during transit as the transit time multiplied by the cost of holding the inventory. The saved inventory costs during transit are according to this logic obtained by the change of the transit time related to the shift from road to rail. Vadali et al. (2017) obtain this benefit by multiplying the commodity value by the daily discount rate and the saved transit time. This method is especially valuable when perishable products are considered, which are characterised by a fast value depreciation. In the current research, non-food retail products are assumed to be transported and thus, the saved inventory costs during transit are calculated based on Blauwens et al. (2016), by means of Equation (48):

$$timesav = h * pallets * \frac{U_{reference} - U_{project}}{24} \tag{48}$$

in which

h	= the daily holding cost of non-food retail products, expressed in euro per pallet per day;
pallets	= the daily number of pallets transported to the customer(s), expressed in number of pallets;
$U_{reference}$	= the total time needed to deliver the non-food products at the customer(s) in the reference case, expressed in hours;
$U_{project}$	= the total time needed to deliver the non-food products at the customer(s) in the project case, expressed in hours.

Following Ayadi (2014), the daily holding cost for non-food retail products equals 0.11 €/pallet in 2018[27] (see Section 4.1.2.4).

Table 62 shows the time savings that can possibly be present for the three types of rail transport. For a dedicated freight vehicle, the time difference between the rail freight vehicle and the road transport determines the potential time savings. For a freight wagon attached to a passenger vehicle and freight transported alongside passengers, the time difference between the passenger rail vehicles and the road transport counts.

Table 62 – Consumer surplus of an urban rail freight supply chain

Consumer surplus	Symbol	Dedicated freight vehicle	Freight wagon attached to passenger vehicle	Freight in a passenger vehicle
Time savings	*timesav*	Reduced inventory carrying cost depending on difference dedicated freight vehicle time versus road time	Reduced inventory carrying cost depending on difference passenger vehicle time versus road time	

Source: Own creation based on Blauwens et al. (2016) and Campos & Hernández (2010)

[27] All monetary data in this chapter are discounted to $euro_{2018}$ values by means of Equation (7) in Section 3.2.2.

In sum, the consumer surplus exists of potential time savings and thus, potentially reduced in-transit inventory. The second aspect to be considered in the socio-economic analysis is the change of the impacts on society, i.e. the external costs.

5.2 External cost savings[28]

An investigation of the external costs plays an important role in the development of a social cost-benefit framework. Existing SCBAs applied to the use of trams and trains for urban freight distribution show the pivotal role of external costs in the profitability calculations. Alessandrini et al. (2012) find that the benefits of an MUDC in Rome coming from emissions equal 57% of total benefits in the conventional vehicles scenario and 65% of the benefits in the hybrid vehicles scenario. Regué & Bristow (2013) find that benefits related to externalities account for 8.4% of the total benefits in the case of using the freight tram for retail deliveries in the first year of operation. More specifically, the main external benefits are related to less congestion and account for 6.2% of the total benefits. When abstracting the benefits related to added value and stockholding activities and reverse logistics, externalities account for 33% of total benefits, while freight tram operations savings explain 67% of the benefits. Hence, it is worth to examine the external costs of the reference and project case a bit more in depth.

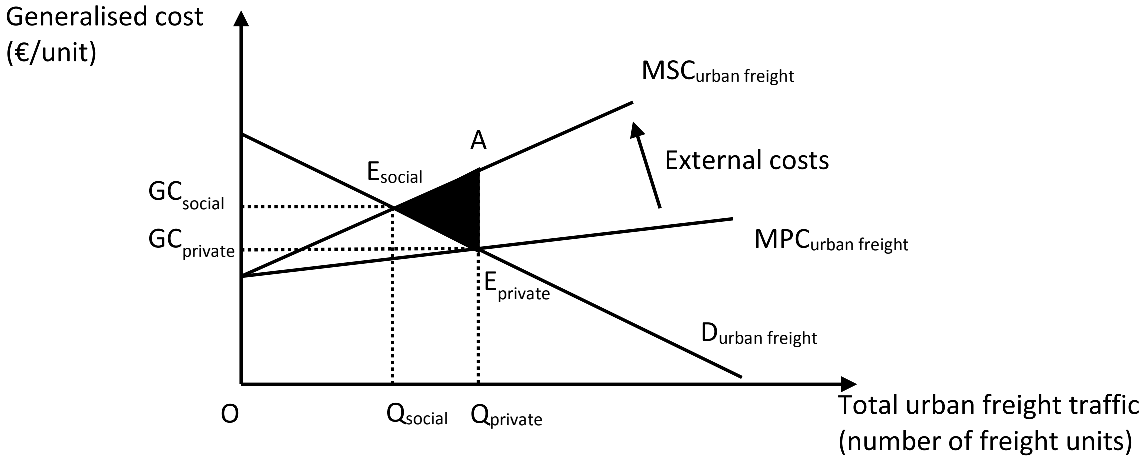
5.2.1 Theoretical background

External costs are one of the main topics in the European Transport White Paper (European Commission, 2011), which states that these costs should be taken into account for especially road and rail transport. Several definitions of external costs exist in the literature. Blauwens & Van de Voorde (1985a, p. 113) define external costs as "*costs that the transport user causes to a third party and for which he does not pay*". Verbruggen (2008, p. 62) defines external costs as "*often unwanted side effects of production and consumption processes, borne by third parties*". These two definitions are in line with the definition provided in the European Handbook on external costs (Korzhenevych et al., 2014, p. 1), which states that external costs equal the difference between the private and the social costs. Social costs are defined in this handbook as "*all costs occurring due to the provision and use of transport infrastructure*", while private costs are defined as "*costs directly borne by the transport user*".

External costs can graphically be understood as follows. Figure 80 displays the market equilibrium $E_{private}$ taking into account the marginal private cost (MPC) of urban freight distribution and the market equilibrium E_{social} considering the marginal social cost (MSC). When the external costs are included in the generalised cost, the transport user consumes Q_{social} units at a cost GC_{social}. When the external costs are not paid for by the transport user, the latter consumes $Q_{private}$ units at a cost $GC_{private}$. Thus, $Q_{private}$-Q_{social} units are consumed more if the external costs are not paid for by the user than it would be the case in the social equilibrium. The exclusion of the external costs leads to a deadweight loss that equals the shaded area $AE_{private}E_{social}$. In order to avoid this deadweight loss, external costs should be taken into account in the social cost-benefit framework.

[28] An earlier version of this section has been published as De Langhe, K. (2017). The importance of external costs for assessing the potential of trams and trains for urban freight distribution. Research in Transportation Business & Management (24), pp. 114-122.

Figure 80 – Deadweight loss due to non-internalised costs



Source: Verbruggen (2008)

The socio-economic costs of an urban rail freight project consist of the sum of the private and the external costs of all the legs of the supply chain. This is expressed by Equation (49):

$$MSC = C_{p,rail} + C_{p,road} + C_{p,h\&s} + C_{e,rail} + C_{e,road} + C_{e,h\&s} \tag{49}$$

The marginal social cost in Equation (49) equals the sum of the private costs of the rail leg $C_{p,rail}$, the road legs $C_{p,road}$ and the handling and storage point $C_{p,h\&s}$ and the external costs of these three legs, respectively $C_{e,rail}$, $C_{e,road}$ and $C_{e,h\&s}$. In the reference case, i.e. the use of only road transport, only the private and external costs of road transport remain in Equation (49).

Table 63 gives a non-exhaustive overview of academic papers between 1996 and 2019 that use external cost figures in their research, relevant for the use of rail transport in urban freight distribution. The literature overview starts from 1996, since the study of Mayeres et al. (1996) is very relevant for the current research at that moment. The authors are listed in chronological order and the papers are evaluated for the transport mode included, the urban versus interurban scope and the external costs examined. The first observation of Table 63 concerns the transport mode used. The modes considered are LGVs, trams and trains. The incorporation of LGVs is important as a benchmark. External costs of rail transport are compared in the SCBA to those of road transport. Three main observations are made.

Firstly, only a few papers discuss the external costs related to the use of rail freight transport. Some authors (den Boer, Brouwer, & van Essen, 2008; Gorçun, 2014; Kim & Wee, 2014; Mayeres et al., 1996; Regué & Bristow, 2013; Schroten, van Essen, Aarnink, Verhoef, & Knockaert, 2014; Zych, 2014) discuss the external effects of trams and road transport, although for example Mayeres et al. (1996) only consider passenger transport and Zych (2014) only makes a qualitative analysis. Other authors (Alessandrini et al., 2012; Andersson & Ögren, 2007; Beuthe, Degrandsart, Geerts, & Jourquin, 2002; De Nocker et al., 2010; Delhaye et al., 2017; den Boer et al., 2008; Fridell, Bäckström, & Stripple, 2019; Janic, 2007; Korzhenevych et al., 2014; Merchan, Léonard, Limbourg, & Mostert, 2019; Mostert, Caris, & Limbourg, 2017; Nijland & Wee, 2005; Schroten et al., 2014) examine the external effects of trains and road transport.

Secondly, not all papers determine their geographical scope. An urban scope means either that the external costs are measured in the centre of an urban area, or that the term “urban” is used in the paper. Interurban means that the figures concern transport between urban areas, or that the term “interurban”, or “rural” is used in the paper. It is not in all papers clear whether the external costs are considered for an urban or interurban area. All papers dealing with trams have an urban scope; the scope of the papers dealing with trains is not that clear.

Table 63 – Literature overview of external costs of road and rail transport

Author (s) (year)	Mode			Scope		External costs examined						
	LGV	Tram	Train	Urban	Interurban	Accidents	Air pollution	Climate change	Congestion	Infrastructure damage	Noise	Up-and downstream processes
Mayeres et al. (1996)	X	X		X		X	X		X		X	
Beuthe et al. (2002)	X		X			X	X	X	X	X	X	
Nijland & van Wee (2005)	X		X	X	X						X	
Bickel et al. (2006)	X					X	X		X			
Andersson & Ögren (2007)			X								X	
Janic (2007)	X		X			X	X	X	X		X	
den Boer et al. (2008)	X	X	X	X	X		X	X				X
De Nocker et al. (2010)	X		X	X	X		X	X				
van Lier & Macharis (2011)	X			X		X	X	X	X	X	X	
Alessandrini et al. (2012)	X		X	X	X		X	X				
European Environment Agency (2013)							X					
Regué & Bristow (2013)	X	X		X		X	X	X	X	X	X	
Gorçun (2014)	X	X		X				X				
Kim & van Wee (2014)	X	X						X				
Korzhenevych et al. (2014)	X		X	X	X	X	X	X	X	X	X	X
Schroten et al. (2014)	X	X	X	X	X	X	X	X	X		X	X
Zych (2014)	X	X		X			X	X	X	X	X	
Garcia-Castro & Monzon (2015)	X			X					X			
Gérard et al. (2015)	X					X	X	X	X		X	
Kijewska & Iwan (2015)	X			X			X	X				
Le Maître (2015)	X										X	
Rizet et al. (2015)	X			X				X	X			X
Spijkerman (2015)	X			X			X	X				
Blauwens et al. (2016)	X			X	X	X	X	X	X	X	X	
Cárdenas et al. (2017)	X			X		X	X	X	X		X	
Crozet (2017)	X					X			X			
Delhaye et al. (2017)	X		X	X	X	X	X	X	X	X	X	
Mostert et al. (2017)	X		X				X	X				
Papoutsis et al. (2018)	X			X		X	X	X	X	X	X	
Daubresse et al. (2019)	X						X	X				
Fridell et al. (2019)	X		X									X
Merchan et al. (2019)	X		X				X	X				

Source: Own creation

The third observation is related to the external costs examined in the papers. Some papers deal with several external cost categories, others focus on one category. Most papers do not include up- and downstream processes in their external cost figures. Up- and downstream processes are the activities that occur outside the transport market (Korzhenevych et al., 2014). Some authors incorporate this externality in the calculation of the external costs of air pollution and climate change. Not any of the papers dealing with the external costs of road transport and trams provides an analysis of all external cost categories, often due to data unavailability, or the limited scope of the studies.

The European Environment Agency (2013) states that the external costs of heavy goods vehicles depend amongst others on the engine type, the tonnage, the number of axles, the driving patterns, the population density of the urban area and the site-specific exposure. Korzhenevych et al. (2014) mention the location (urban, interurban), the time of the day (peak, off-peak, night) and the vehicle characteristics (euro-standards) as factors influencing the values of the external costs in general. More specifically, these authors state that the external costs caused by a lorry in an urban context during peak hours can be five times the external costs caused in an interurban context during off-peak hours. Therefore, it is important to specify the context before calculating external costs. The level of external costs is not constant for all urban areas. Gorçun (2014) sees a relationship between the population and the income level of the population in an urban area and the logistics and transport activities. This corresponds to the idea of Dablanc (2009), who relates freight activities to the population.

Table 64 displays the existing case studies for which external cost data on urban rail freight systems are available. Mainly environmental and energy consumption costs are considered by the different authors. The main rail emissions that contribute to climate change and air pollution are CO, CO_2, NOx, PM, SO_2 and VOCs. As a comparison, Meersman et al. (2015) mention in descending order NOx, CO, NMVOS and PM as the main emissions resulting from road transport. Regué & Bristow (2013) are the only authors who also take accidents, congestion, infrastructure damage and noise into account. The exclusion of these categories by Alessandrini et al. (2012) can be explained by the rail infrastructure charges that rail operators pay. These infrastructure charges should be based on the short-run marginal costs, including the external effects of rail transport, such as congestion and noise (Andersson & Ögren, 2007). Hence, these costs are internalised and do not have to be taken into account in the analysis of external rail costs.

Table 64 – External costs calculated in urban rail freight distribution case studies

Author(s) (year)	Mode	Case study	External costs
Alessandrini et al. (2012)	Train	Rome	CO, CO_2, HC, NOx, PM, electricity consumption
Regué & Bristow (2013)	Tram	Barcelona	Accidents, congestion, infrastructure damage, noise, CO_2, NOx, PM10, SO_2, VOCs
Gorçun (2014)	Tram	Istanbul	Energy consumption, environmental pollution

Source: Own creation

The European Environment Agency (2013) argues that NOx emissions cover a larger geographical scope than PM2.5 emissions. The latter are local emissions, which affect the nearby population. However, in densely populated urban areas, PM2.5 emissions may result in higher external costs than NOx emissions, since more people are affected. A list of larger urban areas, i.e. areas with more than 500,000 inhabitants, is made for which part of the roads may have PM2.5 external costs above national levels. For Belgium, the listed urban areas are Antwerp, Brussels and Liege (Aphekom, 2011). Thus, Antwerp suffers from some environmental externalities and a reduction of them would provide benefits to society.

Different categorisations of external costs exist. Schreyer et al. (2004) divide the external costs in the following categories: accidents, additional costs in urban areas, air pollution, climate change, congestion, nature and landscape, noise and up- and downstream processes. Nature and landscape costs and additional costs in the urban area mentioned by these authors are mainly related to transport infrastructure. Den Boer et al. (2008) include landscape contamination with respect to the construction of new transport infrastructure. Korzhenevych et al. (2014) propose, based on Maibach et al. (2008) and van Essen et al. (2011), seven external costs categories: accidents, air pollution, climate change, congestion, infrastructure damage, noise and up- and downstream processes.

External cost categories differ in the scope of their impact. External accident costs affect in general the victims of the accidents and their relatives. External congestion costs are of importance to all transport users involved. Air pollution and climate change affect the whole society, ranging from local to global effects (Korzhenevych et al., 2014). Blauwens et al. (2016) make a distinction between four different categories: accidents, congestion, environmental costs and infrastructure costs. The environmental costs consist of air pollution, climate change, noise, soil and water pollution. However, soil and water pollution are the least significant in the case of road and rail transport. Delhaye et al. (2017) add other categories including the loss of space, odour nuisance, parking and sprawl. However, these authors do not include these costs in their analysis of external costs for transport projects and therefore also do not provide any figures with respect to these costs.

In the current research, the classification proposed by Korzhenevych et al. (2014) is chosen, since it is the most complete classification, covering all the external cost categories mentioned by other authors that need to be quantified in this research. This classification is also used by Papoutsis et al. (2018) and applied to a case study in Antwerp. In order to know the external cost savings for all these categories ($C_{e,saved}$), the external costs of the reference ($C_{e,reference}$) and project case ($C_{e,project}$) have to be compared to each other. This is shown by Equation (50):

$$C_{e,saved} = C_{e,reference} - C_{e,project} \tag{50}$$

The external costs of the reference case, in which road transport is used, are calculated by means of Equation (51):

$$C_{e,reference} = acc_{reference} + air_{reference} + \mathrm{clim}_{reference} + cong_{reference} + \mathrm{infra}_{reference} + noise_{reference} \tag{51}$$

In which

$acc_{reference}$	= the marginal external accidents cost of the reference case;
$air_{reference}$	= the marginal external air pollution cost of the reference case;
$clim_{reference}$	= the marginal external climate change cost of the reference case;
$cong_{reference}$	= the marginal external congestion cost of the reference case;
$infra_{reference}$	= the marginal external infrastructure damage cost of the reference case;
$\mathrm{noise}_{\mathrm{reference}}$	= the marginal external noise cost of the reference case.

All costs in Equation (51) are expressed in euro. The external costs of the project case have to be calculated analogously as in Equation (51), but now for all legs of the urban rail freight supply chain, which consists of different transport modes, as shown in Equation (52), again expressed in euro:

$$C_{e,project} = C_{e,rail} + C_{e,pre} + C_{e,post} + C_{e,h\&s} \tag{52}$$

In which

$C_{e,rail}$	= the marginal external cost of the rail leg;
$C_{e,pre}$	= the marginal external cost of the pre-haulage leg;
$C_{e,post}$	= the marginal external cost of the post-haulage leg;
$C_{e,h\&s}$	= the marginal external cost of handling and storage.

For the rail external costs $C_{e,rail}$, energy consumption is an important driver. In the road pre- and post-haulage leg, fuel consumption causes external costs (Alessandrini et al., 2012). Other external costs, such as accidents, congestion, infrastructure damage and noise also have to be included in the external costs (Alessandrini et al., 2012; Gorçun, 2014; Janic, 2007). It has to be remarked here as well that different road legs can lead to different external costs, depending on their characteristics, such as the vehicle and road type. The external costs of handling and storage $C_{e,h\&s}$ include mainly the air pollution and climate change costs due to electricity generation for the equipment used in the distribution centre (Janic, 2007). For all the urban rail freight supply chain legs, both producer and user costs have to be taken into account (Ayadi, 2014). Fridell et al. (2019) indicate the need to include external costs caused by the construction, service, repair and scrapping of vehicles, production and supply of fuel and electricity, and the construction, maintenance and operation of traffic infrastructure.

Producer emissions can be present for the three types of investment considered in this research: rolling stock, line infrastructure and nodal infrastructure. Firstly, the emissions during the production process of the rolling stock can be divided into materials emissions and non-materials emissions. The materials used for producing the transport vehicle include amongst others steel, plastic, aluminum, glass, rubber and liquids. Depending on the specific mix of these materials used for a certain vehicle, different emissions result. The non-materials emissions include for example the electricity used for producing the vehicle. It has to be added here that a vehicle that is operational in one country is not necessarily produced in the same country. Therefore, it is better to use non-country-specific emission factors for the electricity emissions for producing a vehicle. On average, a factor of 5.58 tonnes CO_2 emitted per tonne weight of a vehicle can be used as a proxy for the producer emissions (Ayadi, 2014). In the current research, it is assumed that no new vehicles are produced. Hence, producer emissions are not incorporated in the calculations of the external costs.

Secondly, the external cost of the production of line infrastructure has to be considered. This cost depends on the type and quantity of the materials used. Relevant external cost categories here include the visual quality of the environment, noise nuisance, barriers and diversions, uncertainty of construction, forced relocation, costs related to the movement of vehicles such as accidents, averting behaviour, safety perceptions, noise, nuisance, soil, air and water quality (Geurs, Boon, & Wee, 2009). The aim of current research is not to evaluate the construction of long distances of new rail infrastructure. Therefore, it is decided to leave the external producer costs of new line infrastructure out of the analysis. If the analysis is further developed in the direction of constructing more line infrastructure, these costs have to be added[29].

Thirdly, the emissions related to the production of nodal infrastructure consist of emissions associated with the construction of logistics buildings and emissions related to the operations. Ayadi (2014) offers figures for the emissions due to the construction of distribution centres. On average, 200 kg of CO_2-emissions emerge per square meter when building a distribution centre. Given the scarcity of space in urban areas, it is assumed in current research that existing buildings are used if storage of the goods is needed. When a transit platform is used, only handling constructions are needed, making it difficult to reliably estimate the emissions. Therefore, these potential emissions as well are left out the calculations.

User emissions for the different legs in the project case are obtained by Equations (53), (54), (55) and (56):

$$C_{e,rail} = acc_{rail} + air\,\&\,\mathrm{clim}_{rail} + cong_{rail} + \mathrm{infra}_{rail} + noise_{rail} \tag{53}$$

[29] This is for instance done in studies focusing on Life Cycle Assessment (LCA), such as Fridell et al. (2019) and Merchan et al. (2019)

$$C_{e,pre} = acc_{pre} + air\,\&\,\mathrm{clim}_{pre} + cong_{pre} + \mathrm{infra}_{pre} + noise_{pre} \quad (54)$$

$$C_{e,post} = acc_{post} + air\,\&\,\mathrm{clim}_{post} + cong_{post} + \mathrm{infra}_{post} + noise_{post} \quad (55)$$

$$C_{e,h\&s} = air\,\&\,\mathrm{clim}_{h\&s} \quad (56)$$

The user emissions of the rail leg comprise all external costs due to operating a tram or train. The road pre-haulage is assumed to be executed by the same van or lorry as the one used in the reference case and thus, the externalities are obtained in a similar way as for the reference case. For the road post-haulage, different options are possible: an employee or a courier can walk, bike, or use an LGV. Hence, the external costs of walking, biking and driving have to be analysed. Ayadi (2014) considers the emissions of walking to be zero. Food and shoes of the person walking could lead to additional emissions, but these are considered negligible. The emissions of using a bike include the emissions of maintenance and repair. The exhaust emissions for a traditional bike equal zero, since no electricity is used. The maintenance and repair emissions are estimated by Ayadi (2014) to be 10g CO_2 per kilometre. For an electric bike, Hendriksen & van Gijlswijk (2010) assume CO_2-equivalent emissions of 17g per kilometre covered. Papon et al. (2017) take a coefficient of 21g CO_2-equivalent emissions per kilometre into account. This is valued by these authors as €0.001 per kilometre. This value is used in the current research.

The user emissions of handling and storage are the last component that has to be investigated. Based on Ayadi (2014), the emissions of a distribution centre, including cooling, heating, lighting and the end of life of the building, amount 25 kg $CO_{2,eq}$ per m² per year. When the EU objectives of allowing a maximum increase of global temperature of 2°C are considered, a cost of €95 per tonne CO_2 (value for 2018) emitted has to be paid. Combining these two figures, an external cost of a distribution centre of around €0.00625 per m² per day is obtained (value for 2018). It is assumed here that the figures calculated for the Lyon region can also be used for the Antwerp region (see Appendix 7). In Appendix 8, some more background information is provided on the emissions related to electricity generation, as well as the electricity mix of Belgium.

Ultimately, different external costs are present for the different types of rail transport taken into account in this research. Table 65 provides an overview of the extent to which external costs are relevant. When a dedicated freight vehicle is used, all external cost components have to be taken into account for the full rail vehicle. When a freight wagon is attached to a passenger vehicle, only part of the rail external costs have to be assigned to the freight transport. When a parcel is transported in a passenger vehicle, the marginal external rail costs can be neglected. For the road pre-haulage, the external costs of the van or lorry used have to be incorporated in the analysis for all three rail types. With respect to road post-haulage, the external costs of the use of a bike or LGV have to be added in case a dedicated freight vehicle or a freight wagon attached to a passenger vehicle is used. For the transport of freight in a passenger vehicle, no external post-haulage costs are taken into account, since the courier walks to the customer to deliver the goods. The external costs of handling and storage consist of the use of a distribution centre for the three rail types.

In order to obtain a robust social cost-benefit framework for assessing the potential of rail for urban freight distribution, accurate and appropriate external cost data are crucial. Therefore, external cost figures of freight distribution by respectively light goods vehicles (LGVs) of less than 12 tonnes, trams and trains are provided in the following sections. All figures in the next sections are converted to $€_{2018}$-values[30]. The effect of the external cost values on the project outcome is evaluated in Chapter 6 by

[30] See Step 4 (Section 3.2.2.4) of the SCBA framework for the explanation of the discounting.

sensitivity and scenario analyses. The model is developed in such a way that the effect of extreme external cost values can easily be tested.

Table 65 – External costs per rail type

External costs	Symbol	Dedicated freight vehicle	Freight wagon attached to passenger vehicle	Freight in passenger vehicle
Rail	$C_{e,rail}$	Rail vehicle external cost	Rail wagon external cost	No rail external costs
Pre-haulage	$C_{e,pre}$	Van or lorry external cost		
Post-haulage	$C_{e,post}$	Bike or LGV external cost		No post-haulage external cost
Handling & storage	$C_{e,h\&s}$	Distribution centre external cost		

Source: Own creation

The values in the next sections are expressed in euro$_{2018}$ per vehicle kilometre (€/vkm). The choice for euro per vehicle kilometre comes from the fact that the vehicle is the unit causing the external costs. When comparing different transport modes, the vehicles are compared to each other. When comparing the external costs of a tram or train to those of an LGV, it has to be borne in mind that multiple LGVs might be needed to transport the same volume of goods as one tram or train, depending on the loading factors of the respective vehicles. Mayeres et al. (1996) for instance, consider a peak tram to have 40 passengers on board. Assuming an average weight of 80 kg per passenger (Comi et al., 2014), the loading capacity of one freight tram is 3.2 tonnes. More recent trams have a theoretical loading capacity of around 16 tonnes in Flanders (Nuytemans & Fierens, 2014a). In this case, one tram substitutes multiple LGVs.

Figures concerning Belgium and Flanders are selected, because of the application of the framework to a case study for Antwerp in Section 5.3. Hence, no adaptation of the figures for the differences in purchasing power parity between countries has to be made when using the figures in a Belgian context. Moreover, no adaptation for different electricity generation mixes in different countries has to be made. Although the figures provided in the following sections are applicable to Belgium, the main ideas of these sections can also be applied to other countries, with the only adaptation that the values of the figures are country-dependent. Different values provided for one country cannot always be compared to each other as such, since they result from different assumptions. Furthermore, comparisons of figures offered by different authors can be misleading for two reasons.

Firstly, different authors use their own definitions of urban areas and urban roads, and light and heavy vehicles. Delhaye et al. (2017) define an urban road as a paved municipal road, while Korzhenevych et al. (2014) define an urban road as a road inside the urban boundary signs. An urban area is defined by these authors as an area with more than 10,000 inhabitants. Rebel (2013) considers goods vehicles below 12 tonnes as light goods vehicles, while Korzhenevych et al. (2014) define light goods vehicles as vehicles below 3.5 tonnes. Due to these different definitions, comparisons between figures of different authors become more difficult.

Davydenko et al. (2014) state that many calculation methods and tools exist to estimate the CO_2 emissions in supply chains, but they all have their own focus and background, making it difficult to compare results amongst different chains and modes. For trains for example, the Global Logistics Emissions Council (GLEC) framework is applied to calculate the external costs. This framework was established by GLEC, led by Smart Freight Centre. GLEC is a voluntary partnership between associations, companies and green freight programmes and the objective of the framework is to have a universal method to calculate emissions for air transport, inland waterways, maritime transport, rail transport and road transport (Smart Freight Centre, 2019). Davydenko et al. (2014) argue that the development of a global standard is needed, and this should be led by an international and independent organisation.

Secondly, figures coming from one source are not necessarily identical anymore after being converted to the same base year by different authors. Gérard et al. (2015) updated the figures of Rebel (2013) for their research. However, when converting the figures from both sources to values of 2018, slightly different values are obtained. This means that differences between the values can partially be explained by different converting methods used by different authors.

In the next sections, external costs are in first instance discussed for the use of a dedicated freight vehicle. The external costs of a freight wagon attached to a passenger vehicle are highlighted at the end of each section. For transporting parcels alongside passengers, no external costs are taken into account.

5.2.2 Accidents

Blauwens et al. (2016) define the marginal external accident costs as the product of the increased accident risk for other transport users and the number of vehicles affected. However, no proof exists that an additional vehicle makes traffic more dangerous to other users. Other factors, such as traffic regulations, or promoting transport safety, influence the accident risk as well. Korzhenevych et al. (2014) define external accident costs as "*those social costs of traffic accidents, which are not covered by risk-oriented insurance premiums*". Accidents occur in road and rail transport and can lead to material and infrastructure damage, but also to injuries and death of people (Janic, 2007). In order to calculate the accident risk, an estimation of the value of life has to be made. The value of life depends on factors such as the country in which the person lives, the age and the type of risk and the risk aversion of the person. Therefore, at least country-specific values are preferable (Korzhenevych et al., 2014; Nellthorp, Sansom, Bickel, Doll, & Lindberg, 2001).

In order to calculate the saved external accident costs, the costs in the reference and project case have to be determined and compared. The marginal external road accident cost depends on several factors related to the study in which the cost is calculated. Mayeres et al. (1996) for instance make a distinction between peak hour and off-peak hour. Forkenbrock (2001) argues that the marginal rail accident costs depend on i.a. the topography, the tracks and weather conditions and specific train and operator conditions. Delhaye et al. (2017) provide different marginal external accident costs depending on the road type and the gross tonnage of the vehicle. The marginal external accident costs of the project case consist of the cost caused by the rail, pre- and post-haulage leg. It is assumed that the marginal external accident cost is only present for the road post-haulage in case an LGV is used. For pedestrians and cyclists, no external accident costs are found in the literature.

Table 66 displays marginal external accident cost values for LGVs, trams and trains, all expressed in €$_{2018}$. The range of marginal external cost values of LGVs varies between 0.0068 €/vkm and 0.5667 €/vkm. The minimum value of a train, 0.0002 €/trainkm, and the maximum value of a train, 0.4037 €/trainkm, are both lower than the ones of LGVs. The minimum value of transport by tram, 0.7386 €/tramkm is higher than the minimum value of an LGV and a train, whereas the maximum value of a passenger tram, 0.8208 €/tramkm, is higher than the one of an LGV and lower than the one of a train. The latter is explained by the fact that trains have dedicated rail lines, whereas trams often share their way with road traffic and thus, have more chance to collide with road traffic. An additional remark here is that the marginal external accident costs of a freight tram can be considered lower than the one of a passenger tram, since no passengers are potentially involved in an accident of a freight tram (Mayeres, 2016).

Mayeres et al. (1996) calculate the marginal external accident costs for Brussels and arrive at values between 0.3565 €/vkm (peak hour) and 0.5667 €/vkm (off-peak hour) for lorries and values between 0.7689 €/tramkm (off-peak hour) and 0.8208 €/tramkm (peak hour) for passenger trams. The figures are calculated as the product of the accident risk and the external social cost. Rebel (2013) recommends to use marginal external road accident costs between 0.0315 €/vkm (motorways) and 0.0510 €/vkm (other roads). The proposed costs for tram and train are respectively 0.7386 €/tramkm and 0.4037 €/trainkm. All figures are based on Bickel et al. (2006). Korzhenevych et al. (2014) provide marginal accident values for road transport varying between 0.0068 €/vkm and 0.2434 €/vkm. The lower value is valid on motorways, whereas the upper value counts for urban roads.

Table 66 – Marginal external accident costs

Mode	Description	Region	Value (in $€_{2018}$)	Author(s) (year)
LGV	Van	Flanders	0.0167-0.0459 €/vkm	Delhaye et al. (2017)
	Lorry	Brussels	0.3565-0.5667 €/vkm	Mayeres et al. (1996)
		Belgium	0.0315-0.0510 €/vkm	Rebel (2013)
	LGV of > 3.5 tonnes	Belgium	0.0068-0.2434 €/vkm	Korzhenevych et al. (2014)
		Flanders	0.0115-0.0202 €/vkm	Delhaye et al. (2017)
Tram	Passenger tram	Brussels	0.7689-0.8208 €/tramkm	Mayeres et al. (1996)
		Belgium	0.7386 €/tramkm	Rebel (2013)
Train	Freight train	Belgium	0.4037 €/trainkm	Rebel (2013)
		Belgium	0.0002 €/trainkm	Korzhenevych et al. (2014)
	Average train	Flanders	0.2529 €/trainkm	Delhaye et al. (2017)

Source: Own creation

Crozet (2017) discusses the values provided by Korzhenevych et al. (2014) for France. Commissariat Général au Développement Durable (2013) suggests external road accident figures for France that are 12 times higher than the ones proposed by Korzhenevych et al. (2014). Crozet (2017) explains that the value of statistical life was multiplied by three between 1990 and 2013, whereas the number of lethal accidents was more than halved in this period. The reason for the low external road accident costs proposed by Korzhenevych et al. (2014) lies in two methodological choices: 75% of the accident costs of private cars are assumed to be internalised and 25% of the ones of goods vehicles, and a marginal coefficient of 25% is used, further reducing the external costs of accidents on the road.

Delhaye et al. (2017) offer marginal external accident cost figures for Flanders, ranging between 0.0167 €/vkm on a motorway and 0.0459 €/vkm on other roads than motorways and urban roads for vans and between 0.0115 €/vkm on motorways and 0.0202 €/vkm in urban areas for light goods vehicles between 3.5 and 12 tonnes. The cost for an average train equals according to these authors 0.2529 €/trainkm. With respect to post-haulage transport by bike, Delhaye et al. (2017) count external costs of 0.0252 €/bikekm in urban areas and 0.0223 €/bikekm on other roads.

When freight is transported by a freight wagon attached to a passenger vehicle, not all external costs of the rail vehicle can be assigned to the freight wagon. With respect to the external accident costs, it is assumed that an accident of a rail vehicle with a road vehicle, pedestrian or cyclist happens at the front or at the back of the rail vehicle. Therefore, it is assumed that adding a freight wagon to a passenger vehicle does not increase the accident risk. It could be argued that adding a freight wagon means that the rail vehicle is not rigid and thus, accidents could potentially happen in between the passenger vehicle and the freight wagon. This would be a similar situation as when an articulated lorry is used. Delhaye et al. (2017) do not make a distinction between the external costs of a rigid and articulated lorry. Therefore, it is assumed here that a tram with a freight wagon and a passenger tram are characterised by the same external accident cost. Hence, no marginal external accident cost is assigned to the freight wagon. The effect of this assumption is investigated in Chapter 6.

5.2.3 Air pollution and climate change

The second component of the external cost is the marginal external cost of air pollution and climate change. These two categories are discussed together, since often, values for these two externalities are provided together (Blauwens et al., 2016; Delhaye et al., 2017). Moreover, up- and downstream activities are added in this section. Rebel (2013) and Delhaye et al. (2017) describe up-and downstream emissions as indirect emissions resulting from the production of fuels and electricity. Korzhenevych et al. (2014) identify three main types of up- and downstream processes: energy production (pre-combustion), vehicle and rolling stock production, maintenance and disposal, and infrastructure construction, maintenance and disposal.

Air pollution caused by road transport includes emissions, nitrogen oxides (NOx), lead (Pb), particulate matter (PM10), sulfur dioxide (SO_2) and volatile organic compounds (VOCs). The emission of sulfur oxides (SO_x) is important, while the emissions of Pb are negligible for road transport thanks to the decreasing use of leaded gasoline (Mayeres et al., 1996). Air pollution results mainly in health problems (Beuthe et al., 2002; Korzhenevych et al., 2014; Mayeres et al., 1996), such as eye and lung diseases, the chronic fatigue syndrome, neurosis and strain (Zych, 2014). Other negative effects include the damage to buildings and to crops (Korzhenevych et al., 2014; Mayeres et al., 1996; Piecyk, McKinnon, & Allen, 2010).

Janic (2007) distinguishes among two types of air pollution: direct and indirect air pollution. Direct air pollution comes from the use of diesel vehicles. The diesel direct emissions can further be split in exhaust and non-exhaust emissions. Exhaust emissions originate from the burning of fuel, while non-exhaust emissions result from wear and tear of tires and brakes. Indirect air pollution comes from the use of electric traction. The air pollution depends in the latter case on the way of electricity generation. The external costs that arise here are sometimes taken into account in the up- and downstream external costs (Korzhenevych et al., 2014). Merchan et al. (2019) take exhaust and non-exhaust emissions of freight trains into account in their calculation of external costs of freight transport in Belgium.

Climate change is brought about by the emission of greenhouse gases, such as carbon oxide (CO) and carbon dioxide (CO_2). De Nocker et al. (2010) and Delhaye et al. (2017) add the emissions of methane (CH_4) and nitrous oxide (N_2O) to this category of emissions that evoke climate change and De Nocker et al. (2010) also mention sulfur hexafluoride (SF_6) emissions. The amount of CO_2 emitted is related to the fuel consumption of the vehicle doing the transport and the type of fuel used (ICF Consulting, 2006). Figliozzi (2011) states that the fuel consumption depends on the travel speed and the distance covered. In addition, this author assumes that the weight of the transported goods can be ignored when estimating CO_2 emissions, since the impact of travel speeds is much more important.

In order to calculate the saved air pollution and climate change costs, both costs are calculated for the reference and project case and then compared. Firstly, the marginal external air pollution cost related to the road transport in the reference case is derived. This external cost depends on the area, the fuel type, the gross vehicle weight and the euro standard of the vehicle according to Korzhenevych et al. (2014). These authors make a distinction between urban areas, suburban areas and motorways. Concerning the fuel type, petrol and diesel are distinguished among by these authors. With respect to the gross vehicle weight, a difference is made between vans of less than 3.5 tonnes, lorries between 3.5 and 7.5 tonnes and lorries between 7.5 and 12 tonnes. The euro standard varies between zero and six. For the marginal external climate change costs, Rebel (2013) makes a difference between urban roads, motorways and rural roads. Moreover, the cost depends on the gross tonnage of the vehicle.

Delhaye et al. (2017) distinguish among diesel and petrol vehicles, and vans and lorries with a gross weight of more than 3.5 tonnes.

Secondly, the marginal external air pollution and climate change cost is derived for the project case. Again, the costs of all supply chain legs have to be included. Considering climate change, the CO_2 emissions of rail transport are related to the energy consumption of the freight trains. As a result, only diesel freight trains cause direct climate change emissions. Vlaamse Milieumaatschappij (2018) declares a decrease of sulphur in diesel from 350 ppm (parts per million) in 2000 to 10 ppm in 2009 and states that total emissions caused by diesel trains are decreasing, since fewer diesel trains are used in Belgium.

The potential indirect emissions caused by electric freight trains are considered indirect climate change emissions (Korzhenevych et al., 2014). The way of electricity generation is crucial to reliably estimate these costs (Merchan et al., 2019). In 2015 in Belgium, 37% of the electricity production originated from nuclear power, 33% from natural and derived gas, 10% from biomass and waste, 8% from wind energy, 5% from solar energy, 3% from coal and lignite, and 3% from other fuels and 1% from hydropower (Gusbin & Devogelaer, 2017). Moreover, electric trains emit cupper due to the friction between the pantograph and the catenary. In total, all electric trains in Belgium cause 12-15% of all cupper emissions in Flanders (Vlaamse Milieumaatschappij, 2018). Merchan et al. (2019) consider the sulphur hexafluoride (SF_6) emissions due to the conversion of electricity to traction as well as the indirect emissions related to electricity generation.

With respect to the pre-haulage leg, the marginal external air pollution and climate change cost depends on several factors, which are different depending on the source used. For the climate change costs, Rebel (2013) makes a distinction between motorways, rural roads and urban roads. For the air pollution costs, Korzhenevych et al. (2014) provide another value depending on the gross vehicle tonnage, the fuel type (diesel or petrol), and the road type (urban, interurban, suburban or motorway). Delhaye et al. (2017) suggest other values related to the gross vehicle weight and the fuel type.

It is assumed that the road post-haulage is taking place in an urban area, and thus, only air pollution in urban areas has to be considered. It is assumed that pedestrians do not cause air pollution and hence, only bikes and LGVs have to be considered for the calculation of the marginal external air pollution costs in the post-haulage leg. With respect to a bike, Delhaye et al. (2017) assign a marginal external cost of 0.0001 €/bikekm to an electric bike, whereas the cost of a traditional bike is zero. This figure includes the direct and indirect costs, as well as the exhaust and non-exhaust emissions. The marginal external climate change cost depends on the energy type used, being 100% green energy or the standard electricity mix of the country in which the transport takes place (see Appendix 8). The value for an LGV is a bit higher, i.e. 0.0001 €/vkm in case of green energy and 0.0023 €/vkm (values for 2018) for the standard Belgian energy mix, according to the middle scenario of Vandresse (2012). Table 67 displays some values available in the literature for the direct and indirect marginal external air pollution and climate change costs of LGVs, trams and trains.

Mayeres et al. (1996) provide marginal external air pollution costs for diesel lorries in Brussels, ranging between 0.1809 €/vkm during off-peak hours and 0.2089 €/vkm during peak hours. The value for a passenger tram equals 1.1613 €/tramkm. No distinction is made between peak and off-peak hour. This high marginal external air pollution and climate change cost for a tram consists for 85% of the costs of SO_X-emissions. The SO_X-emissions are so high, because they are related to the electricity generation. In other words, the up- and downstream processes of the tram are included in this figure too. The SO_X-emissions are taken from the Lauffen plant in Germany, which uses coal for electricity generation. Emissions used equal 0.83g SO_2 per kWh. However, more recent studies, such as Ito (2011, p. 12), give emissions of 0.45g SO_2 per kWh for German plants and a best available technology emitting only <0.06-0.08 g per kWh in Japan. Therefore, it can be assumed that the external air pollution costs of a tram are in 2018 much lower. A quick calculation of the external cost using an emission factor of 0.06 g/kWh, ceteris paribus, provides a total external air pollution and climate change cost of 0.0840 €/tramkm.

Table 67 – Marginal external air pollution and climate change costs, including up-and downstream costs

Mode	Description	Region	Value (in €$_{2018}$)	Author(s) (year)
LGV	Diesel van	Belgium	0.0035-0.0579 €/vkm	Korzhenevych et al. (2014)
		Flanders	0.0705 €/vkm	Delhaye et al. (2017)
	Petrol van	Belgium	0.0012-0.0177 €/vkm	Korzhenevych et al. (2014)
		Flanders	0.0637 €/vkm	Delhaye et al. (2017)
	Diesel lorry	Brussels	0.1809-0.2089 €/vkm	Mayeres et al. (1996)
	Lorry 3.5-7.5 tonnes	Belgium	0.0035-0.1584 €/vkm	Korzhenevych et al. (2014)
	Lorry 7.5-12 tonnes	Belgium	0.0035-0.2176 €/vkm	Korzhenevych et al. (2014)
	Lorry <12 tonnes	Belgium	0.0437-0.1058 €/vkm	Rebel (2013)
	Diesel lorry 3.5-12 tonnes	Flanders	0.1373 €/vkm	Delhaye et al. (2017)
Tram	Passenger tram	Brussels	1.1613 €/tramkm	Mayeres et al. (1996)
Train	Freight train	Belgium	1.4054 €/trainkm	Rebel (2013)
	Diesel freight train	Flanders	7.7677 €/trainkm	Delhaye et al. (2017)
	Electric freight train	Flanders	0.5453 €/trainkm	Delhaye et al. (2017)

Source: Own creation

When generalising this finding, it can be argued that the tram external cost figures estimated in 1996 are likely an overestimation of the external costs in 2018. Although all the figures in Table 67 are discounted to euro$_{2018}$ values, they are estimated in another base year. As a result, the figures coming from for example Mayeres et al. (1996) are compiled based on the traffic situation and available vehicle technology of 1996. As examined by several authors, such as Bünger et al. (2014), Dray et al. (2018) and Wang et al. (2018), technological changes can lead to lower vehicle emissions. Alternatively, the air pollution and climate change cost can be calculated by means of Equation (57):

$$air\,\&\,\mathrm{clim} = \frac{€}{g} * \frac{g}{kWh} * \frac{kWh}{tramkm} \tag{57}$$

The cost used in Equation (57) in €/g is estimated by Vandresse et al. (2012) to be 0.0004 €/g under moderate conditions. According to De Lijn (2019a), the emissions of a tram are equal to 349g CO_2 per kWh when the standard electricity mix of Belgium is used and 20 g CO_2 when 100% green energy, more specifically hydropower, is used. Moreover, a tram needs 4kWh per tramkm. When applying these figures to Equation (57), a marginal external cost of 0.0558 €/tramkm is obtained when the standard electricity mix of Belgium is used and a cost of 0.0032 €/tramkm when 100% green energy is used (values for 2018).

Rebel (2013) offers values for the direct marginal air pollution costs of lorries, varying between 0.0232 €/vkm (motorways) and 0.0747 €/vkm (urban roads) and for climate change ranging between 0.0098 €/vkm and 0.0150 €/vkm. The indirect air pollution and climate change costs are respectively ranging between 0.0093 €/vkm and 0.0139 €/vkm and 0.0014 €/vkm and 0.0022 €/vkm. The direct air pollution cost for a freight train in Belgium equals 0.4150 €/trainkm, whereas the direct cost for climate change amounts 0.1407 €/trainkm. The indirect costs related to air pollution and climate change are respectively equal to 0.6110 €/trainkm and 0.2387 €/trainkm. The direct and indirect air pollution and climate change costs are added together and their sum is displayed in Table 67. The cost estimates are based on De Nocker et al. (2010) and European Commission (2010).

Korzhenevych et al. (2014) provide values for different types of LGVs. Depending on the area and the euro standard, other values are provided. For petrol light goods vehicles of <3.5 tonnes, i.e. vans, the marginal external air pollution cost lies between 0.0012€/vkm (euro 4-6, interurban area and motorways) and 0.0177€/vkm (euro 1, urban area). For diesel vans, the cost ranges between 0.0035€/vkm (euro 6, interurban area and motorways) and 0.0579€/vkm (euro 2, urban area). For lorries between 3.5 and 7.5 tonnes, costs vary between 0.0035€/vkm (euro 6, interurban area and motorways) and 0.1584 €/vkm (euro 0, urban area). Lorries with a gross tonnage between 7.5 and 12 tonnes cause marginal external air pollution and climate change costs between 0.0035 €/vkm (euro 6, motorways) and 0.2176 €/vkm (euro 0, urban area). The figures are derived from Preiss & Klotz (2008) and European Commission (2010). Mostert et al. (2017) use the figures provided by Korzhenevych et al. (2014) and convert them to euro per tonne kilometre.

Delhaye et al. (2017) also provide marginal external air pollution figures for LGVs, but these figures include all direct and indirect, and exhaust and non-exhaust emissions. This explains why the figures in Table 67 provided by these authors exceed the maximum figure for a diesel and petrol van provided by Korzhenevych et al. (2014). For an LGV, the average figure offered by Delhaye et al. (2017) is lower than the maximum figures mentioned by Korzhenevych et al. (2014), which is normal given the average figure used by the former authors. The values for a diesel and an electric freight train are converted to euro per trainkm and amount respectively 7.7677 €/trainkm and 0.5453 €/trainkm. These figures again include the direct and indirect and exhaust and non-exhaust emissions.

Ultimately, the marginal external air pollution and climate change costs of a freight wagon attached to a passenger vehicle have to be derived. A correction factor is applied to the external cost used for a dedicated freight vehicle. The external cost is obtained by adapting the traction energy needed in Equation (57). One tram with a length of 30 m and a weight of 39 tonnes (type “Hermelijn”) needs 4kWh of electricity in order to drive one kilometre (De Lijn, 2019a). A freight wagon attached to the tram has a gross weight of around 21 tonnes. This is more or less half of 39 tonnes and therefore, it is assumed that the traction unit needs 2kWh extra when the freight wagon is added to the passenger tram. Thus, the external costs of air pollution and climate change of the freight wagon are more or less half the ones of the passenger tram.

5.2.4 Congestion

Congestion is present when “*an additional vehicle on the road reduces the speed of the other road users*” (Mayeres et al., 1996). Gérard et al. (2015, p. 16) define congestion as “*a traffic phenomenon in which the driver is confronted with a limited traffic flow, because the infrastructure capacity (temporarily) cannot meet the demand. This results in a higher density and low(er) speeds, causing an increase of the (time- and distance-related) cost of travelling and a decrease of the road traffic reliability*”. The consequences of road congestion can be split in two categories: additional costs for the actors affected by congestion due to extra fuel needed and time losses and additional vehicle emissions due to frequent speed changes (M. A. Figliozzi, 2011; Frey, Rouphail, & Zhai, 2008). Mayeres et al. (1996) only take the effect of congestion on time losses of other transport users into account. Changing operating costs and air pollution are not incorporated in these congestion cost figures. Blauwens et al. (2016) identify the main negative effect of congestion as time costs. Other costs, such as higher fuel consumption and inconvenience, can be simplified to time costs.

Firstly, the marginal external congestion costs of the reference case are derived. These costs depend on several factors, being according to Korzhenevych et al. (2014) the time of the day (peak hour, off-peak hour, night), the area (motorways, suburban area, urban area) and the vehicle type (rigid, articulated). It is assumed that traffic is at over-capacity during peak hour, near-capacity during off-peak hour and at free flow during the night. Over-capacity traffic is traffic where the volume-capacity ratio exceeds 1, near capacity traffic is traffic where the volume-capacity ratio lies between 0.75 and 1, and free flow traffic is traffic where the volume-capacity ratio is smaller than 0.25. An urban area has more than 10,000 inhabitants, a suburban area less. The marginal external congestion cost is obtained by multiplying the distance covered by a certain vehicle on a certain type of road at a certain traffic flow by the unit cost for the combination of these three characteristics. Delhaye et al. (2017) make a distinction between peak and off-peak hours, motorways, N-roads and urban roads, and vans (<3.5 tonnes gross weight) and lorries (>3.5 tonnes gross weight) in order to calculate the marginal external congestion costs.

Secondly, the marginal external congestion costs of the project case are analysed. These consist of the costs of the rail, pre- and post-haulage leg. Congestion costs of rail transport are referred to as scarcity costs, related to slot allocation. Rail vehicles have to get access to the rail network (Korzhenevych et al., 2014). Depending on whether a tram uses dedicated tramways on a separate part of the street, or tracks on the street on shared space with the road transport, the external congestion costs differ. At intersections and level crossings, the tram and the train respectively may cause congestion costs to third parties. Therefore, external congestion cost figures have to be seen in the context of the urban area for which they are calculated. When generalising these figures to other urban areas, the configuration of those other urban areas has to be taken into account (Mayeres et al., 1996).

The marginal external road pre-haulage congestion cost is derived analogously as for the reference case. Depending on the road type, traffic flow and vehicle type, another cost is assigned to the distance covered. With respect to the road post-haulage cost, marginal external costs are only assumed to be present if the post-haulage is carried out by LGV. Moreover, the transport only takes place in an urban area and is supposed to be executed by a rigid LGV. Hence, the marginal external congestion cost per kilometre covered only differs depending on the traffic flow. Furthermore, it is assumed that pedestrians and bikes do not cause an external cost.

Table 68 shows marginal external congestion costs suggested by different authors. Especially the very low minimum value of a train (0 €/trainkm) and the very high maximum value of an LGV (9.5377 €/vkm) catch the attention.

Table 68 – Marginal external congestion costs

Mode	Description	Region	Value (in $€_{2018}$)	Author(s) (year)
LGV	Van	Belgium	0.0597-0.2568 €/vkm	Delhaye et al. (2017)
	Lorry >3.5 tonnes	Belgium	0.1194-0.5136 €/vkm	Delhaye et al. (2017)
	Lorry	Brussels	0.0100-3.4611 €/vkm	Mayeres et al. (1996)
	Articulated lorry	Belgium	0-9.5377 €/vkm	Korzhenevych et al. (2014)
	Rigid lorry	Belgium	0-6.2490 €/vkm	Korzhenevych et al. (2014)
Tram	Passenger tram	Brussels	0.0100-3.4611 €/tramkm	Mayeres et al. (1996)
Train	Rail transport	Belgium	0 €/trainkm	Rebel (2013)

Source: Own creation

Mayeres et al. (1996) provide marginal external congestion costs for road and tram transport. The costs for a lorry lie between 0.0100 €/vkm during off-peak hours and 3.4611 €/vkm during peak hours. The costs for a tram are considered the same as for a lorry, since the trams shared their way with the road traffic at the moment of the study by these authors. The external congestion costs of a tram are higher than the ones of a train. The reasoning behind this is that the tram figures come from the Brussels context (Mayeres et al., 1996), in which the trams do not have separate tramways and thus, share the road network with the road traffic. Therefore, congestion costs are higher for trams than for trains. Mayeres (2016) argues that the marginal external congestion cost of a tram in 2016 is lower than the one in 1996, because trams have more often their own tramways. As a result, trams do not cause that often congestion for the road vehicles as in 1996. Furthermore, the marginal external congestion cost can be considered zero if trams operate on their own tramways and pay access charges. Fierens et al. (2019) do not see a big difference between the external congestion costs during peak hour and off-peak hour.

Rebel (2013) states that no congestion problems are present on the Belgian rail network and thus, the external congestion cost of a train can be considered zero. Delhaye et al. (2017) state that for Belgium, no reliable estimations of the marginal external congestion costs of rail transport are available and thus, these authors leave these costs out of their quantification. Korzhenevych et al. (2014) provide figures for rigid lorries between 0 €/vkm on motorways at free flow traffic and 6.2490 €/vkm on other roads at over-capacity traffic and for articulated lorries between 0 €/vkm on motorways at free flow traffic and 9.5377 €/vkm on other roads at over-capacity traffic.

Crozet (2017) compares the values provided by Korzhenevych et al. (2014) for France with the ones offered by Commissariat Général au Développement Durable (2013) and finds that the figures suggested by the latter are 2.3-3 times lower, depending on the type of road and the traffic flows. Delhaye et al. (2017) provide marginal external congestion cost figures for vans between 0.0597 €/vkm during off-peak hours on the N-roads and 0.2568 €/vkm during peak hours on motorways and ringroads. The cost figures for lorries of more than 3.5 tonnes lie between 0.1194 €/vkm during off-peak hours on N-roads and 0.5136 €/vkm during peak hour on motorways and ringroads.

Ultimately, Delhaye et al. (2017) do not make a distinction between the marginal external congestion costs of a rigid and an articulated van. When following this logic, adding a freight wagon attached to a passenger tram does not change the marginal external congestion cost of the tram, although it could be argued that longer trams have more chance of blocking crossroads and thus, disturbing the road traffic. Moreover, these authors state that no reliable marginal external congestion cost values for rail transport are available for Belgium. As a result, these authors use a value of 0 €/trainkm in their calculations. This logic is followed here. The effect of this choice on the project outcome is evaluated in the sensitivity and scenario analyses in Chapter 6.

5.2.5 Infrastructure damage

Marginal infrastructure costs are defined by Blauwens et al. (2016, p. 417) as "*the costs that an additional user causes in terms of maintenance and operating of infrastructure*". This corresponds to the definition of Korzhenevych et al. (2014, p. 68), being the "*increase in road maintenance and repair expenditures that are induced by higher traffic levels*". Zych (2014) mentions the deterioration of the infrastructure and degradation of buildings caused by vibrations of lorries as external effects from road transport. Heavy goods vehicles can cause ruts in the roads and a slow damaging of the curbs and pavements. Blauwens et al. (2016) state that road wear is the main factor of the marginal infrastructure costs of road transport and this only for heavy goods vehicles. The marginal infrastructure costs are proportional to the axle load to the fourth power.

Firstly, the marginal external infrastructure damage cost of the reference case is derived. This cost is related to the gross weight of the vehicle and the type of road. A distinction is made by Korzhenevych et al. (2014) between motorways and trunk roads. Motorways are federal motorways or municipal roads with a freight traffic share of more than 6%. Trunk roads are federal roads or municipal roads with a freight traffic share larger than 3% and lower than or equal to 6%. Korzhenevych et al. (2014) distinguish a third road type, being the other roads, characterised by a freight traffic share of less than 3%. It is assumed that this type of road is not taken by any lorry or van delivering goods in urban areas and thus, this type of road is not included in the external cost calculations. Delhaye et al. (2017) provide other marginal external infrastructure damage cost figures depending on the gross vehicle tonnage and the type of road, being a motorway or another road.

In Belgium, commercial vehicles of less than 3.5 tonnes pay a yearly road tax, whereas vehicles with a gross weight between 3.5 and 12 tonnes pay road pricing (Viapass, 2019b; Vlaamse Belastingdienst, 2017). The amount of the tax and the road pricing depends on the euro standard of the vehicle. In this research, these taxes and road pricing are considered additional taxes that have to be paid by the road vehicles and not as the partly internalisation of the external costs. The reason behind this assumption is that it is not always clear from the external cost figures provided in the literature whether these taxes are already subtracted from the external costs. In order to avoid double counting, it is decided not to correct the external costs for road taxes and road pricing here. In Chapter 6, the effect of this assumption is tested in the sensitivity analyses. Companies that use combined transport, i.e. road and rail, can get a compensation from the government with respect to the road tax they pay. However, this compensation is only valid if the rail transport takes place between European member states (Vlaamse Belastingdienst, 2017). This is not the case in this research and hence, no compensation is taken into account.

Secondly, the marginal external infrastructure damage costs are derived for all legs of the urban rail freight supply chain, being rail, pre- and post-haulage. The marginal external infrastructure damage costs of the rail leg can be assumed zero for trams and trains, since potential rail damage is included in the rail access charges (Blauwens et al., 2016). However, Delhaye et al. (2017) assign an external cost to a train of 0.3630 €/trainkm. These authors state that the rail access charges paid by rail operators do not fully cover the marginal infrastructure costs and therefore, this cost does not equal zero. The infrastructure damage costs of a tram are considered to be internalised (Mayeres, 2016). This conclusion is drawn for the Belgian context in which in 1996 and still in 2019, the tram infrastructure manager and the tram operator are one and the same actor.

With respect to the post-haulage leg, it is assumed that walking and biking does not cause external infrastructure damage costs and thus, only the post-haulage costs of using an LGV have to be added to the external costs of the project case. Furthermore, the post-haulage transport is assumed to take place on trunk roads and by vehicles with a gross tonnage of 3.5 tonnes. Table 69 displays values for the marginal external infrastructure damage cost for LGVs and trains. The external infrastructure damage costs caused by LGVs are in general higher than the ones caused by trains if calculated per tonne transported.

Table 69 – Marginal external infrastructure damage costs

Mode	Description	Region	Value (in $€_{2018}$)	Author(s) (year)
LGV	Van	Belgium	0.0035-0.0142 €/vkm	Korzhenevych et al. (2014)
		Flanders	0 €/vkm	Delhaye et al. (2017)
	Lorry 3.5-7.5 tonnes, 2 axles	Belgium	0-0.0047 €/vkm	Korzhenevych et al. (2014)
	Lorry 7.5-12 tonnes, 2 axles	Belgium	0.0071-0.1017 €/vkm	Korzhenevych et al. (2014)
	Lorry of 3.5-12 tonnes	Flanders	0.0112-0.0203 €/vkm	Delhaye et al. (2017)
	Lorry of 10 tonnes	Belgium	0.00004-0.0084 €/vkm	Beuthe et al. (2002)
Train	Train	Flanders	0.3630 €/trainkm	Delhaye et al. (2017)

Source: Own creation

Beuthe et al. (2002) provide figures for an LGV of 10 tonnes, ranging between 0.00004 €/vkm for unloaded lorries and 0.0084 €/vkm for loaded lorries. The figures are based on Newbery (1988). Korzhenevych et al. (2014) estimate the costs of vans between 0.0035 €/vkm on motorways and

0.0142 €/vkm on other roads. For lorries between 3.5 and 7.5 tonnes, the estimated values lie between 0 €/vkm on motorways and 0.0047 €/vkm on other roads. For lorries between 7.5 and 12 tonnes, the values vary between 0.0071 €/vkm on motorways and 0.1017 €/vkm on other roads. All figures used by these authors are based on Link et al. (2009). Delhaye et al. (2017) provide marginal external infrastructure damage cost figures for Flanders varying between 0.0112 €/vkm on motorways in the low scenario and 0.0203 €/vkm in the high scenario. For vans, these authors assume that these costs are zero.

With respect to the transport of goods in a freight wagon attached to a passenger vehicle, it is assumed that the marginal external infrastructure damage cost is zero.

5.2.6 Noise

The marginal external noise costs are the costs of the effect of an additional vehicle kilometre on the noise level (Mayeres et al., 1996). Noise effects include annoyance and health effects. Le Maître (2015, p. 4) defines annoyance as the "*disturbance which is experienced when exposed to traffic noise*" and relates the health effects to the long-term exposure to noise. Zych (2014) mentions damage of the hearing organ as an effect caused by long-term exposure to elevated noise levels. Noise is measured during a certain period of time and at a certain time of the day (Le Maître, 2015).

The marginal external noise cost on the road network depends on several factors. Mayeres et al. (1996) make a distinction between peak hour and off-peak hour. Korzhenevych et al. (2014) suggest values depending on the time of the day (peak hour, off-peak hour, night), the traffic density (dense, thin), the gross vehicle weight and the area (urban, suburban, motorways) in which the transport takes place. An urban area is according to Korzhenevych et al. (2014) an area with a population of 3,000 inhabitants per kilometre road length, a suburban area is an area with a population density of 700 inhabitants per kilometre road length, whereas a rural area has a population density of 500 inhabitants per kilometre road length. In the current research, motorways are considered rural areas. For the post-haulage leg, marginal external noise costs are only taken into account if the goods are delivered by LGV.

The marginal external noise cost of a rail vehicle depends on multiple factors, such as the speed, the wheel-rail connection and the type of track. Bouland et al. (1998) state that the wheel-rail connection is the largest source of noise and the noise level depends on the size and the number of wheels. Other authors (Andersson & Ögren, 2007; Le Maître, 2015) mention especially the braking and starting of the rail vehicles, as well as the act of driving on the tracks itself. The noise level of rail transport depends according to these authors on the traffic volume, the distance to the noise emission source and other factors such as barriers, traffic composition and ground characteristics. Depending on the time of the day, i.e. day time versus night time, or peak versus off-peak hour, the external noise costs differ. Andersson & Ögren (2007) observe that the marginal cost of a train during the night is a tenfold of the marginal cost during the day. Therefore, noise emissions should always be considered in their specific context. However, Delhaye et al. (2017) provide for the marginal external costs of the rail leg only one figure which is valid for an average train in Belgium.

Table 70 gives an overview of marginal external noise costs for LGVs, trams and trains available in the literature. The minimum marginal external noise costs are associated with a lorry of less than 12 tonnes in rural areas (0.0011 €/vkm), while the maximum external noise costs relate to a freight train operating at night in Belgian urban areas (2.7893 €/trainkm). The minimum value of the external LGV costs is rather low. The reasoning behind this low figure is that lorries driving in an urban area during peak hour, drive at a low speed. Hence, their noise level is limited (Mayeres et al., 1996). In Barcelona, the noise level of passenger trams was in 2013 at all periods of the day lower than the noise of road traffic (Regué & Bristow, 2013).

Table 70 – Marginal external noise costs

Mode	Description	Region	Value (in €$_{2018}$)	Author(s) (year)
LGV	Road traffic	Belgium	0.0135 €/vkm	Delhaye et al. (2017)
	Van	Belgium	0.0621-0.2746 €/vkm	Korzhenevych et al. (2014)
	Lorry	Brussels	0.0188-0.0772 €/vkm	Mayeres et al. (1996)
	Lorry <12 tonnes	Belgium	0.0011-0.1432 €/vkm	Rebel (2013)
Tram	Passenger tram	Brussels	0.0186-0.0772 €/tramkm	Mayeres et al. (1996)
Train	Train	Belgium	0.5907 €/trainkm	Delhaye et al. (2017)
	Freight train	Belgium	0.0534-0.8935 €/trainkm	Rebel (2013)
		Belgium	0.6837-2.7893 €/trainkm	Korzhenevych et al. (2014)

Source: Own creation

Mayeres et al. (1996) estimate the marginal external noise costs of a passenger tram between 0.0186 €/vkm during peak hours and 0.0772 €/vkm during off-peak hours. The costs of a lorry are estimated by these authors between 0.0188 €/vkm during peak hour and 0.0772 €/vkm during off-peak hours. Rebel (2013) estimates the costs of a lorry less than 12 tonnes between 0.0011 €/vkm in rural areas and 0.1432 €/vkm in urban areas. The costs of a freight train lie between 0.0534 €/trainkm in rural areas and 0.8935 €/trainkm in urban areas. These values are obtained by a noise model which measures the impact of the project on inhabitants around the transport infrastructure. Korzhenevych et al. (2014) estimate the costs of a van between 0.0621 €/vkm during the day at dense traffic in urban areas and 0.2746 €/vkm during the night at thin traffic in urban areas. For freight trains, the values vary between 0.6837 €/trainkm during the day at dense traffic in urban areas and 2.7893 €/trainkm during the night in urban areas. Delhaye et al. (2017) provide marginal external noise costs of 0.0135 €/vkm for road traffic and 0.5907 €/trainkm for trains.

If a freight wagon is added to a passenger tram, more wheels will be used and thus, more noise is produced. Bouland et al. (1998) state that by reducing the number of wheels, noise savings of maximum 2dB(A) can be obtained. As a result, by adding the extra wheels of the freight wagon to the ones of the passenger tram, the noise level increases maximum by 2 dB(A). The cost of this increase of 2dB(A) depends on the absolute noise level. The noise level expressed in dB(A) and the external noise cost are not characterised by a linear relationship. Therefore, the increase of the external noise cost depends a lot on the specific circumstances of the tram. According to Fierens et al. (2019), a freight wagon of 21 tonnes gross weight does not make more noise than a passenger tram having 100 people on board. In order not to underestimate the external noise cost that the additional freight wagon might have, half of the passenger tram external noise cost is added here in the module. The effect of this choice is tested in Chapter 6.

5.2.7 Intermediate conclusion

The analysis of several potential external cost savings categories (accidents, air pollution and climate change, congestion, infrastructure damage and noise) shows that quantifying the external costs is a challenging task. Firstly, figures from existing sources cannot always be used, because they become outdated. An explanation can be found in technological and traffic changes. Secondly, it is impossible to obtain 'the' external cost figures. The context in which the transport occurs, i.e. the vehicle type, the time of the day, the area and the load, determines largely the external cost value. However, external cost values have to be decided on in order to quantify the externalities. Thirdly, different authors provide figures that sometimes differ a lot. This highlights the complexity that is involved when analysing how certain externalities have to be priced.

Table 71 shows the marginal external cost values that are used in the socio-economic calculations in the next section. It is chosen to use as many external cost figures provided by one and the same source as possible. Combining external cost figures from different sources could lead to double counting, due to different methodologies used in different studies. The choice is made to use the figures provided by Delhaye et al. (2017), since these figures are calculated for Flanders and they are the most recent figures available. Moreover, Papoutsis et al. (2018) calculate the external costs of different retail logistics solutions by road for Antwerp and use the figures provide by Delhaye et al. (2012), which is the previous study of Delhaye et al. (2017). For tram transport, Delhaye et al. (2017) do not provide figures.

For the marginal external tram accident costs, the same cost as the one for a van operating in an urban area is taken, since trams in Antwerp often share their way with road traffic. Concerning air pollution and climate change, the external cost is calculated based on Equation (57). With respect to congestion, the reasoning of Delhaye et al. (2017) provided for trains is followed and for the infrastructure damage cost, no figures are available. With respect to the external noise cost, the value suggested by Mayeres et al. (1996) for tram transport during peak hours is used. This figure was obtained for the traffic conditions in Brussels in 1995. Since traffic grew, it is assumed that the marginal external noise cost of one vehicle is not higher in 2018 than the cost during peak hours in 1995, since there is no linear relationship between the number of vehicles and the level of noise. In Chapter 6, the value of the external cost is altered in sensitivity analyses, in order to examine their effect on the cost-benefit outcome.

Table 71 – Marginal external costs used in the calculations for a dedicated freight tram

External cost in $€_{2018}$/vkm	LGV		Tram	Train	
	Van (<3.5t)	Lorry (3.5-12t)		Diesel	Electric
Accidents	0.0167-0.0459	0.0115-0.0202	0.0310	0.2529	
Air pollution and climate change	0.0637-0.0705	0.1373	0.0558	7.7677	0.5453
Congestion	0.0597-0.2568	0.1194-0.5136	0	0	0
Infrastructure damage	0	0.0112-0.0203	n/a	0.3630	
Noise	0.0135		0.0580	0.5907	

Source: Own creation based on Delhaye et al. (2017) and Mayeres et al. (1996)

The external cost values provided in Table 71 are now used in the following section to evaluate the use of a tram for urban freight distribution in Antwerp from a socio-economic perspective.

5.3 Socio-economic appraisal

As the last part of this chapter, the socio-economic appraisal of a case study of using rail for urban freight distribution is computed, continuing the same case study as the one presented in Chapter 4 (see Section 4.3.1).

In order to analyse the socio-economic success or failure of using a tram instead of road transport, the net social benefit is calculated. This is done by adding the consumer surplus and external cost savings to the financial and economic net benefits. The net social benefit equals the difference between the changes in social costs ΔC_s and the changes in social benefits ΔB_s, as shown in Equation (58):

$$benefits_{social,net} = \Delta B_s - \Delta C_s \tag{58}$$

If the net social benefit exceeds a certain social threshold y, using the tram is considered to be a social success, if the net benefit is lower than y, it is considered a failure. The changes in social benefit are calculated by means of Equation (59):

$$\Delta B_s = external_{reference} = timesav + C_{e,reference} \tag{59}$$

The changes in social cost are calculated by means of Equation (60):

$$\Delta C_s = external_{project} = external_{rail} + external_{pre} + external_{post} + external_{h\&s} \quad (60)$$

In the following sections, the net social benefits are calculated for the case study in Antwerp for three types of rail transport: a dedicated freight tram (Section 5.3.1), a freight wagon attached to a passenger tram (Section 5.3.2), and the transport of freight alongside passengers (Section 5.3.3).

5.3.1 Dedicated freight tram

The socio-economic appraisal is firstly done for the use of a dedicated freight tram. Table 72 displays the social discount rate used for this analysis, as well as the yearly socio-economic benefits, being the change of the consumer surplus and external cost savings. All input values besides the discount rate are the same as for the financial and economic analysis presented in Chapter 4[31]. From Table 72, it is clear that the largest part of the socio-economic benefits for the considered case study consists of external cost savings. The in-store stockholding surface reduction is zero and the reduced inventory carrying cost is a cost in this case study instead of a benefit, given the minus sign in Table 72.

Table 72 – Input and annual socio-economic benefits for a dedicated freight tram (values for 2018)

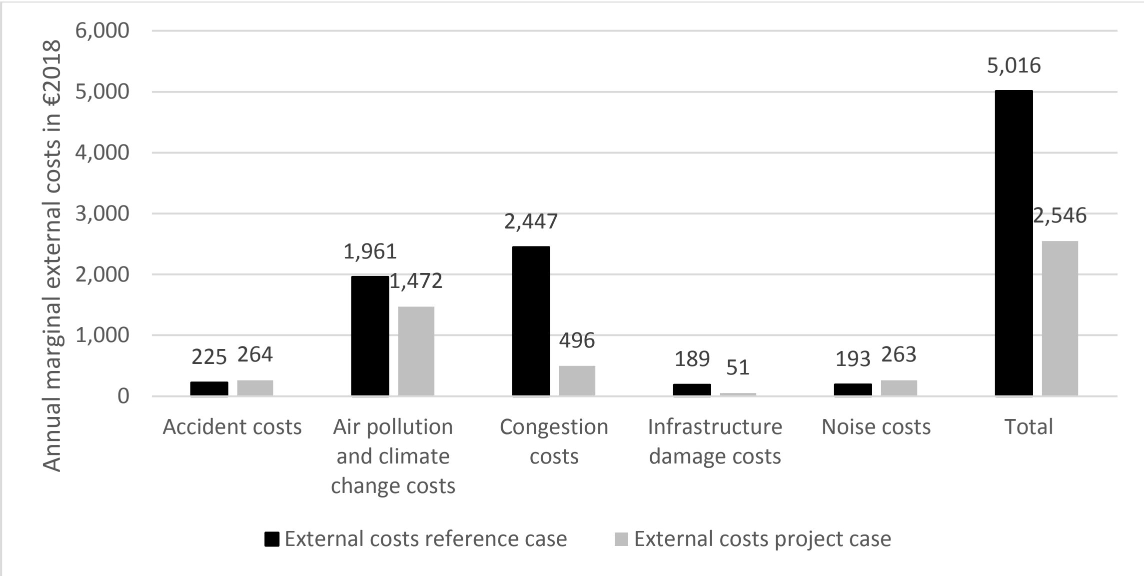
Variable	Unit	Value
Social discount rate	%	4%
Consumer surplus change		
Reduced inventory carrying cost	€/year	-9
In-store stockholding surface reduction	€/year	0
External cost savings		
External benefits - external costs	€/year	2,469

Source: Own creation

The external cost savings are calculated by subtracting the external costs of the reference case from the external costs of the project case. Figure 81 shows the yearly marginal external costs for the reference and project case, split up per external cost category. The total yearly marginal external costs of the reference case (€5,016) exceed the ones of the project case (€2,546), meaning that external cost savings are present when shifting from road to tram. This is mainly related to a strong decrease of the marginal congestion costs, and a reduction of the air pollution and climate change costs.

[31] See Table 53 in Section 4.3.2.

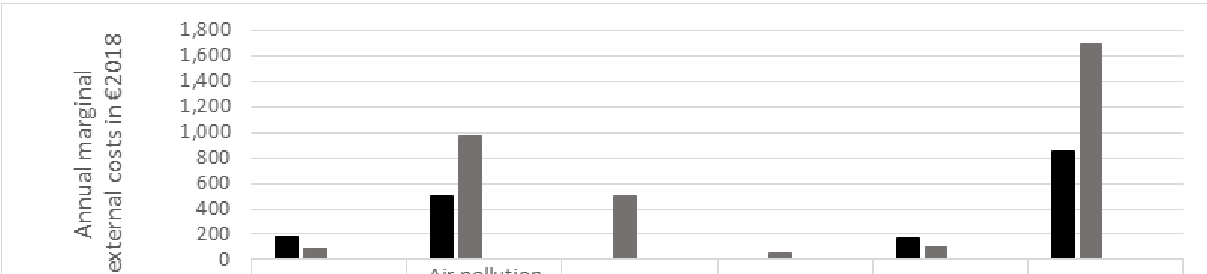
Figure 81 – Annual marginal external costs in the reference and project case for a dedicated freight tram



Source: Own creation

The marginal external costs shown in Figure 81 for the project case are related to the different legs of the urban rail freight supply chain. Hence, the costs are assigned to the tram, pre-haulage, post-haulage and handling and storage legs. This distinction of external costs per leg is shown in Figure 82. For the post-haulage and handling and storage, no external costs emerge. The post-haulage is executed by walking and for the handling and storage, no distribution centre is used and hence, no additional storage is needed. This leads to zero marginal external costs for these two legs. Hence, the external costs in the project case are caused by the road pre-haulage and by the tram leg. The tram leg is responsible for the largest part of the marginal external accident and noise costs, whereas the road pre-haulage leg causes the main part of the air pollution and climate change, congestion and infrastructure damage costs.

Figure 82 – Annual marginal external costs for a dedicated freight tram per supply chain leg



	Accidents	Air pollution & climate change	Congestion	Infrastructure damage	Noise	Total
Tram	182	502	0	0	167	851
Pre-haulage	82	971	496	51	96	1,696
Post-haulage	0	0	0	0	0	0
Handling & storage	0	0	0	0	0	0

Source: Own creation

The higher accident costs for the tram leg are explained by the fact that the transport is taking place in the urban area, and thus, a higher unit cost is applicable than for the road pre-haulage. With respect to the noise costs, the unit cost used from the literature is slightly higher for tram transport than for road transport. Table 73 displays the socio-economic analysis of using a dedicated freight tram in Antwerp for the given case study. The full socio-economic analysis over 30 years is added in Appendix 13.

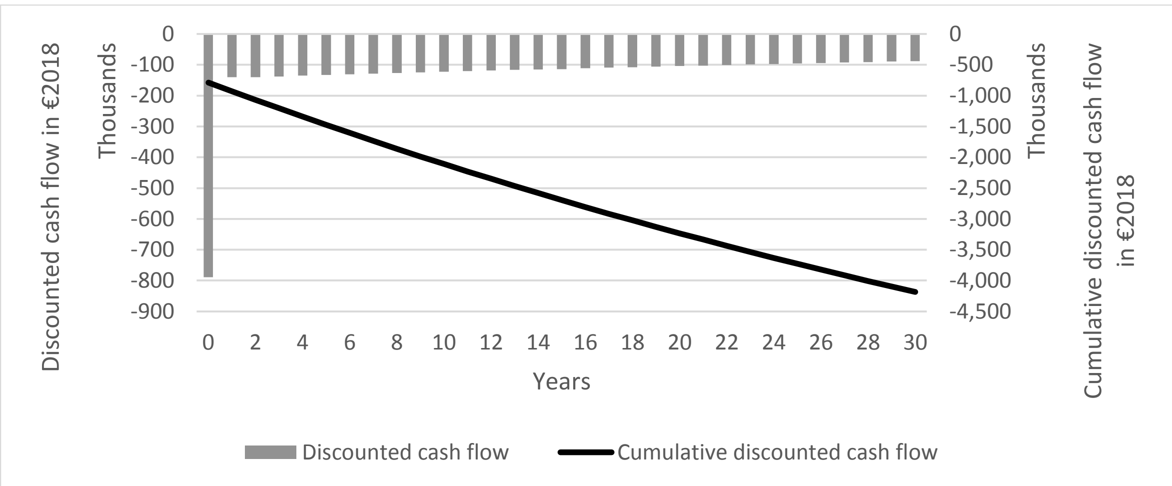
Table 73 – Socio-economic analysis of a dedicated freight tram in Antwerp (values in €$_{2018}$)

Item	Year					
	0	1	2-14	15	16-29	30
Residual value		0	…	0	…	0
Total investment	**788,832**	**0**	**…**	**0**	**…**	**0**
Tram		126,749	…	174,262	…	245,097
Road pre-haulage		4,730	…	6,503	…	9,146
Road post-haulage		12,044	…	16,559	…	23,290
Handling & storage		21,931	…	30,152	…	42,408
Replacement costs		0	…	2,000	…	0
Total operational + replacement cost		**165,454**	**…**	**229,476**	**…**	**319,941**
Operational income		17,405	…	23,929	…	33,656
Consumer surplus existing users		-9	…	-12	…	-17
Consumer surplus new users		0	…	0	…	0
External cost savings		2,469	…	3,395	…	4,775
Total inflows		**19,865**	**…**	**23,917**	**…**	**33,639**
Net result		-145,588	…	-205,559	…	-286,302
Cash flow	-788,832	-145,588	…	-205,559	…	**-286,302**
Discounted cash flow	-788,832	-139,989	…	-114,140	…	**-88,272**
Cumulative discounted cash flow	**-788,832**	**-928,821**	**…**	**-2,695,161**	**…**	-4,184,934

Source: Own creation

The social net present value equals -€4,184,934 and the present value to capital ratio is -5.31. The internal rate of return cannot be calculated, since all cash flows are negative. Figure 83 shows the discounted cash flow and the cumulative discounted cash flow graphically. It is clear that from a socio-economic perspective, using a dedicated freight tram instead of road transport is still not viable for the considered case study. This is due to the economic costs, which are so high that they cannot be compensated for by the external cost savings.

Figure 83 – (Cumulative) socio-economic discounted cash flow for a dedicated freight tram in Antwerp



Source: Own creation

The social costs and benefits of using a dedicated freight tram in 2018 can also be quantified per transported parcel. A social cost of 0.78 €/parcel, and a social benefit of 0.09 €/parcel is obtained. This leads to a net social cost of 0.69 €/parcel. In the next section, the use of a freight wagon attached to a passenger tram is examined from a socio-economic viewpoint.

5.3.2 Freight wagon attached to a passenger tram

Secondly, the use of a freight wagon attached to a passenger tram is evaluated for the case study in Antwerp. Table 74 shows the social discount rate used, as well as the resulting consumer surplus change and the external cost savings. As for the use of a dedicated freight tram, the largest part of the socio-economic benefits is related to the external cost savings, no in-store stockholding surface reduction is obtained and the reduced inventory carrying cost is a cost here instead of a benefit.

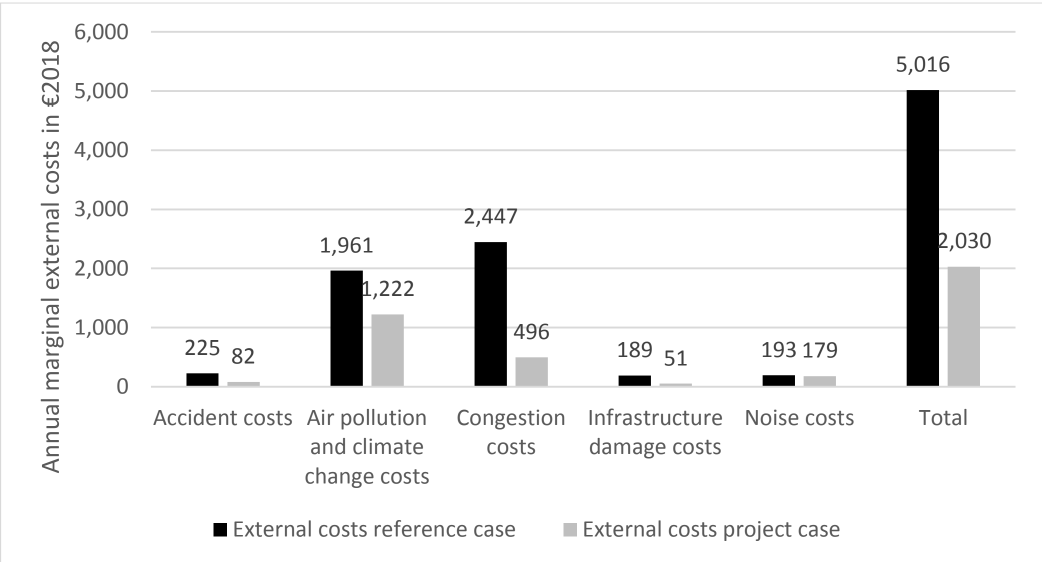
Table 74 – Input and annual socio-economic benefits for a freight wagon (values for 2018)

Variable	Unit	Value
Social discount rate	%	4%
Consumer surplus change		
Reduced inventory carrying cost	€/year	-4.50
In-store stockholding surface reduction	€/year	0
External cost savings		
External benefits - external costs	€/year	2,986

Source: Own creation

Figure 84 displays the yearly marginal external costs in the reference and project case per external cost category. It is clear that the total marginal external costs of the project case are less than half of the costs of the reference case. As shown in Figure 84, the external costs in the reference case are higher than the ones in the project case for all external cost categories.

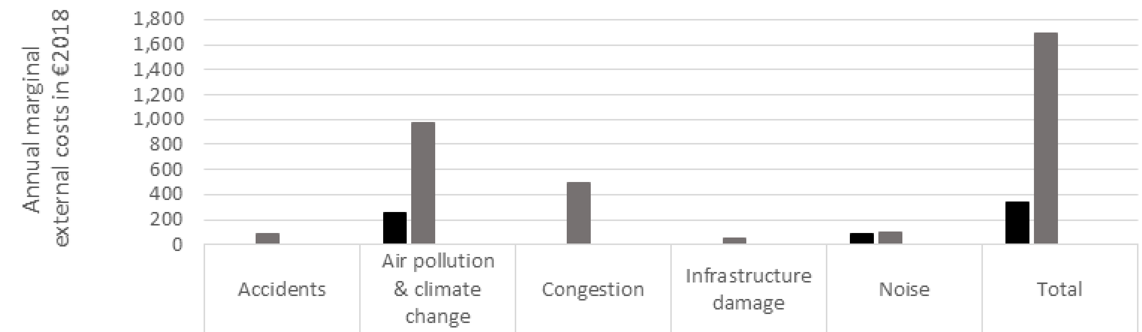
Figure 84 – Annual marginal external costs in the reference and project case for a freight wagon



Source: Own creation

The external costs of the project case comprise the costs of all urban rail freight supply chain legs, being the tram, pre-haulage, post-haulage and handling and storage legs. Figure 85 shows the division of the project case external costs over the different supply chain legs. No post-haulage and handling and storage external costs are present, as for the use of a dedicated freight tram. The largest part of the external costs is caused by the road pre-haulage (€1,696), with especially the air pollution and climate change (€971) and congestion (€496) costs as important aspects.

Figure 85 – Annual marginal external costs for a freight wagon per supply chain leg



	Accidents	Air pollution & climate change	Congestion	Infrastructure damage	Noise	Total
Tram	0	251	0	0	84	335
Pre-haulage	82	971	496	51	96	1,696
Post-haulage	0	0	0	0	0	0
Handling & storage	0	0	0	0	0	0

Source: Own creation

The yearly marginal external costs are now, together with the change of the consumer surplus, taken into account in the socio-economic part of the cost-benefit analysis. This is presented in Table 75. The full analysis over a time horizon of 30 years is added in Appendix 14.

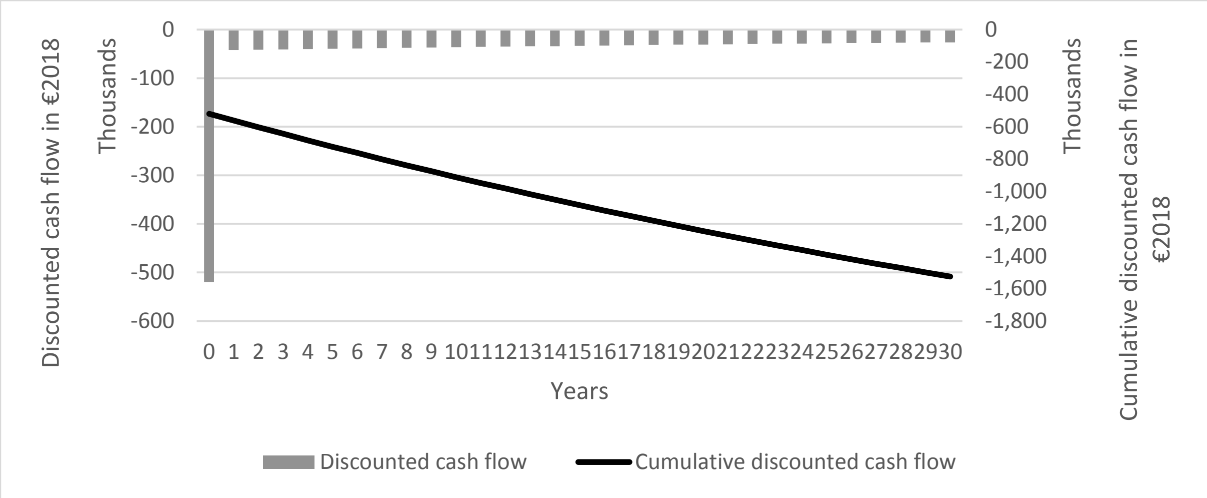
Table 75 – Socio-economic analysis of a freight wagon in Antwerp (values in €$_{2018}$)

Item	Year					
	0	1	2-14	15	16-29	30
Residual value		0	…	0	…	0
Total investment	**519,642**	**0**	**…**	**0**	**…**	**0**
Tram		36,854	…	50,669	…	71,265
Road pre-haulage		4,730	…	6,503	…	9,146
Road post-haulage		4,593	…	6,314	…	8,881
Handling & storage		18,043	…	24,807	…	34,890
Replacement costs		0	…	0	…	0
Total operational + replacement cost		**64,219**	**…**	**88,293**	**…**	**124,182**
Operational income		17,405	…	23,929	…	33,656
Consumer surplus existing users		-5	…	-6	…	-9
Consumer surplus new users		0	…	0	…	0
External cost savings		2,986	…	4,105	…	5,773
Total inflows		**20,386**	**…**	**28,028**	**…**	**39,420**
Net result		-43,834	…	-60,265	…	-84,762
Cash flow	-519,642	-43,834	…	-60,265	…	-84,762
Discounted cash flow	-519,642	-42,148	…	-33,463	…	-26,134
Cumulative discounted cash flow	**-519,642**	**-561,790**	**…**	**-1,084,401**	**…**	**-1,525,460**

Source: Own creation

The socio-economic net present value equals -€1,525,460 and the present value to capital ratio is -2.94. The internal rate of return cannot be calculated since all cash flows are negative over the considered time horizon of 30 years. Figure 86 shows the discounted cash flow and the cumulative discounted cash flow graphically. It is clear that for this type of rail transport too, shifting from road to tram is not viable given all case study characteristics, although society would benefit from this modal shift thanks to external cost savings.

Figure 86 – (Cumulative) discounted socio-economic cash flow for a freight wagon in Antwerp



Source: Own creation

When now comparing all socio-economic costs and benefits for 2018 per parcel transported, a social cost of 0.33 €/parcel emerges, whereas a social benefit of 0.09 €/parcel is achieved. Combining these two, this type of rail transport is characterised by a net social cost of 0.24 €/parcel.

5.3.3 Freight alongside passengers

Next to the use of a dedicated freight tram or a freight wagon attached to a passenger tram, freight can be transported alongside passengers. The socio-economic evaluation of this type of transport is presented in this section. Table 76 shows the change of the consumer surplus and the external cost savings. The change of the consumer surplus is a cost here instead of a benefit, but is almost inexistent.

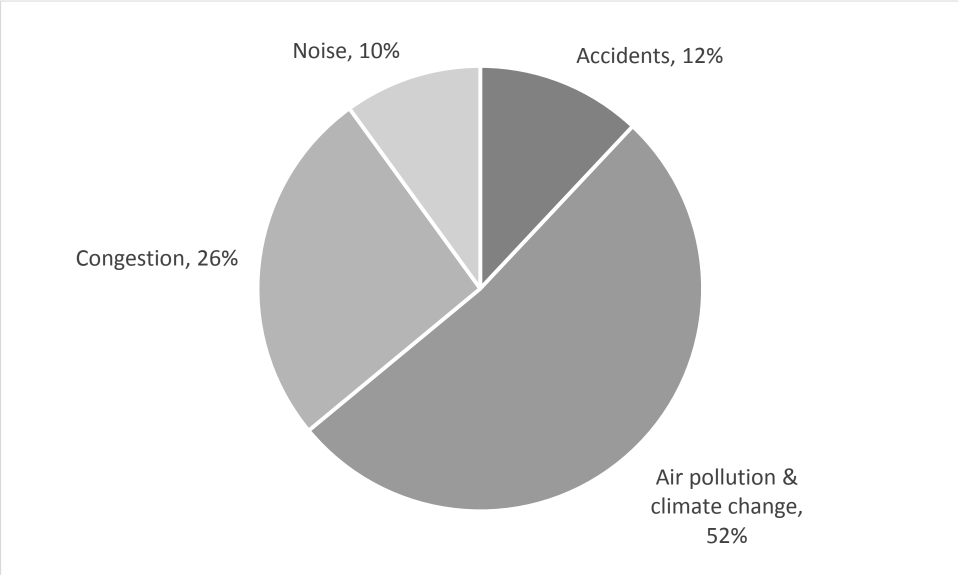
Table 76 – Input and annual socio-economic benefits for freight alongside passengers (values for 2018)

Variable	Unit	Value
Social discount rate	%	4%
Consumer surplus change		
Reduced inventory carrying cost	€/year	-1
In-store stockholding surface reduction	€/year	0
External cost savings		
External benefits - external costs	€/year	1,795

Source: own creation

The external costs are caused by all urban rail freight supply chains legs. However, for the tram leg, road post-haulage and handling and storage, the external costs equal zero. Hence, all external costs are caused by the road pre-haulage. In total, the marginal external road pre-haulage costs are €961 per year. Figure 87 shows how these costs are divided over different external cost categories. The marginal external costs of infrastructure damage are considered zero and therefore they are not visible in Figure 87.

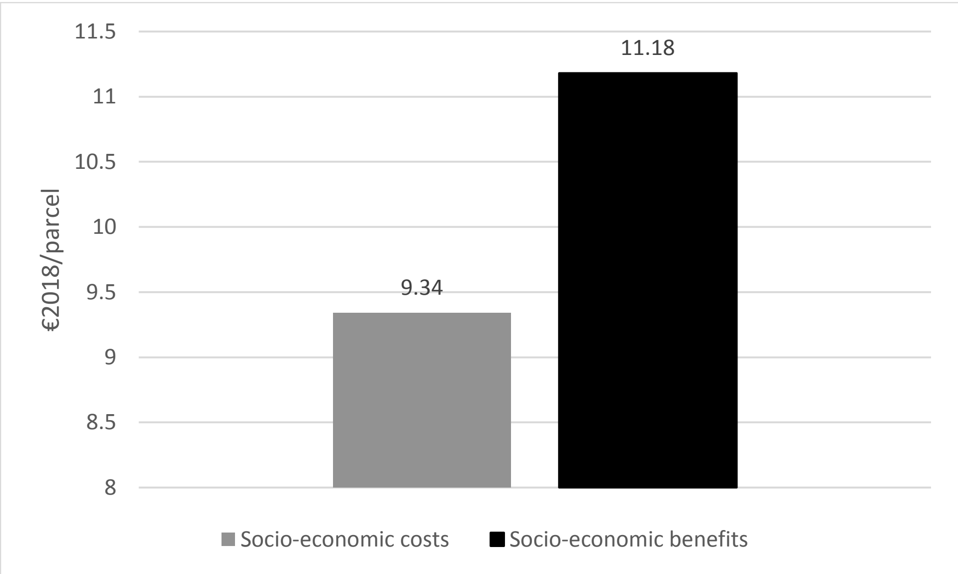
Figure 87 – Marginal external costs of road pre-haulage (values for 2018)



Source: Own creation

Subsequently, the socio-economic costs and benefits of transporting parcels alongside passengers are calculated (see Figure 88). The socio-economic cost equals €9.34 per parcel, whereas the socio-economic benefit amounts to €11.18 per parcel. Combining these two, a net socio-economic benefit of €1.84 is obtained when shifting from road to tram, leading to a success of the project.

Figure 88 – Socio-economic costs and benefits of freight alongside passengers



Source: Own creation

5.3.4 Intermediate conclusion

The use of a tram to distribute goods of Torfs in Antwerp is examined from a socio-economic viewpoint. In other words, the effects of the project on the users and on the impactees is included in the cost and benefit calculations. Table 77 displays the resulting change in consumer surplus and external cost savings, as well as the socio-economic output of the analysis for the three rail types considered in this research.

Table 77 – Overview socio-economic analysis (values for 2018)

Aspect	Dedicated freight tram	Freight wagon attached to passenger tram	Freight in passenger tram
Amount of goods	8 roll cages	8 roll cages	8 parcels
Lorry/van in reference case	12 tonnes	12 tonnes	3.5 tonnes
Consumer surplus change	-€9.00	-€4.50	-€1.00
External cost savings	€2,469	€2,986	€1,795
Socio-economic NPV	-€4,184,934	-€1,525,460	n/a
Socio-economic IRR	n/a	n/a	n/a
Socio-economic present value to capital ratio	-5.31	-2.94	n/a

Source: Own creation

For all three rail types, the change of the consumer surplus is negative, but very small and therefore almost negligible. The external cost savings are the main factor of the socio-economic analysis and are positive for the three rail types. The transport of freight in a passenger tram cannot be compared to the other two types, because only eight parcels are transported here instead of eight roll cages. Concerning a dedicated freight tram and a freight wagon attached to a passenger tram, it is clear that these two types are not viable from a socio-economic viewpoint, given the negative socio-economic NPV and the negative present value to capital ratio. The internal rate of return cannot be calculated for both cases.

When comparing the external cost savings for the three types of rail transport shown in Table 77, it is clear that the highest external cost savings are present when a freight wagon is attached to a passenger tram (€2,986 per year). This comes from the lower external costs caused by a freight wagon (€2,030 per year) than by a dedicated freight tram (€2,546 per year). Transporting parcels alongside passengers causes yearly external costs of only €961, related to the road pre-haulage leg. Hence, this type of rail transport is characterised by the lowest external costs, although it does not show the highest external cost savings in Table 77. This is explained by the fact that the three rail projects are not compared with the same reference case. For the transport of parcels alongside passengers, transport in the reference case is done by a van, whereas for the use of a dedicated freight tram or a freight wagon, transport in the reference case is done by a lorry. This explains the lower external costs in the reference case where vans are used (€2,757 per year) compared to the one where lorries are used (€5,016 per year). Hence, it is important to keep in mind that the effect of external cost savings is dependent on the external costs of the project case, as well as on the ones of the reference case.

5.4 Conclusion

The socio-economic evaluation of using rail for urban freight distribution incorporates, the impact of the project case on the users and on the impactees. The inclusion of these impacts is important, since it can alter the viability of the rail-based project. The users can experience a change in their consumer surplus, whereas all impactees can benefit from external cost savings. The consumer surplus is related to the in-transit inventory, which depends on the potential time savings of using the tram compared to road transport. The external cost savings result from the external costs of the reference case that does not take place anymore, reduced by the external costs of the project case. For the latter, the costs of all legs of the urban rail freight supply chain are taken into account. In general, producer and user emissions have to be considered. In this research, it is decided to leave the producer emissions outside the calculations. The user emissions consist of marginal external accident, air pollution and climate change, congestion, infrastructure damage and noise costs.

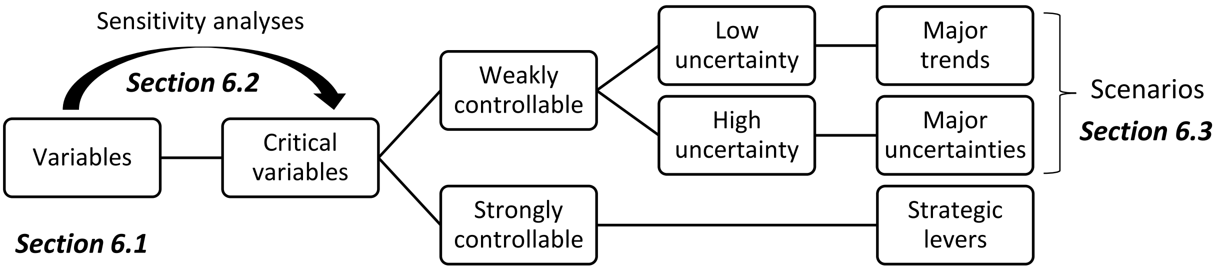
The consumer surplus changes and the external cost savings are added to the financial and economic analysis discussed in Chapter 4. For the case study under consideration, it can be concluded that net social costs are present when using a dedicated freight tram or attaching a freight wagon to a passenger tram. Furthermore, these net costs are higher from a private than from a social perspective. This leads to the important insight that including the external cost savings in the analysis can alter the decision whether to continue with the project or not. If a project has a negative NPV which is very small in absolute terms, incorporating the external costs in the calculations and hence, adopting the socio-economic viewpoint instead of a purely financial or economic viewpoint, can increase the NPV such that it becomes positive. This insight is very valuable for policy makers, who are striving for socially-viable projects.

The analysis provided in this chapter also shows valuable insights for the scenario and sensitivity analyses performed in the next chapter. It is clear that a lot of uncertainty is present in the monetisation of the external costs. For some costs, no values are available and for others, different authors provide figures that are far apart. Moreover, including the external cost savings to the analysis decreases the net costs of using a dedicated freight tram or attaching a freight wagon to a passenger tram. It also increases the net benefit of transporting parcels alongside passengers. This means that the external costs will have a pivotal role in making the project case viable. Hence, the external costs receive a central role in Chapter 6.

6. Dealing with uncertainty and risk

Tackling risk and uncertainty is an important part of the development of an SCBA framework. Risk is present in the sense of potential changes in the economy, as well as decisions made by the project leader. Moreover, the conditions in which a project is implemented can change due to exogenous factors. Uncertainty is related to unpredictable and unimaginable situations. Several assumptions are made in the different steps of the framework, and input values are often subject to risk and uncertainty. This may significantly alter the outcome of the framework. Sensitivity and scenario analyses are used to deal with this (see Section 3.2.2). Figure 89 shows the structure of this chapter. In Section 6.1, the variables subject to sensitivity and scenario analyses are identified. In Section 6.2, the sensitivity analyses identify the critical variables in the project cases under consideration. In Section 6.3, scenario analyses are performed with respect to the major trends and major uncertainties in order to obtain interesting insights for different possible realities. Ultimately, in Section 6.4, conclusions are drawn. All monetary data used in this chapter are discounted to values for 2018.

Figure 89 – Sensitivity and scenario analyses



Source: Own creation based on Arcade (2003), Crozet (2003, p. 60) and Sartori (2015)

6.1 Variables subject to sensitivity and scenario analyses

The variables that are subject to sensitivity or scenario analyses are identified starting from the success and failure factors of urban rail freight projects. Table 78 and Table 79 display these success and failure factors respectively, as well as how they are taken into account in the social cost-benefit framework that is developed, how they should be used in sensitivity or scenario analyses according to the literature, and the main findings with respect to these factors that are derived from Chapter 4 and Chapter 5. Ultimately, the last column in Table 78 and Table 79 shows which specific variable in the developed social cost-benefit framework is now changed in scenario and/or sensitivity analyses. Variables that are not displayed in Table 78 and Table 79, although Vadali et al. (2017) recommend to include them in sensitivity analyses, are construction delays, financial difficulties, legal action, legislative action, property acquisition costs, results of contract negotiations, the spatial resolution and the temporal scale of analysis. The reason why these variables are not included here is that they cannot be quantified in the case study under consideration. Moreover, the discount rate should be subjected to sensitivity analyses, although this is not shown in Table 78 and Table 79 (see Section 3.3.1). An explanation can be found in the fact that the discount rate is not related to success or failure factors.

Table 78 – Variables subject to sensitivity or scenario analysis based on success factors (see Table 8)

Success factors		How taken into account in the SCBA framework	Sensitivity/scenario analyses according to the literature	Findings from case study in Chapter 4	Findings from case study in Chapter 5	Variable to be changed in scenario/sensitivity analyses
Operations	Just in time	As little storage as possible at the shop	Inventory space	No costs/benefits		Distribution centre versus transit platform
	Non-time-sensitive, low value commodity	Non-food products				Commodities value
	Standard units	Roll cages/ shoe boxes	Standard unit			Post-haulage need
	Time gains	Time savings examined	Timing transport, assumed travel times, value of time, commodities value	Time costs		Time needed, value of time, commodities value, routing
	Value added services	Lower inventory costs examined		Higher in-transit inventory		Time needed
Target city environment	Congestion present	Present in Antwerp	Congestion			Time needed
	Good environmental performance of rail	Examined through external costs	Energy use models, externality costs		Marginal external costs very uncertain, no correction for road pricing and taxes	All external costs
	Low fatality risk	Examined through external accident cost	Accident rates		Marginal external accident cost very uncertain for a freight wagon	External accident cost
	Other urban freight measures	Road pricing	Road measures	Road pricing		Road pricing
Urban logistics spaces	Ancillary revenue	Not present	Ancillary revenue	No ancillary revenue		Ancillary revenue
	Synergies	Use of existing storage space in urban area				Amount of goods
Vehicles	Tram dimensions	Tram/wagon length		Length is not a limit		Load capacity tram

Source: Own creation based on Arvidsson & Browne (2013), Behrends (2012b), Boardman et al. (2018), Cochrane et al. (2017), Comi et al. (2014), de Rus (2010), Gorçun (2014), Maes & Vanelslander (2011), Mortimer (2008), Regué & Bristow (2013), Robinson & Mortimer (2004a), Sartori et al. (2015), Vadali et al. (2017)

Table 79 – Variables subject to sensitivity or scenario analysis based on failure factors (see Table 9)

Failure factors		How taken into account in the SCBA framework	Sensitivity/scenario analyses according to the literature	Findings from case study in Chapter 4	Findings from case study in Chapter 5	Variable to be changed in scenario/sensitivity analyses
Operations	Amount of goods	Goods of one retailer	Sharing resources, freight traffic growth rate	Small amount of goods leading to high costs per parcel		Amount of goods
	High investment costs	Line and nodal infrastructure and rolling stock	Cost rail infrastructure, rail operational cost, capital investment, labour costs, maintenance & operating costs, construction costs, fuel price	High tram operational costs due to long distance to be covered and courier on board		Capital investment, operational costs
	Lack of cooperation between stakeholders & stakeholder involvement (incl. politicians)	Government viewpoint				Retailer and rail operator viewpoint
	Low flexibility	Max. axle load		Not a limit		Load capacity tram
	Low service level	Number of rail vehicles, vehicle capacity	Number of rail vehicles, vehicle capacity	One vehicle needed		Number of rail vehicles, vehicle capacity
	Pre- and post-haulage, extra handling, transit time	Pre- and post-haulage needed	Handling cost, supply chain structure changes, pre- and post-haulage	Pre- and post-haulage needed, leading to additional costs		Pre- and post-haulage
	Stakeholder resistance	Not considered				n/a
Target city environment	Interference with passenger transport	Shared network	Timing transport, night versus day	Off-peak hour transport by tram		Night versus peak versus off-peak
	Pressure on railway areas	Not considered	Land use changes			n/a
Vehicles	Technological limitations	Not considered				Post-haulage need

Source: Own creation based on Alessandrini et al. (2012), Arvidsson & Browne (2013), Behrends (2012b), Bickel et al. (2006), Boardman et al. (2018), Cochrane et al. (2017), Comi et al. (2014), Delaître & De Barbeyrac (2012), de Rus (2010), Maes & Vanelslander (2011), Mortimer (2008), Regué & Bristow (2013), Robinson & Mortimer (2004a), Sartori et al. (2015), Sivakumaran et al. (2010), Vadali et al. (2017)

From the last column of Table 78 and Table 79, scenarios can be developed and sensitivity analyses can be set up. **The variables that appear to be critical after conducting sensitivity analyses, are added to the development of scenarios**. According to Sartori et al. (2015), a variable is considered to be critical if the NPV of the project case changes by more than 1% when the variable itself is altered by 1%.

Table 80 displays all variables that are derived based on the last columns of Table 78 and Table 79. The variables are divided in general variables and variables related to the financial and economic analysis (Chapter 4) and the socio-economic analysis (Chapter 5). For the latter two types of analysis, the cost and benefit category that is affected by a change of the variable is displayed in the second column. For each variable, it is indicated whether it is used in the sensitivity and/or in the scenario analyses performed in the following sections. The distinction between these two types of analysis is made based on whether the value of the variable can be altered by 1% in a meaningful way. If this is the case, the value is used in the sensitivity analysis. If this is not the case, the effect of the value is tested in the scenario analysis. A change by 1% is chosen to examine whether the project outcome behaves elastically with respect to the altered variable. If the project outcome changes by more than 1%, it is elastic concerning the altered variable.

Table 80 – Classification of variables used in scenario and sensitivity analyses

Analysis	Costs and benefits	Variable	Sensitivity analyses	Scenario analyses
General		Amount of goods	X	X
		Discount rate	X	
Financial and economic analysis	Capital investment	Line infrastructure	X	
		Loading capacity		X
		Nodal infrastructure	X	
		Number of vehicles		X
		Rolling stock	X	
	Operations	Distance (routing)		X
		Labour cost	X	
		Pre- and post-haulage		X
		Time needed	X	
		Timing transport		X
	Operational income	Ancillary revenue		X
		Road pricing	X	
Socio-economic analysis	Consumer surplus change	Commodities value	X	
		Value of time	X	
	External cost savings	External costs	X	

Source: Own creation

A variable that is used in the sensitivity analysis and proves to be critical, is added to the scenario analysis as well. The viewpoint of the analysis can be changed in order to correct for the involvement of different stakeholders. Until now, the government is considered to be the project leader. It is most interesting to examine the effect on the project outcome if the project leader would be a private actor, such as a rail operator or a retailer. The effect of the viewpoint is discussed throughout this chapter.

The general variables include the amount of goods and the discount rate. Firstly, the amount of transported goods is important. In general, a tram can transport more goods than a van, but requires higher initial capital investments. More specifically, the minimum required amount of goods needed to operate break-even is important to know. This amount differs according to the conditions in which the transport takes place. In other words, it depends on the values of all other variables characterising the project. The effect of the amount of goods can be evaluated in sensitivity and scenario analyses.

Secondly, given the uncertainty about the financial and social discount rate, the effect of a change of this variable as well has to be checked upon in sensitivity analyses (see Section 3.2.2.5).

In the financial and economic analysis, changes in the capital investment, operations and operational income are investigated firstly by sensitivity analyses. With respect to the capital investment, sensitivity analyses are carried out for the investment needed in line and nodal infrastructure and in rolling stock. Concerning the operations, the effect of a 1% change of the labour cost and the time needed to cover a certain distance on the project outcome are investigated. Regarding the operational income, the effect of the road pricing fee is evaluated. Secondly, scenario analyses are performed for the capital investment, operational costs and operational income. Concerning the capital investment, the loading capacity of the vehicles and the number of vehicles needed are evaluated in the scenario analyses. Regarding the operational costs, the effect of the route followed by the tram, the need for pre- and/or post-haulage and the timing of the transport, i.e. during the night, peak hour, or off-peak hour are analysed. With respect to the operational income, the presence of ancillary revenue is assessed.

In the socio-economic analysis, consumer surplus changes and external cost savings are altered in sensitivity analyses. With respect to the consumer surplus, the effect of a change of the value of the commodities and the value of time is examined. For the external cost savings, the cost of the externalities of road and rail is checked upon its effect on the project's outcome.

In the following section, sensitivity analyses are carried out for the variables presented in Table 80. An additional remark here is that before testing the effect of these variables, it is valuable to examine the effect of a change in the capital investment, operations, operational income, consumer surplus and external cost savings in general. If a general change of one of those cost or benefit categories does not alter the project outcome, a change of one variable that is only a part of the cost or benefit category will also not critically affect the project outcome.

6.2 Sensitivity analyses

Sensitivity analyses are carried out in the next sub-sections for the use of a dedicated freight tram (Section 6.2.1), a freight wagon attached to a passenger tram (Section 6.2.2) and the transport of freight alongside passengers (Section 6.2.3). An intermediate conclusion is drawn in Section 6.2.4.

6.2.1 Dedicated freight tram

Firstly, the amount of goods to be transported is checked upon its effect on the outcome of the project cases. Following Campos & Hernández (2010) and Regué & Bristow (2013), the question rises which amount of goods is minimally required to have a viable tram-based solution. The transported amount of goods in the reference case can be altered in four ways: by considering larger or smaller lorries, by considering higher or lower utilisation rates of the existing lorries, by adding additional round trips, or by adding new customers receiving goods in the urban area. It is chosen to keep in first instance the type of vehicle fixed to vehicles of 12 tonnes gross weight, as well as to keep the number of customers served in the urban area unchanged. These two ways are the least likely to change for Torfs in the short run. Hence, the utilisation rate and the number of daily round trips are altered in order to see the effect of a change of the amount of goods on the viability of the tram project.

In the reference scenario, the lorry carries eight roll cages for three customers. The maximum loading capacity of the lorry is 18 roll cages. Hence, the utilisation rate of the lorry can be decreased or increased. If up to three roll cages are transported, a van with a gross weight of 3.5 tonnes and a loading capacity of three roll cages would be chosen instead of the lorry that can carry 18 roll cages.

Hence, the utilisation rate of the lorry varies between 4 and 18 roll cages. The number of daily round trips is currently one, but this can be increased as well. The additional round trips can come from other retailers than Torfs, but then it is assumed here that these round trips have identical characteristics as the ones of Torfs. For all combinations of the number of round trips and the utilisation rate of the lorries, the net present value is calculated from a financial, economic and socio-economic perspective.

When altering the number of roll cages transported per round trip, this number has to be adapted for each customer. In order to be consistent, this is from now on always done as shown in Table 81.

Table 81 – Division of roll cages over the three customers

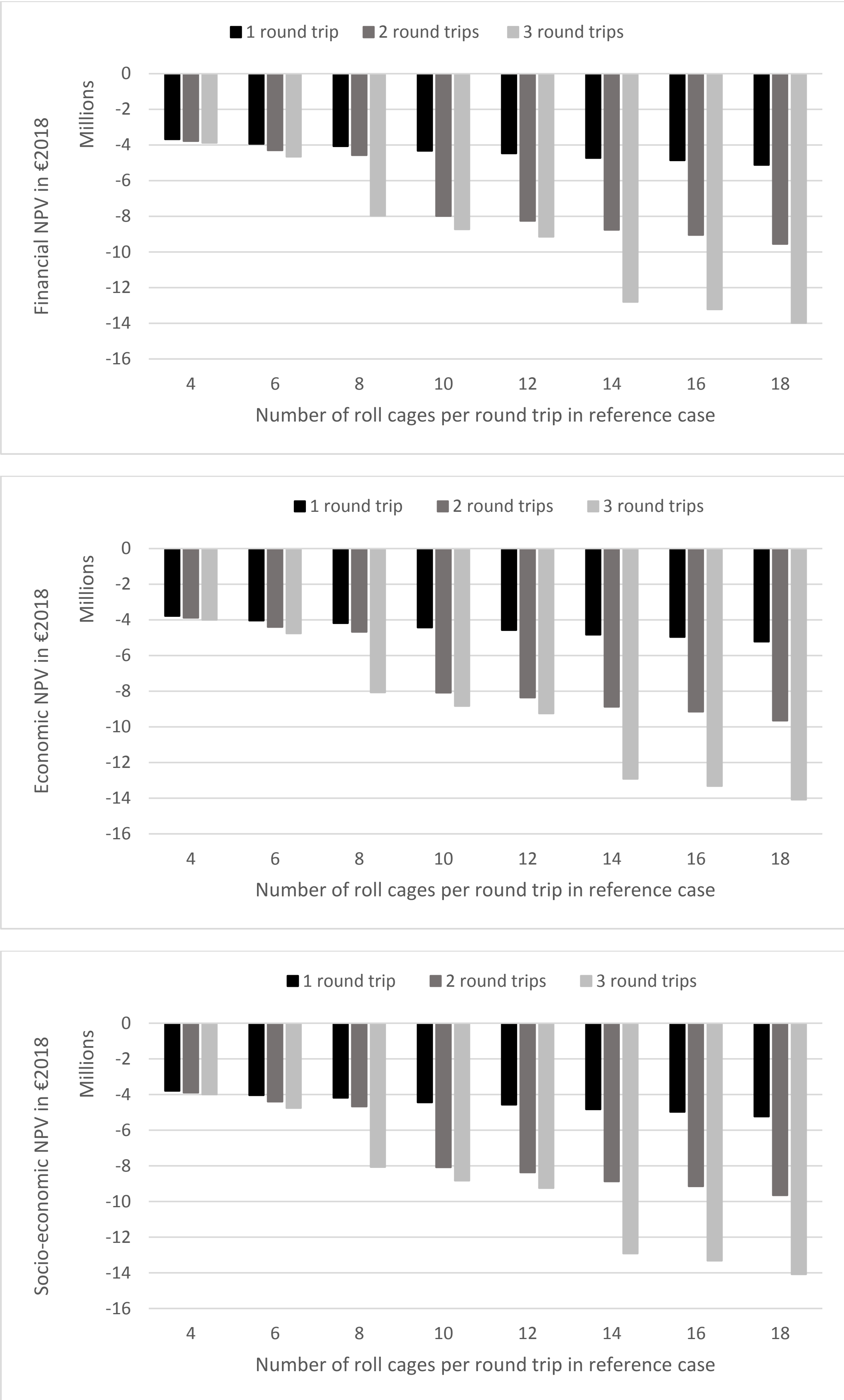
Number of roll cages per round trip	Shop Meir	Shop Groenplaats	Shop Wijnegem Shopping Centre
4	2	1	1
6	4	1	1
8	4	2	2
10	6	2	2
12	6	3	3
14	8	3	3
16	8	4	4
18	10	4	4

Source: Own creation

Figure 90 shows the financial, economic and socio-economic net present value for a changing number of round trips and different numbers of roll cages transported. The number of round trips varies between one and three, whereas the number of roll cages transported ranges from 4 to 18. The first observation is that irrespective of the number of round trips, the net present value decreases if more roll cages are transported in the lorry. This is valid for the financial, economic and socio-economic net present value. This decreasing trend is explained by the handling and post-haulage costs, which are dependent on the number of roll cages, since each roll cage needs separate handling and post-haulage in the project case under consideration.

Secondly, if two round trips take place, it can be seen from Figure 90 that the NPV strongly decreases for the three graphs when shifting from eight to ten roll cages. This is because from ten roll cages on, two tram trips are needed to transport all roll cages in the project case. In other words, the tram operational costs increase at this point. The same logic is displayed if three round trips take place. In the latter case, one tram trip is needed to transport up to six roll cages per lorry, two tram trips are necessary to carry between eight and twelve roll cages per lorry, and three tram trips have to be executed to transport 14 to 18 roll cages per lorry.

Figure 90 – NPVs per number of round trips and per number of roll cages for a dedicated freight tram



Source: Own creation

Thirdly, for each number of transported roll cages, the net present value is more negative the more round trips are performed in the reference case, and thus, in the pre-haulage leg of the project case. Table 82 provides an overview of the annual operational costs, operational income, consumer surplus change and external cost savings when one round trip is executed and when two round trips are carried out, each round trip carrying eight roll cages. The last column displays the cost or benefit difference between one and two round trips. It can be seen that the yearly increase of the operational costs (€38,704) exceeds the increase of the yearly operational income (€17,404), the consumer surplus change (-€9) and the external cost savings (€3,321) when shifting from one to two round trips. This explains the decreasing NPV values in Figure 90. The underlying data for this figure are added in Appendix 16.

Table 82 – Annual costs and benefits for eight roll cages per round trip, dedicated freight tram

Cost/benefit in $€_{2018}$/year	1 round trip	2 round trips	Difference
Operational costs	165,454	204,158	+38,704
• Tram	126,749	126,749	+0
• Pre-haulage	4,730	9,460	+4,730
• Post-haulage	12,044	24,088	+12,044
• Handling & storage	21,931	43,861	+21,930
Operational income (user fee)	17,405	34,809	+17,404
Consumer surplus change (inventory carrying cost)	-9	-18	-9
External cost savings	2,469	5,790	+3,321

Source: Own creation

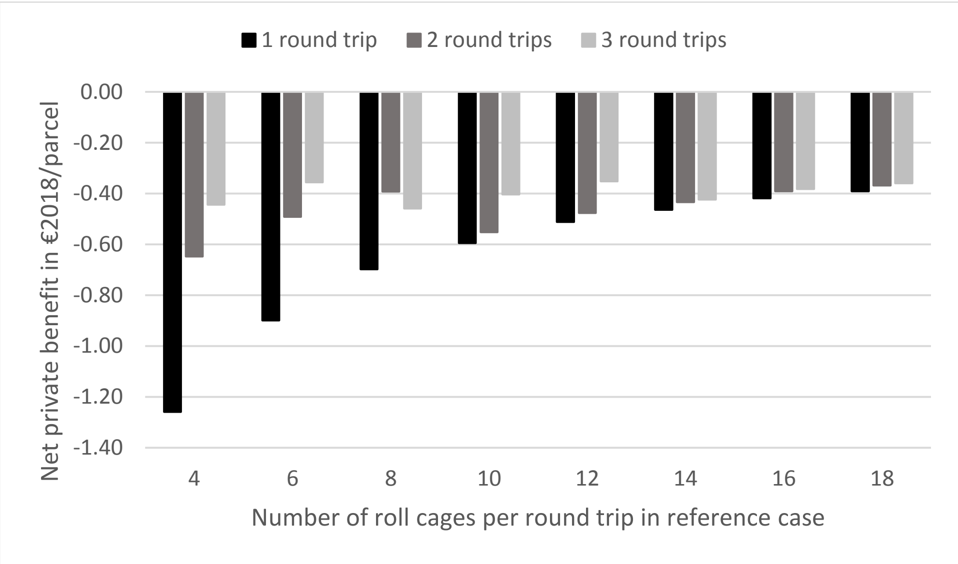
As a result, increasing the amount of goods to be transported under the current project conditions does not lead to a viable project. The reasons are the increasing operational costs of the road pre-haulage, the post-haulage and handling activities. In order to obtain a viable project case, a solution has to be found to lower the operational costs.

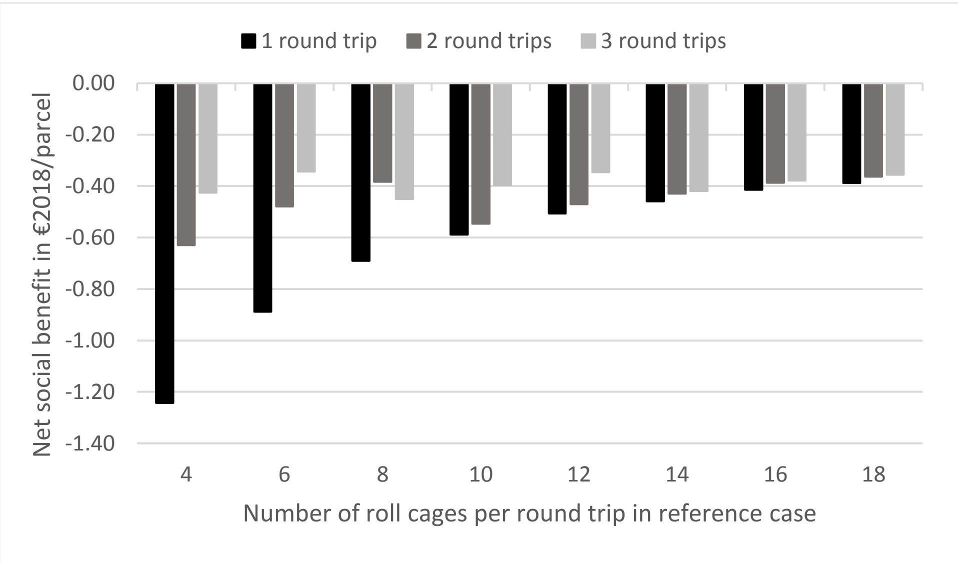
Next to the net present value, the internal rate of return and the present value to capital ratio are calculated for the financial, economic and socio-economic analysis as well. The internal rate of return cannot be calculated for any of the combinations of a certain number of round trips and a certain number of roll cages, in the financial, economic and the socio-economic analysis. The present value to capital ratio is calculated and shows a similar overall pattern as the net present value shown in Figure 90. The ratio is negative for the three analyses and decreases if more roll cages are transported. The resulting net present value to capital ratios are added in Appendix 16.

The yearly private and social costs are now also calculated in euro per parcel. Figure 91 shows the net private (upper figure) and the net social benefit (lower figure), again for a certain number of round trips and roll cages. The first observation of Figure 91 is that the net private and social benefit is negative independent from the number of round trips covered and the number of roll cages taken. Secondly, the more roll cages transported per round trip, the higher the net private and social benefit per parcel. This increase converges to a net private and social benefit between -€0.39 and -€0.36 per parcel if 18 roll cages are transported. Thirdly, the net social benefit lies for a given number of round trips and roll cages between €0.004 and €0.018 per parcel higher than the net private benefit.

When comparing Figure 91, where the net private and social benefit is expressed in euro per parcel, to Figure 90, where the financial, economic and socio-economic net present value over a time horizon of 30 years is shown, these figures look at first sight contradictory. When increasing the number of transported roll cages, regardless of the number of round trips performed, a decreasing trend can be seen in Figure 90, while an increasing trend is noticeable in Figure 91. This is explained a follows. When calculating the NPV, the operational costs of a lorry (reference case) and a tram, combined with road pre- and post-haulage, are used. The operational cost of a lorry consists of time and distance costs, which are assumed here to be independent from the utilisation rate of the lorry. It can be argued that in fact, the utilisation rate of the lorry affects the fuel consumption. This effect is not taken into consideration in this research. Hence, transporting four or eighteen roll cages leads to the same operational cost of the road legs. The same reasoning is followed for the transport by tram and the road pre- and post-haulage legs. On the contrary, when calculating the costs in euro per parcel, the operational costs are divided by the number of parcels carried. It is logical that the net private and social benefit in euro per parcel increases when more roll cages are transported.

Figure 91 – Net private and social benefit for a dedicated freight tram





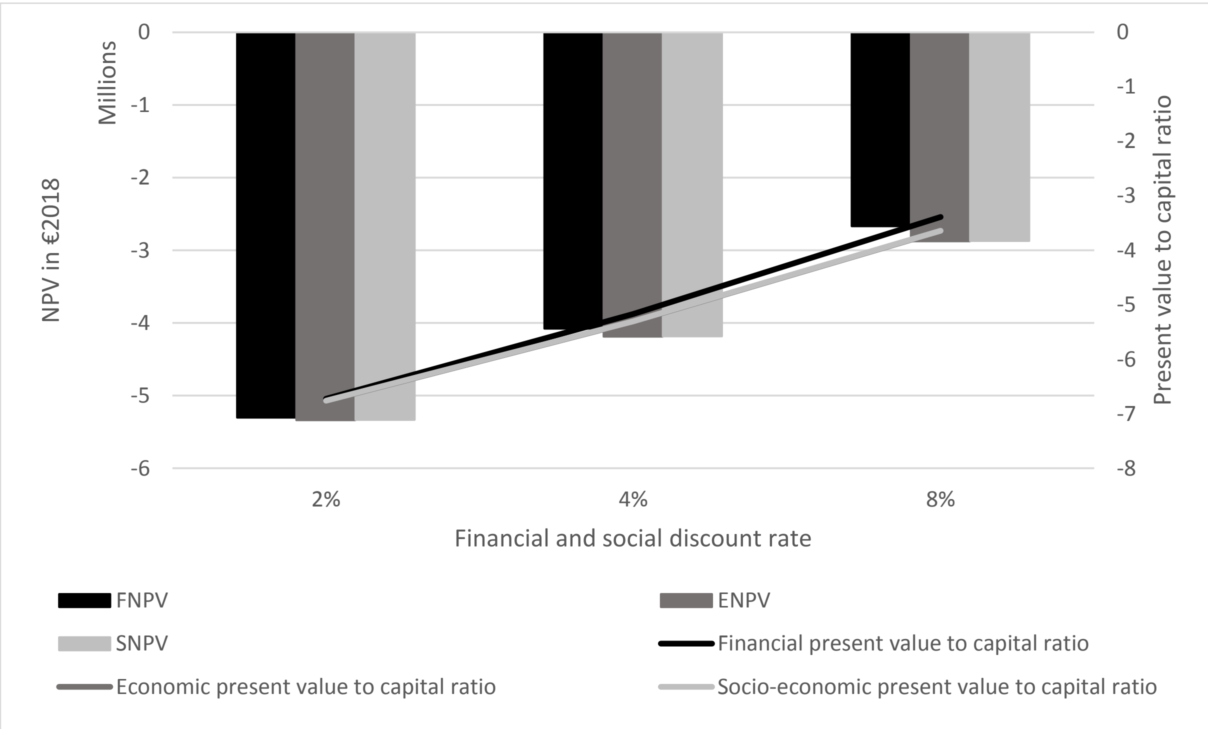
Source: Own creation

This insight in the difference between the net present value over a time horizon of 30 years and the net private and social cost per parcel is important with respect to the viewpoint of the analysis. **The project leader, investing in the rail-based project case, is interested in knowing the net present value of its investment. On the other hand, the project user is more interested in the net private benefits, and potentially also in the net social benefits, expressed in euro per parcel**. The more parcels transported in a lorry, the more parcels the project user can sell to its customers. Regardless of the increasing trend in the net private and social benefit in euro per parcel, transporting eighteen roll cages in three round trips still provides negative benefits. The effect of adding another round trip when transporting eighteen roll cages is negligible, as can be seen in Figure 91. Adding more round trips will not make the tram-based project viable, given all other project case characteristics. Therefore, other project characteristics have to be changed in order to go on with the project.

The net present value shown in Figure 90 is the highest when transporting four roll cages per lorry. However, this figure does not provide information on the NPV if less than four roll cages are transported. It is assumed that when only three roll cages are transported to the three customers, the lorry of the reference case is no longer used. A van with a gross weight of 3.5 tonnes, which can carry up to three roll cages, is used instead. This type of reference case is investigated in the scenario analyses in Section 6.3.1.

Next to changing the amount of goods transported, the effect of a change of the financial and social discount rate is examined. This is done for the project case in which one daily round trip is carried out, transporting eight roll cages to three customers in the urban area. The effect on the NPV and the present value to capital ratio of halving and doubling the financial and social discount rate is displayed in Figure 92. It is clear that by increasing the discount rate, the NPV and present value to capital ratio increase. However, even with a discount rate of 8%, the project is not viable. The underlying data for Figure 92 are displayed in Appendix 16.

Figure 92 – Effect of the discount rate on the outcome of the project case for a dedicated freight tram



Source: Own creation

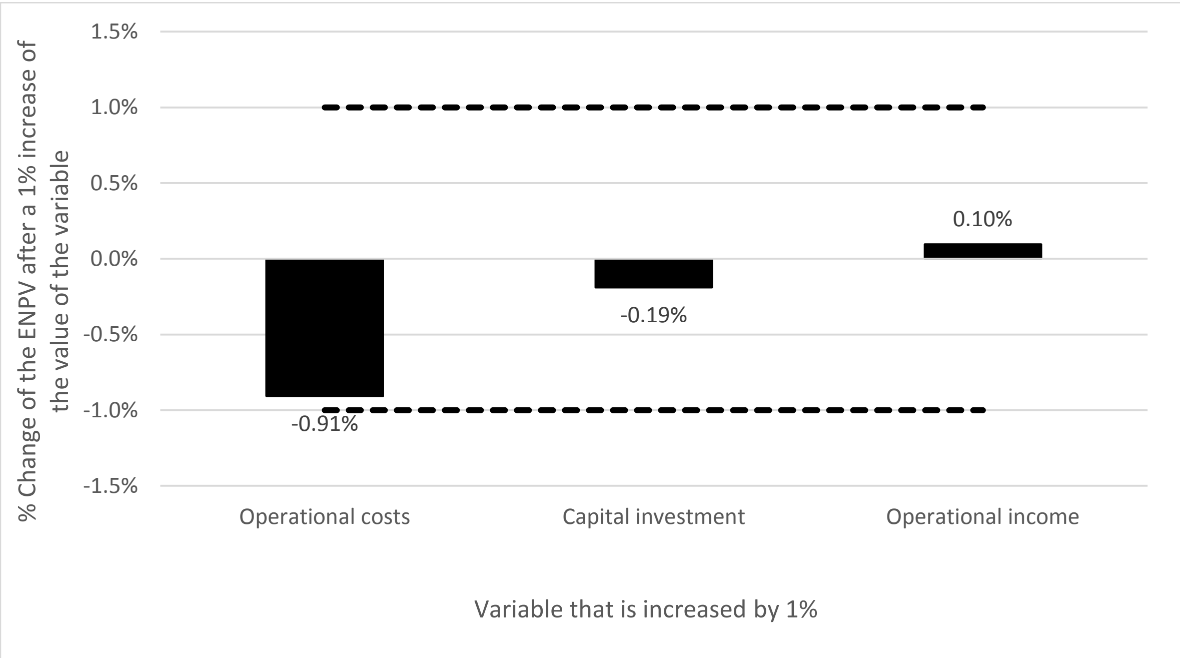
It is clear from the above analysis on the amount of transported goods and on the discount rate that the project is not viable under the current project characteristics. **Hence, more sensitivity analyses have to be carried out to know which project features have to change in order to turn the project viable.** Based on the results of these sensitivity analyses, scenarios are developed in Section 6.3 and then, the effect of the amount of goods is investigated again.

6.2.1.1 Financial and economic analysis

With respect to the financial and economic analysis, the variables that are investigated are the following: line infrastructure, nodal infrastructure, rolling stock, labour cost, time needed and road pricing. Before examining the effect of a change of these variables, the effect of a change of the capital investment, operations and operational income in total is analysed. If the effect of the latter is not critical, the effect of one part of these cost and benefit categories will also not be critical.

Following Boardman et al. (2018), firstly a partial sensitivity analysis is performed, in which one variable is altered and the others are kept constant. Secondly, a worst- or best-case analysis is done in Section 6.3 in order to know if any combination of changes of the project characteristics can reverse the sign of the project outcome. Concerning the partial sensitivity analysis, the capital investment, operational costs and operational income are increased by 1% and the resulting change of the ENPV is displayed in Figure 93.

Figure 93 – Change of the ENPV when a variable is increased by 1% for a dedicated freight tram

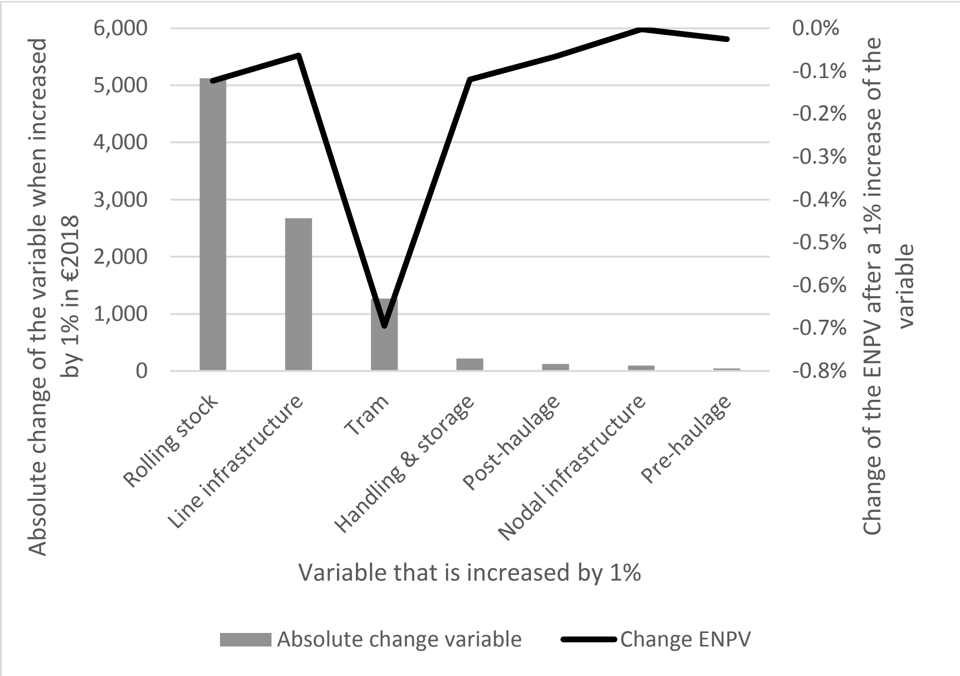


Source: Own creation

The variables in Figure 93 are ranked according to an increasing ENPV. The horizontal dotted lines show the -1% and 1% boundary respectively, which is considered the tipping point at which variables are called 'critical' for the viability of the project. Following Figure 93, none of the variables are critical for the outcome of the project.

It is decided here not to limit the analysis to variables that are critical according to the 1% boundary. Instead, it is chosen to conduct sensitivity analyses for all variables defined in Section 6.1. Figure 94 displays the results of the sensitivity analysis in which the main elements of the investments and operational costs are increased by 1%. The related change of the variable in absolute value, as well as the resulting change of the ENPV in % are shown. The variables are ranked according to a decreasing change of their absolute value when increased by 1%. With respect to the initial investment, the rolling stock shows the highest absolute change when increased by 1%, followed by the line infrastructure. The nodal infrastructure increases the least in absolute terms. Concerning the operations, the tram operational costs experience the largest absolute increase, followed by the operational cost of the handling and storage, post-haulage and pre-haulage. When analysing the change of the ENPV, the tram operational cost has the highest effect on the project outcome, followed by handling and storage, the rolling stock and the line infrastructure. Combining these insights, **the tram operational cost is the most important variable in the project under consideration**. Thus, this variable is further analysed for the different scenarios developed in Section 6.3. The underlying data used for Figure 94 are added in Appendix 16.

Figure 94 – Sensitivity analysis on the reference case for a dedicated freight tram



Source: Own creation

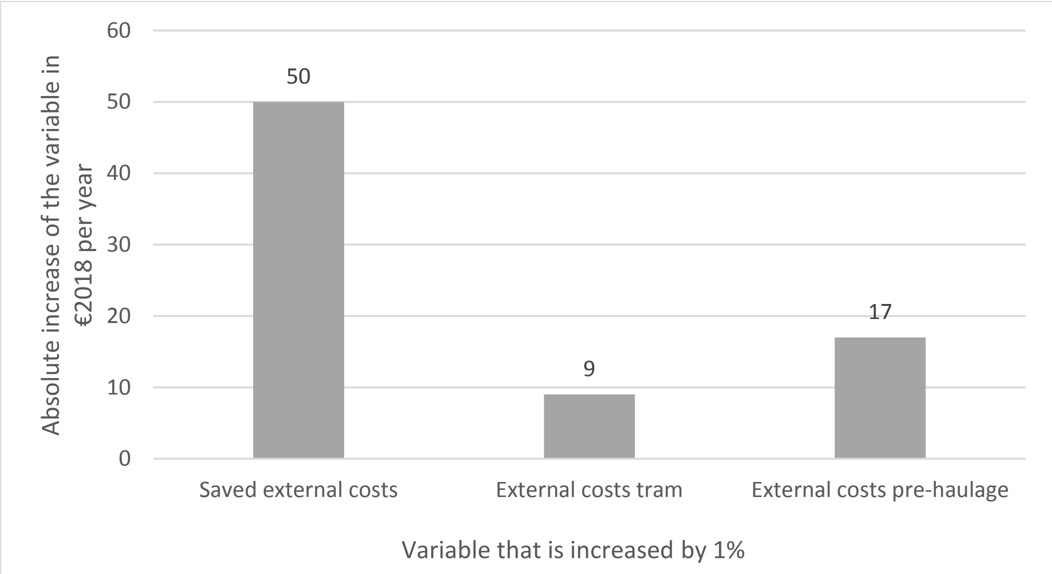
Next to the variables displayed in Figure 94, three other variables are increased by 1% in order to examine their effect on the ENPV: road pricing, the labour cost and the time needed for a round trip in the reference case. These variables are not displayed in Figure 94, because comparing their changes in absolute value is not that meaningful. When increasing the time needed in the reference case by 1%, the ENPV increases by 0.07%, concerning road pricing, the ENPV increases by 0.004% and with respect to the labour cost, the ENPV decreases by 0.05%.

Besides the effect on the financial and economic analysis, the effect of the project characteristics on the socio-economic outcome has to be examined. This is the subject of the following section.

6.2.1.2 Socio-economic analysis

In the socio-economic analysis, the effect of the consumer surplus change and external cost savings on the project outcome is evaluated. With respect to the consumer surplus, the commodities value and the value of time are highlighted in Section 6.1 as variables that have to be checked in sensitivity analyses. In this research, the value of time and the commodities value are reflected in the holding cost of the goods (see Section 5.1.2). When increasing the holding cost by 1%, the SNPV over a time horizon of 30 years changes by €2. Hence, this variable can be neglected in the scenario analysis. Concerning the external cost savings, Figure 95 displays the effect of the increase of the saved external costs, the external costs of the tram leg and the external costs of the pre-haulage leg. The effect is shown as the absolute value change of the variable. Given the conditions under which the reference project takes place, the external cost savings are low compared to the yearly operational costs. Hence, their effect on the SNPV is only limited. As a result, the increase of the external costs of one leg by 1% has almost no effect on the SNPV. If the conditions of the project case change and reduce the operational costs drastically, the SNPV becomes smaller in absolute value (if still negative) and the external costs can play a pivotal role in making the project viable. Therefore, it is most interesting to investigate which external costs play the largest role.

Figure 95 – Absolute increase of external costs for a dedicated freight tram



Source: Own creation

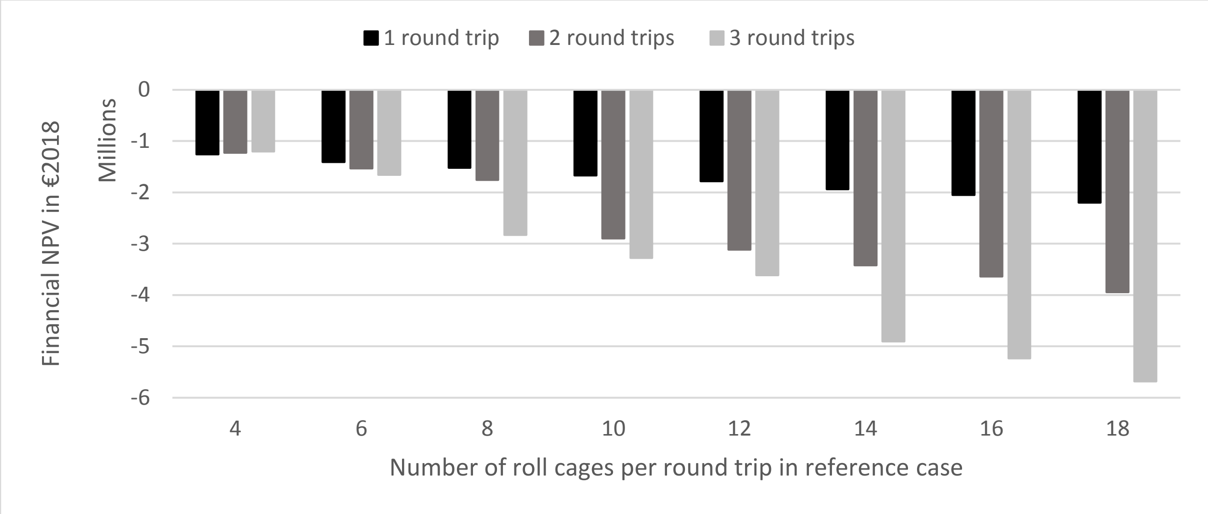
The saved external costs and the external costs of the pre-haulage leg comprise externalities related to road transport. These costs depend on the distance covered, and on the unit cost of the externalities. Either by changing the distance covered, or by altering the unit cost, other external cost values are obtained for the reference and project case. This is further investigated in the scenario analysis in Section 6.3.

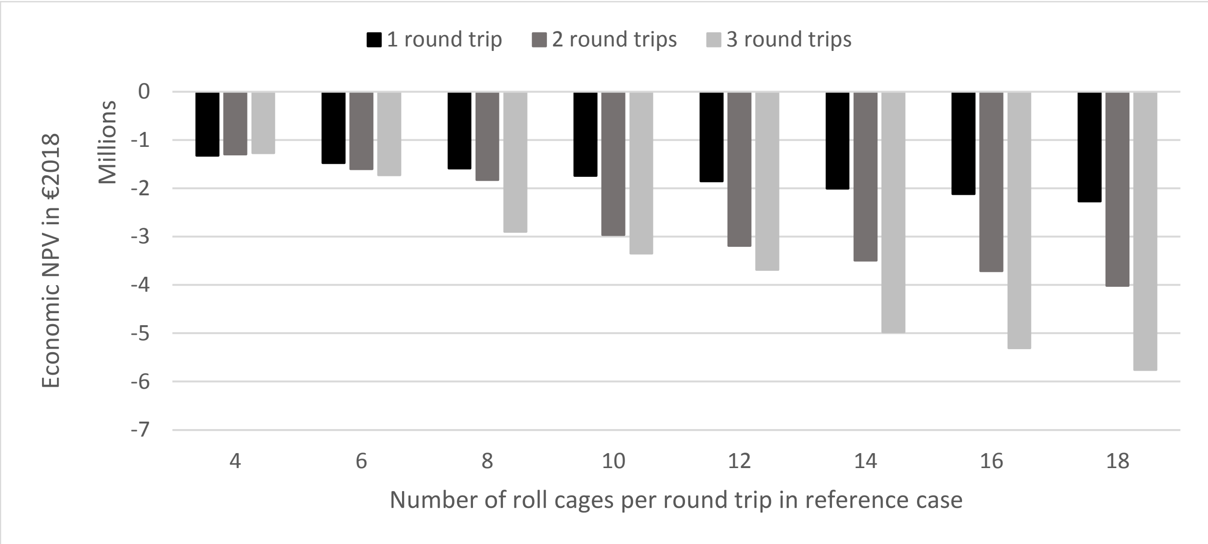
6.2.2 Freight wagon attached to a passenger tram

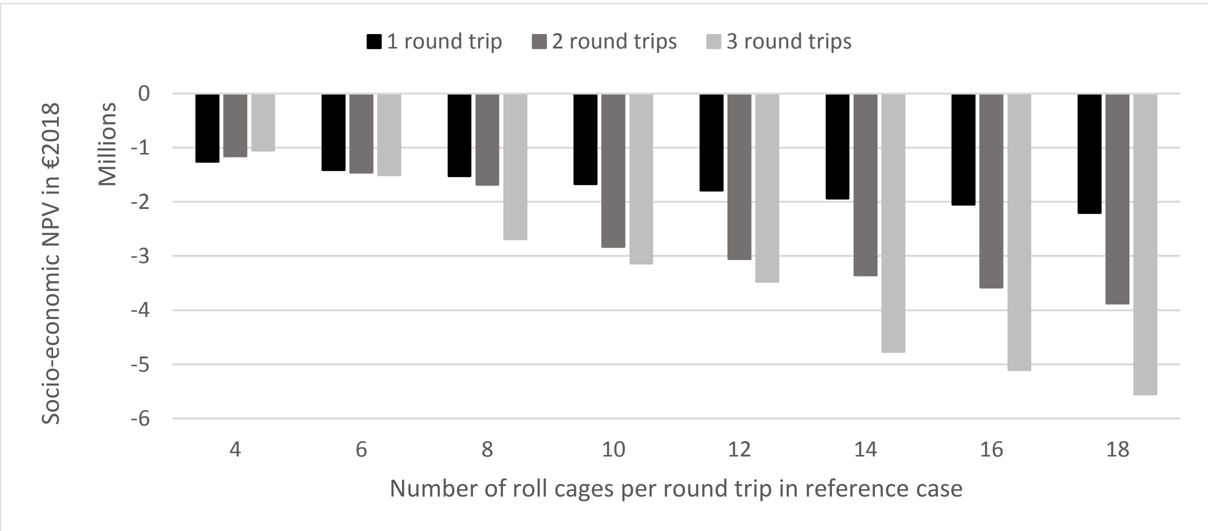
The second type of tram transport investigated in this research is the use of a freight wagon attached to a passenger tram. The effect of the project characteristics on the outcome of this type of rail transport is examined now. This section follows the same structure as Section 6.2.1.

Firstly, the amount of goods to be transported is altered. As for a dedicated freight tram, this is done by changing the utilisation rate of the lorry, and the number of round trips performed in the reference case. The resulting NPVs are shown in Figure 96. It is clear that for this type of tram transport too, the NPV is negative for all combinations of number of roll cages and number of round trips, and for the three analyses. Given the current project characteristics, adding more round trips or more roll cages only worsens the tram-based project. The only exception to this is when only four roll cages are transported in the lorry. When this is the case, adding another round trip, increases the FNPV, ENPV and SNPV. As soon as six roll cages are carried in the lorry, adding another round trip reduces the NPVs. In general, the conclusions for the project case in which a dedicated freight tram is used are also valid here. The main difference is that the NPVs when using a freight wagon attached to a passenger tram are not as low as for a dedicated freight tram. Hence, the project characteristics of a freight wagon are more in favour of the tram-based solution than the ones of the dedicated freight tram.

Figure 96 – NPVs per number of round trips and per number of roll cages for a freight wagon





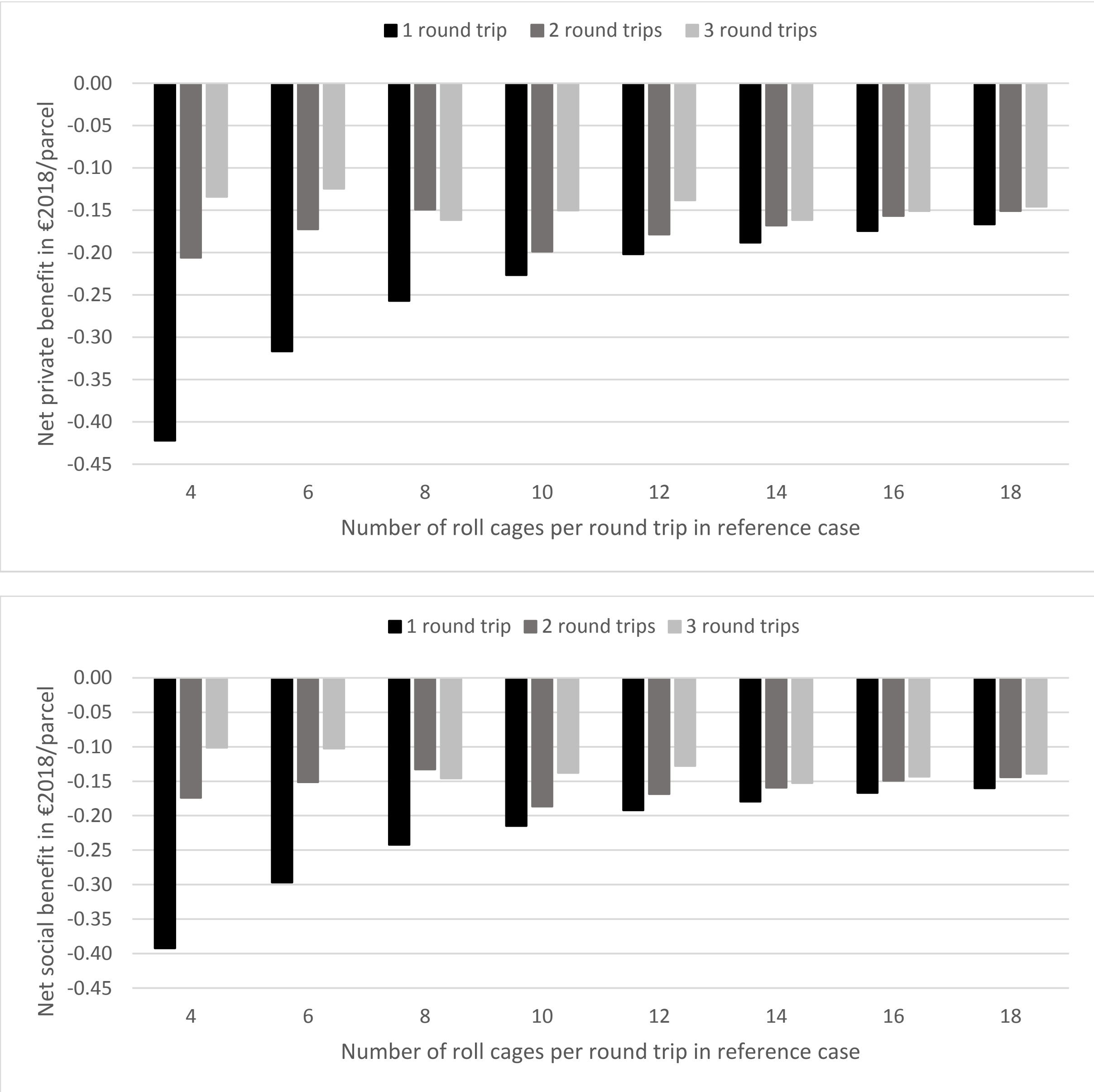


Source: Own creation

Next to the net present value, the present value to capital ratio and the internal rate of return are analysed for this project case as well. The internal rate of return cannot be calculated, since all cash flows over 30 years are negative. The present value to capital ratio shows a similar pattern to the one of the NPV and is added in Appendix 17.

Secondly, the net private and social benefits are calculated in euro per parcel, since this is what the project user is interested in. Figure 97 shows the resulting net benefits for a different number of roll cages and one to three round trips. When adding another round trip, the benefits become less negative. When conducting two round trips and moving from eight to ten roll cages per lorry, a second tram trip needs to be carried out. When doing three round trips and shifting from six to eight roll cages, a second tram trip is needed, and when going from 12 to 14 roll cages, a third one is necessary to transport all the goods to the three customers. The underlying data are added in Appendix 17.

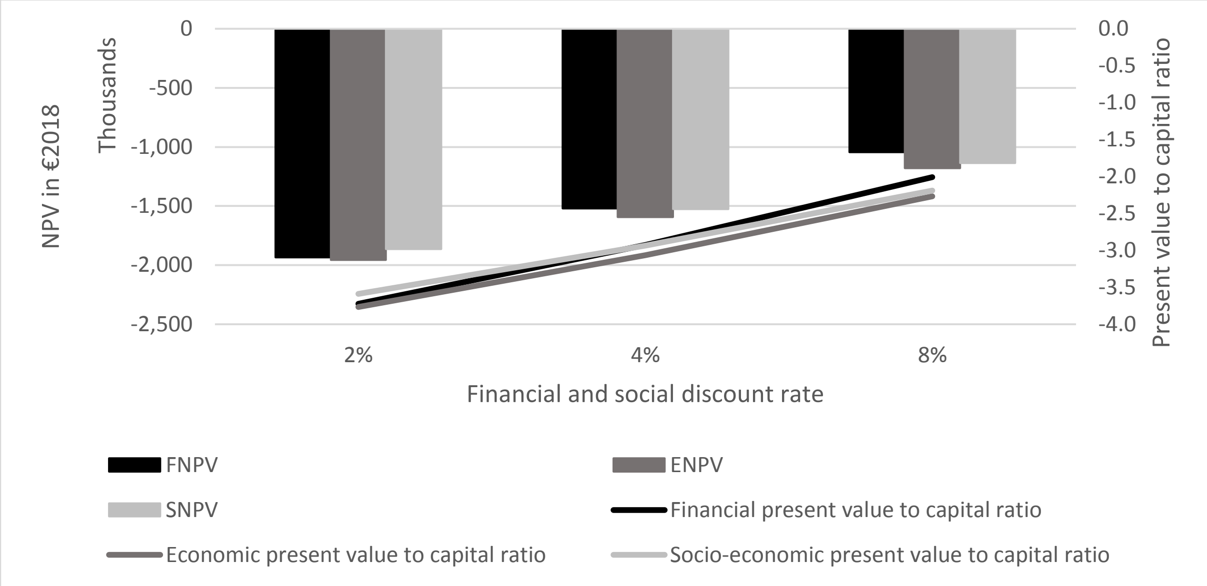
Figure 97 – Net private and social benefit, freight wagon



Source: Own creation

Thirdly, the effect of the discount rate on the project outcome is measured. Figure 98 displays the resulting NPV and present value to capital ratio when the financial and social discount rate equal respectively 2%, 4% and 8%. It is clear from Figure 98 that in all cases and for all three analyses, the NPV remains negative, as well as the present value to capital ratio. Hence, the project is not viable.

Figure 98 – Effect of the discount rate on the outcome of the project case, freight wagon



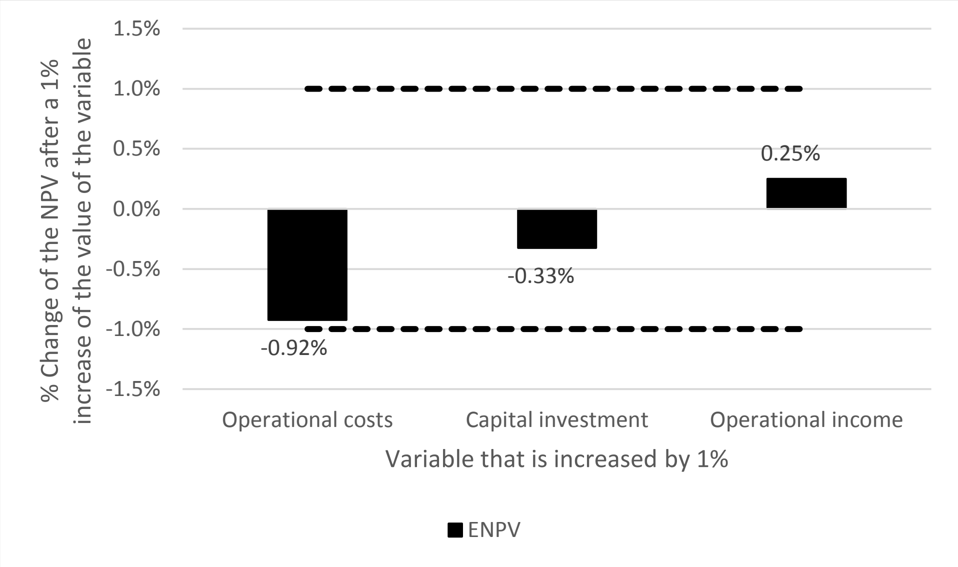
Source: Own creation

Based on the sensitivity analyses related to the number of round trips and number of roll cages, and the financial and social discount rate, **transporting goods in a freight wagon attached to a passenger tram is not viable given all project case characteristics**. However, some future innovations may lead to lower costs, making the project viable. In the following sections, other project characteristics are now altered in sensitivity analyses. Firstly, the financial and economic analysis is examined (Section 6.2.2.1). Secondly, the socio-economic analysis is investigated (Section 6.2.2.2).

6.2.2.1 Financial and economic analysis

As for a dedicated freight tram, the effect of the capital investment, operational costs and operational income is tested firstly. Figure 99 displays the relative change of the ENPV when these three variables are increased by 1%. The -1% and +1% tipping point when a variable can be considered to be critical is added as well. The operational cost is the variable with the highest effect on the project outcome in this case, although given all project characteristics, none of the three variables is critical according to the definition of Sartori et al. (2015).

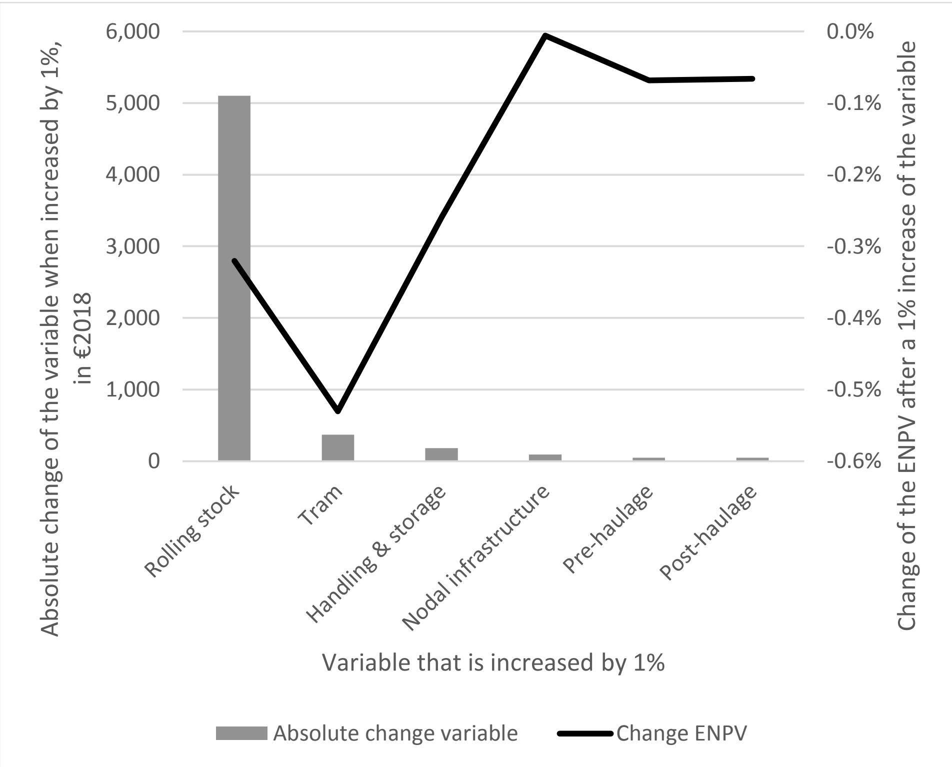
Figure 99 – Change of the ENPV when a variable is increased by 1%, freight wagon



Source: Own creation

In order to better understand the effect of the different elements leading to the operational costs and the capital investment, Figure 100 displays the absolute and relative change of the main operational cost and capital investment elements when the value of these elements is increased by 1%. In absolute terms, the rolling stock changes the most, but in terms of change of the ENPV, it is the tram operational cost that has the most effect. Therefore, the focus of the scenario analyses in Section 6.3 is on the tram operational costs.

Figure 100 – Sensitivity analysis on the reference case, freight wagon



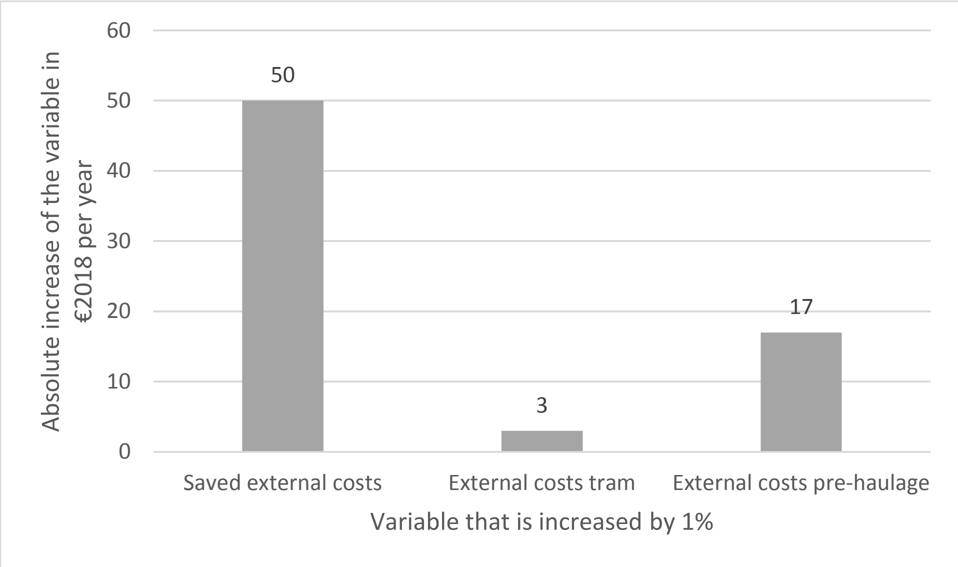
Source: Own creation

Besides the financial and economic analysis, the effect of changes of variables needs to be investigated in the socio-economic analysis was well. This is the subject of the following section.

6.2.2.2 Socio-economic analysis

Given the small change of the consumer surplus of -4.5 €/year, the socio-economic benefits are mainly determined by the external cost savings when shifting from road to rail. Figure 101 shows the absolute increase of the saved external costs, the external costs of the tram leg and the external costs of the pre-haulage leg when these three variables are increased by 1%. From this figure, it can be derived that mainly the value of the external costs due to road transport play an important role. When analysing the effect of a 1% increase of these three variables on the SNPV, none of the variables seems to be critical. Again, this can be explained here due to the very high ENPV in absolute terms.

Figure 101 – Absolute increase of external costs for a freight wagon



Source: Own creation

Although the variables shown in Figure 101 appear not to be critical given the current project conditions, the insights provided in this figure are still valuable as input for the scenario analysis. When the project conditions change, it is still very interesting to see what happens to the SNPV if the external costs increase or decrease slightly. This is examined in Section 6.3.

6.2.3 Freight alongside passengers

The third type of tram-based transport examined in this research is the transport of parcels alongside passengers. For this tram type, it is assumed that vans are used in the reference case instead of lorries. Since no investment is needed, the viability of this type of tram transport is evaluated based on the net private and social benefit expressed in euro per parcel.

Firstly, the effect of the amount of parcels transported on the net private and social benefits of the project case is tested. As for a dedicated freight tram and a freight wagon attached to a passenger tram, parcels have to be divided over the different customers. Table 83 shows how this is done in this research. It is assumed that at least three parcels are delivered per round trip. If less than three parcels are delivered, at least one of the three customers does not receive goods. This would alter other project characteristics, i.a. the post-haulage leg, which would influence the interpretation of the results. Therefore, it is assumed that the courier carries between three and eight parcels.

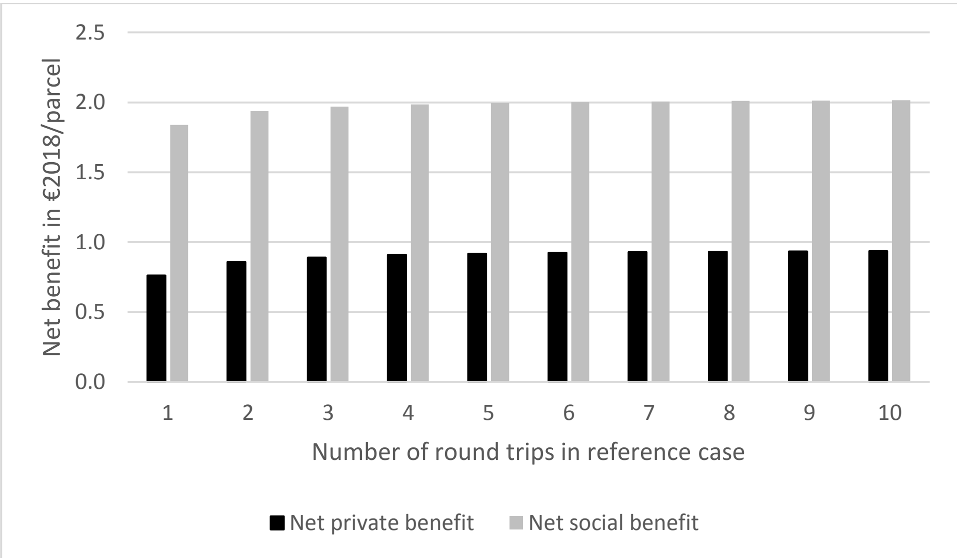
Table 83 – Division of number of parcels per customer

Number of parcels per round trip	Shop Meir	Shop Groenplaats	Shop Wijnegem Shopping Centre
8	4	2	2
7	3	2	2
6	4	1	1
5	3	1	1
4	2	1	1
3	1	1	1

Source: Own creation

When altering the number of round trips executed in the reference case, Figure 102 displays the net private and social benefit for a different number of round trips, ranging from one to ten. When another round trip is added, both the net private and the net social benefit increases. This increase is very small, and also decreasing when more round trips are added. In general, the net private benefit stagnates around 0.93 €/parcel, whereas the net social benefit converges to 2.01 €/parcel. Appendix 18 provides the underlying data used in Figure 102.

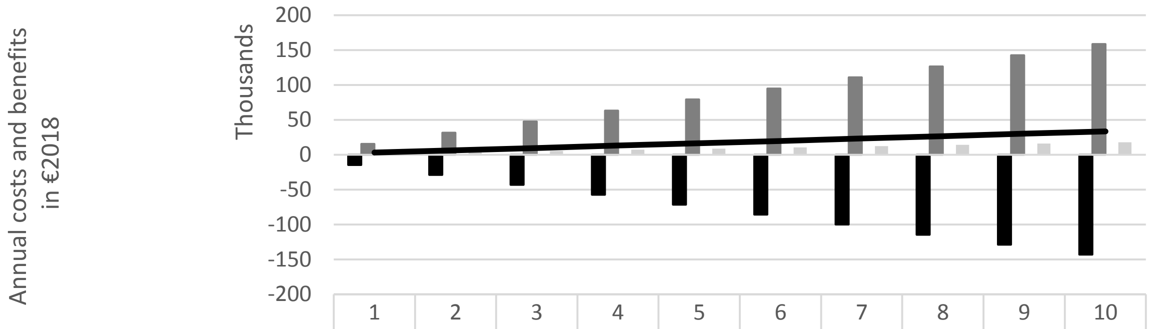
Figure 102 – Net private and social benefit, freight alongside passengers



Source: Own creation

Besides the net private and social benefit in euro per parcel, the yearly costs and benefits are examined for the year 2018. Figure 103 displays these costs and benefits for several number of round trips carried out. On the cost side, the operations are displayed, while on the benefit side, the operational income, consumer surplus and external cost savings emerge. The change of the consumer surplus is negative and hence, becomes a cost as well. The black line through the bars shows the resulting net yearly benefits, which show an increasing trend when more round trips are added. On the cost side, the operations are the most important element. On the benefit side, the operational income is the main element. When the operational costs and the operational income are more or less the same in absolute terms, the presence of external cost savings, and to a lesser extent the change of consumer surplus, plays an important role in turning the project viable.

Figure 103 – Annual costs and benefits for different number of round trips, freight alongside passengers



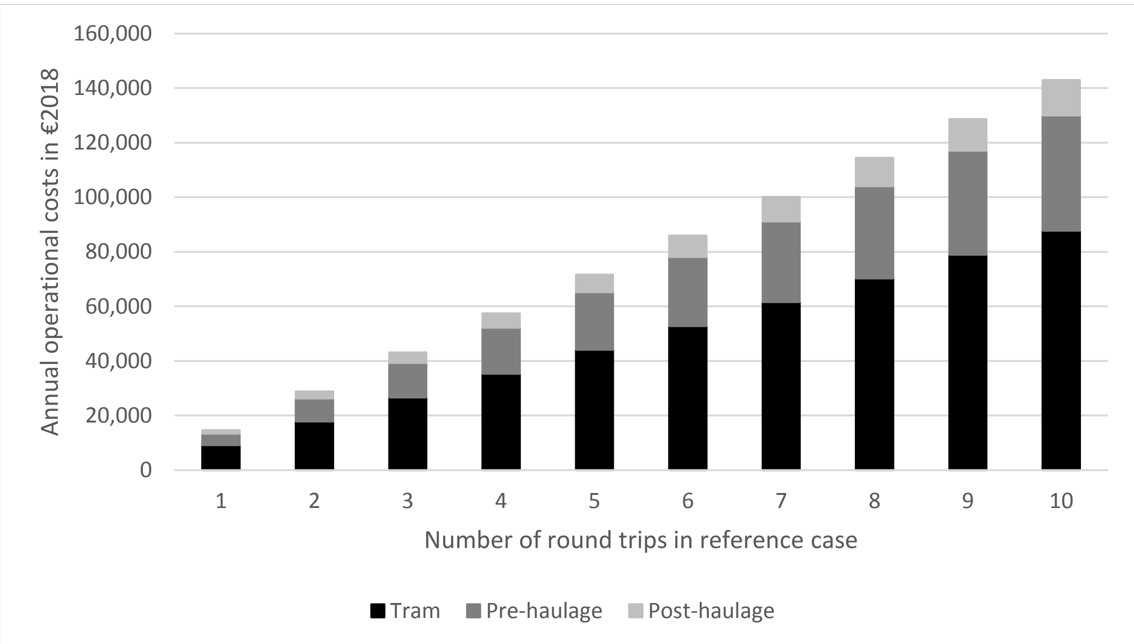
	1	2	3	4	5	6	7	8	9	10
Operations	-14,587	-28,851	-43,114	-57,377	-71,640	-85,904	-100,16	-114,42	-128,69	-142,95
Operational income	15,853	31,706	47,559	63,412	79,265	95,118	110,971	126,824	142,678	158,531
Consumer surplus change	-1.00	-2.00	-3.00	-4.00	-5.00	-6.00	-7.00	-8.00	-9.00	-10.00
External cost savings	1,795	3,591	5,386	7,181	8,977	10,772	12,567	14,363	16,158	17,953
Net benefits per year	3,060	6,444	9,828	13,212	16,597	19,980	23,365	26,750	30,134	33,518

Number of round trips in reference case

Source: Own creation

In order to better understand the absolute value of the operational cost, Figure 104 shows the division of the operational costs for a different number of round trips for each urban rail freight supply chain leg. The operational costs are divided in costs related to the tram, road pre-haulage and road post-haulage leg. The handling and storage costs are not displayed, since they are zero here. It is clear from Figure 104 that the largest part of the operational costs is related to the tram leg. The post-haulage leg only causes a small part of the total operational cost. All three cost elements increase when another round trip is added. Given the high share of the tram operational costs in the total operational costs, this variable is tackled further in the scenario analyses in Section 6.3.

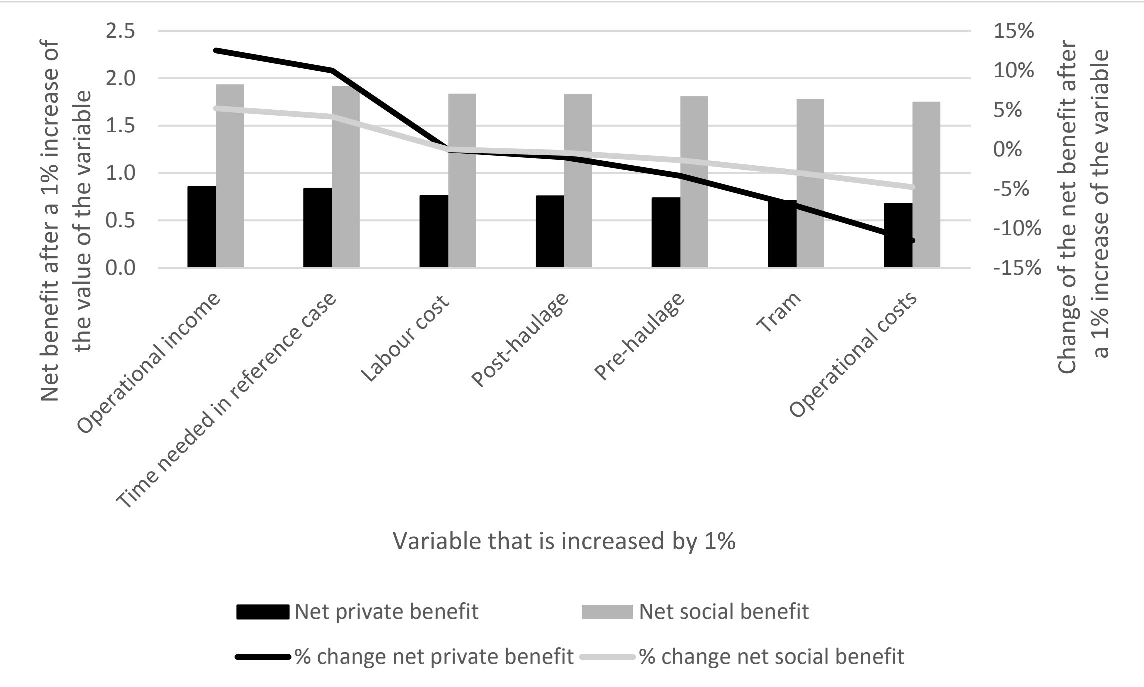
Figure 104 – Annual operational costs, freight alongside passengers



Source: Own creation

Ultimately, some sensitivity analyses are performed regarding the operational income and the operational costs, as well as some specific elements of these two variables. Figure 105 shows the net benefit in euro per parcel if the value of several variables is increased by 1%, as well as the relative change of the net benefit. The variables are ranked according to a decreasing net benefit. At the left and at the right, the two main variables, operational income and operational costs respectively, are shown. When increasing the operational income by 1%, the net private benefit in euro per parcel increases by 12.52%, whereas the net social benefit increases by 5.18%. On the other hand, when increasing the operational costs of the tram-based project by 1%, the net private benefit decreases by 11.52% and the net social benefit by 4.77%. In the middle of Figure 105, specific elements of these two variables, being the time needed in the reference case, the labour cost, post-haulage, pre-haulage and the tram operational cost are displayed. It is clear that except for the labour cost, all variables have an effect on the net benefit of more than 1%, and hence, are critical according to Sartori et al. (2015). Therefore, these variables are examined further in the scenario analyses in Section 6.3.

Figure 105 – Sensitivity analyses on the reference case, freight alongside passengers



Source: Own creation

6.2.4 Intermediate conclusion

Three types of rail-based urban freight projects are assessed on their sensitivity to several input values. The amount of goods to be transported is evaluated, as well as the financial and social discount rate. Moreover, the effect of multiple variables on the financial and economic analysis and on the socio-economic analysis is examined.

With respect to the amount of goods transported, the financial, economic and socio-economic NPV decreases both for a dedicated freight tram and for a freight wagon attached to a passenger tram if more round trips are added in the reference case. The only exception is the transport of four roll cages in one round trip when a freight wagon is attached to a passenger tram. When transporting freight alongside passengers, the net private and social benefit in euro per parcel increases very slightly if another round trip is added. Concerning the financial and social discount rate, it is noticed that for a dedicated freight tram and for a freight wagon attached to a passenger tram, the NPV increases if the discount rate is doubled. However, in both cases, the NPVs remain negative and hence, the project remains unviable. Regarding the capital investment and operational costs, the NPV decreases for a dedicated freight tram and a freight wagon attached to a passenger tram if these variables are increased by 1%. However, the increase is for both lower than 1%. When the operational income is increased by 1%, the NPV of the tram-based projects also increases, but again by less than 1%.

In general, it is observed that the yearly operational costs are very high for the use of a dedicated freight tram and a freight wagon attached to a passenger tram. **Especially the tram leg is under the current project conditions very expensive**. When making use of a freight wagon, the tram operational costs are much lower than for a dedicated freight tram, increasing the NPV already a lot. The external cost savings appear to have an effect on the project outcome, although this is not critical in the observed project cases.

In sum, the focus of the scenario analyses is on the operational income and the operational costs. When these are altered such that the ENPV is increased, **the external cost savings can start to play an important role**. This effect is further investigated in the next section.

6.3 Scenario analyses

In this section, scenario analyses are performed. Vadali et al. (2017) suggest to develop between four and fifteen scenarios. Based on the sensitivity analyses performed in Section 6.2, ten scenarios are developed here. Table 84 provides an overview of the scenarios and their explanation. The last column shows which variables are altered in the following sections. The scenarios are ranked according to whether they change something to the reference case (scenario 1-2), the tram leg (scenario 3-6), the pre- and post-haulage leg (scenario 7), and to the reference and project case (scenario 8-10). Handling and storage activities are related to the need for pre- and post-haulage, and are not discussed separately.

Table 84 – Scenarios

Change to	Scenario		Explanation	Variable that is altered
Reference case	1	Reference case by vans	The reference case is executed by vans that can carry three roll cages	Amount of goods, road pricing, number of vehicles, loading capacity
	2	Congestion on the roads	Roads are congested, extending the time needed to cover the road legs	Time needed
Tram	3	Unaccompanied tram leg	No courier needs to accompany the goods during the tram leg	Labour cost
	4	Shortest tram path without restrictions	Goods can be unloaded in the underground and hence, the tram path becomes shorter	Distance (routing)
	5	Free access to tram network	No track access charges have to be paid by the operator	Tram access charges
	6	Ancillary revenue	Ancillary revenue is earned by selling advertisement space on the tram	Ancillary revenue
Pre- and post-haulage	7	No pre- and/or post-haulage	No pre-haulage and/or post-haulage is needed in the project case	Pre- and post-haulage
Reference & project case	8	Changing external costs	External costs are halved and doubled	External cost
	9	Transport during peak hours or during the night	The timing of the transport is changed from mainly off-peak-hours to peak hours and the night	Timing transport
	10	Best-case scenario	All conditions from scenarios 1-9 leading to a more viable tram project are combined	All before mentioned

Source: Own creation

The ten scenarios described in Table 84 are now executed for the use of a dedicated freight tram, a freight wagon attached to a passenger tram and the transport of goods alongside passengers.

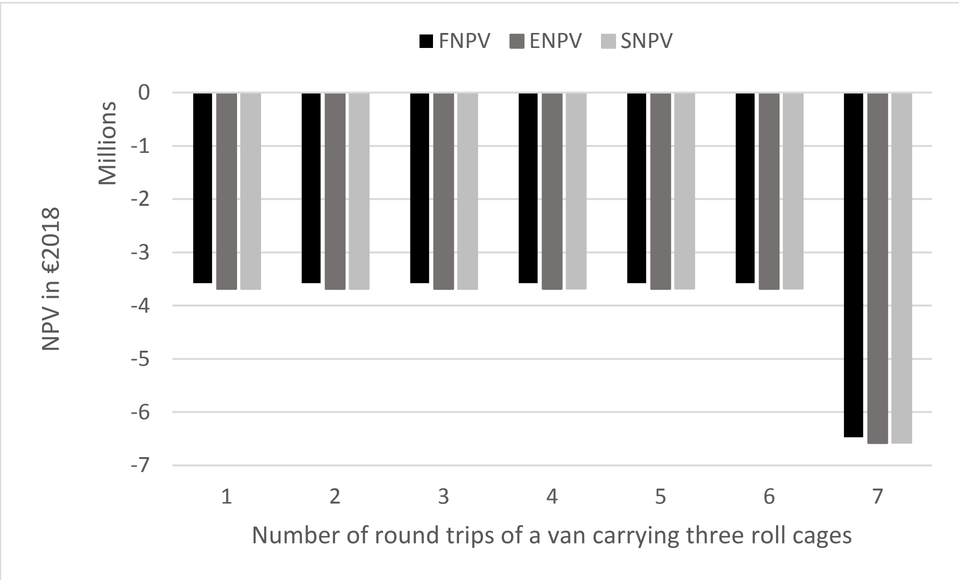
6.3.1 Scenario 1 : Reference case: transport by vans

In the first scenario, it is investigated how the project outcome changes if the transport in the reference case is executed by vans instead of lorries. In order to deliver more or less the same amount of goods at the customers as is done by the lorry, the vans need to execute three daily round trips in which one roll cage is delivered per round trip at each customer. The maximum gross weight of the vans is 3.5 tonnes and the maximum loading capacity is three roll cages. This analysis is firstly done for the use of a dedicated freight tram, and secondly for the use of a freight wagon attached to a passenger tram. For transporting parcels alongside passengers, this analysis is not performed, since vans are already used in the project case.

6.3.1.1 Dedicated freight tram

Figure 106 displays the resulting financial, economic and socio-economic NPV over a time horizon of 30 years. It is clear that the NPV is negative for the three analyses and for all number of round trips. From the seventh round trip, a second tram trip needs to be executed due to tram capacity limitations, which is reflected in Figure 106 by the NPV which is much more negative than for one to six round trips. The internal rate of return cannot be calculated for all number of round trips, since all cash flows are negative. The present value to capital ratio is also negative for the three analyses and all number of round trips. The details with respect to this ratio are added in Appendix 16.

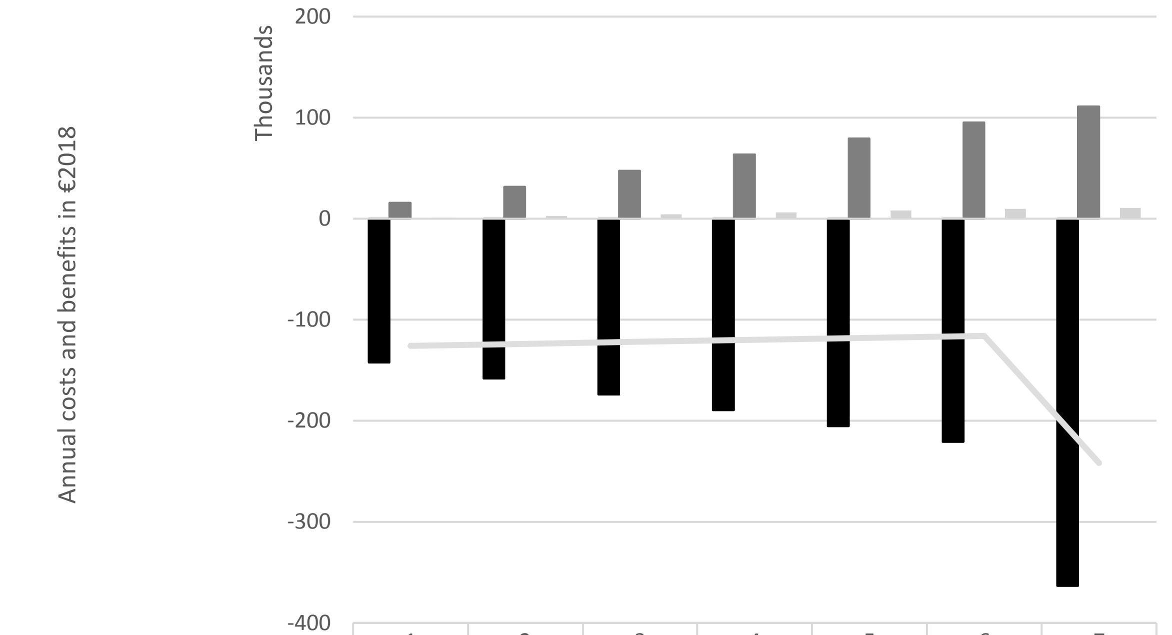
Figure 106 – NPV for a van carrying three roll cages, dedicated freight tram



Source: Own creation

When adding another round trip, the NPV in Figure 106 increases slightly for all three analyses. Hence, this makes the tram-based project less unviable. Figure 107 shows the difference in yearly costs and benefits between different numbers of round trips when abstracting the investment in line and nodal infrastructure and rolling stock. When more round trips are added in Figure 107, the net yearly benefits increase slightly until the seventh round trip is added. The decrease of the net benefit here is related to the need for a second tram trip.

Figure 107 – Annual costs and benefits when a van is used in the reference case, dedicated freight tram



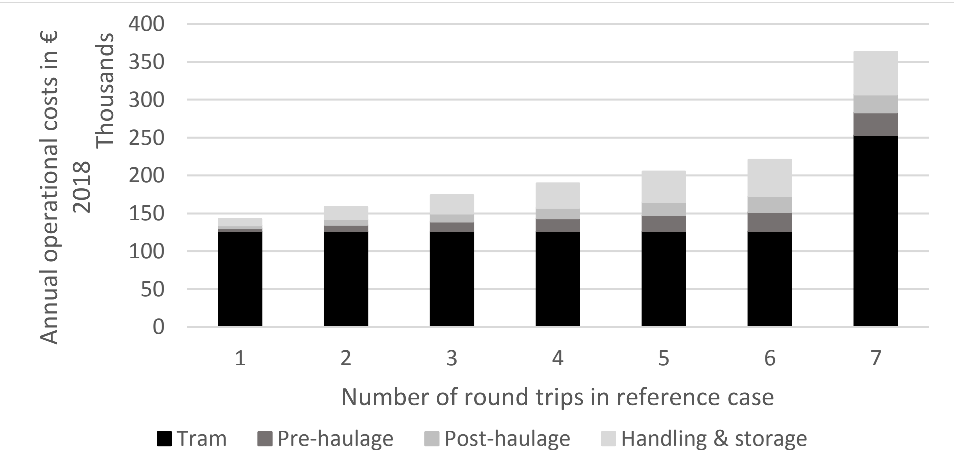
	1	2	3	4	5	6	7
Operations	-142,444	-158,139	-173,834	-189,529	-205,224	-220,919	-363,363
Operational income	15,853	31,706	47,559	63,412	79,265	95,118	110,971
Consumer surplus change	-3.00	-5.00	-8.00	-11.00	-13.00	-16.00	-19.00
External cost savings	848	2,643	4,438	6,233	8,029	9,824	10,672
Net benefits per year	-125,746	-123,795	-121,845	-119,895	-117,943	-115,993	-241,739

Number of round trips in reference case

Source: Own creation

The costs of the operations are shown more in detail in Figure 108. It is clear that the total yearly operational costs increase when more round trips are added. For one to six round trips, no increase of the tram operational cost exists, since one tram trip is sufficient to deliver all goods at the customers. When a seventh round trip is added, two tram trips are needed, because the maximum loading capacity of the tram is exceeded. The pre-haulage costs increase gradually, per round trip added. The same is true for the post-haulage and handling and storage costs. The underlying data for Figure 108 are available in Appendix 16.

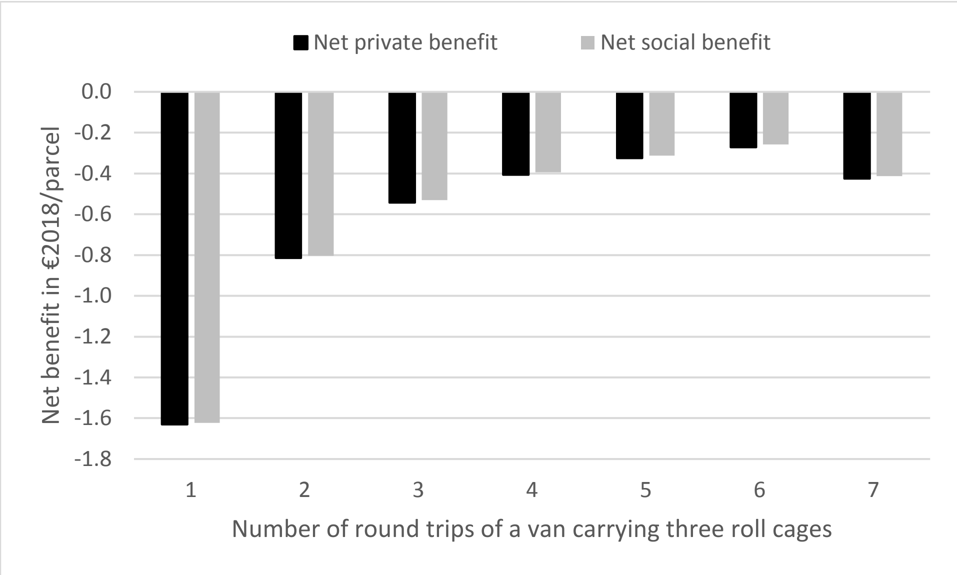
Figure 108 – Annual operational costs when a van is used in the reference case, dedicated freight tram



Source: Own creation

For a van carrying three roll cages, the net private and social benefit is calculated in euro per parcel in Figure 109. The same increasing trend as for a lorry can be identified. The lower net private and social benefit for seven round trips is explained by the need for a second tram trip. When six round trips are carried out, a net private benefit of -€0.27 per parcel is present, and a net social benefit of -€0.26.

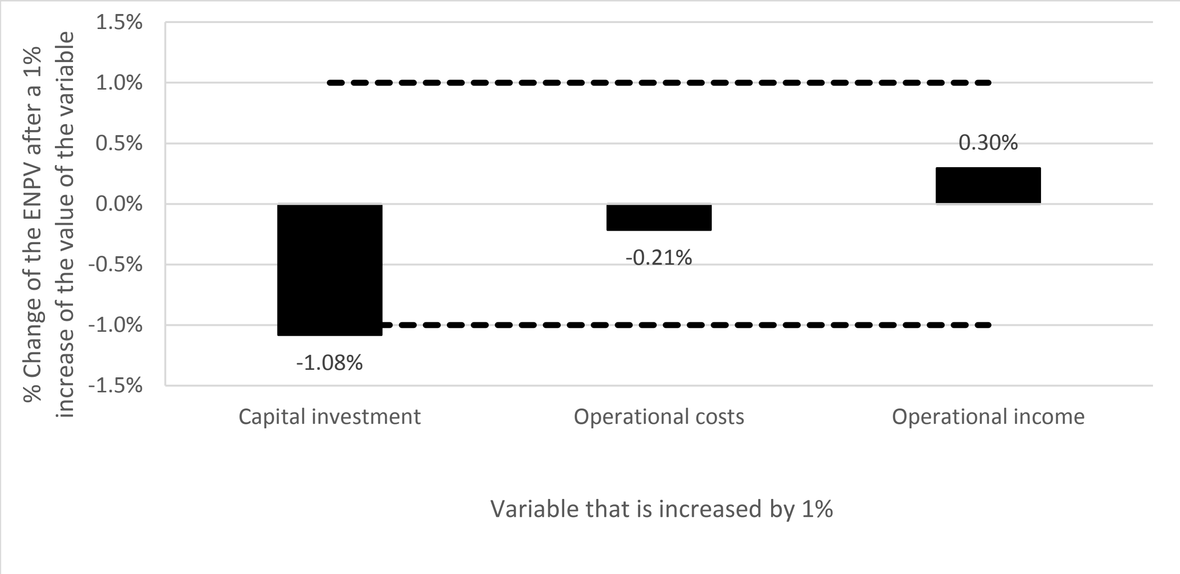
Figure 109 – Net private and social benefit for a van, dedicated freight tram



Source: Own creation

Some sensitivity analyses are now performed for the reference case in which three round trips are made by a van, transporting three roll cages per round trip. Figure 110 shows the results of a 1% increase of the capital investment, operational costs, and operational income. The operational costs exceed the 1% boundary and hence, are considered a critical variable. The reason why the operational costs are critical when a van is used in the reference case and not when a lorry is used, is twofold. Firstly, the ENPV that is used as a reference point, i.e. the ENPV as calculated in Chapter 4, is higher in absolute terms when the lorry is used (ENPV = -€4,187,105) than when the van is used (ENPV = -€3,688,648). Secondly, the operational costs when three round trips are made by a van amount to €173,834 per year, whereas the operational costs when one round trip is made by a lorry equal €165,454 per year. This is only a difference of €8,380 per year, which is very small compared to the difference in ENPV (€498,457). As a result, the relative share of the operational costs in the ENPV is higher for a van than for a lorry. This explains why the operational costs are critical for a van, but not for a lorry, ceteris paribus.

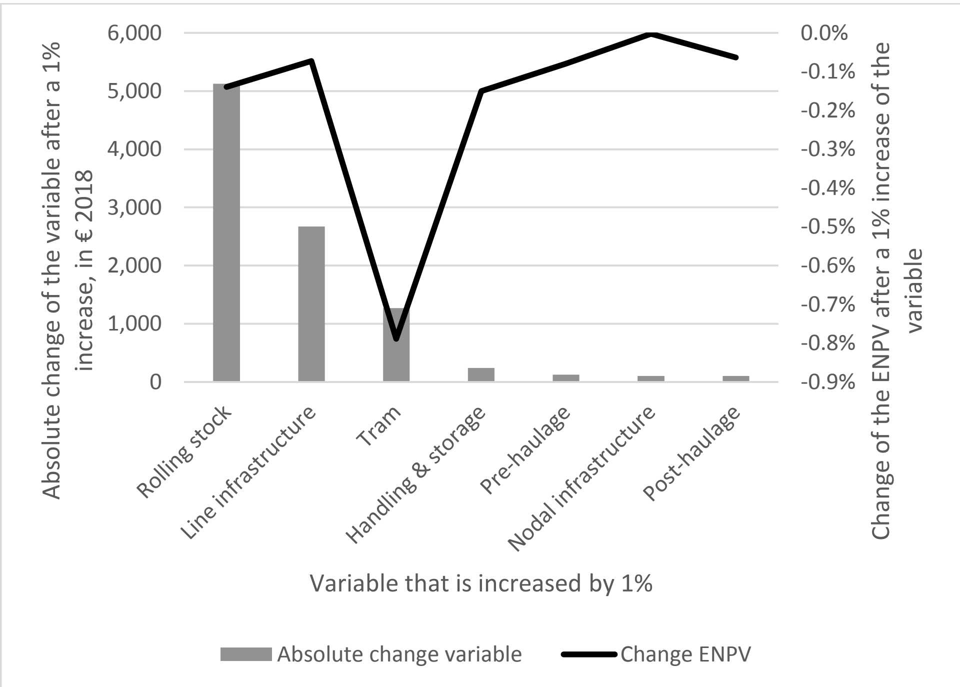
Figure 110 – Change of the ENPV when a variable is increased by 1%, van, dedicated freight tram



Source: Own creation

The effect of all components of the operational costs and investment on the project outcome is now tested separately. The results of the analysis are displayed in Figure 111. The same pattern as in Figure 94 is visible. Hence, the same variables as when a lorry is used appear to have the most effect on the project outcome. The only difference in the ranking of the variables between these two figures is the position of pre- and post-haulage. The underlying data used for Figure 111 are added in Appendix 16.

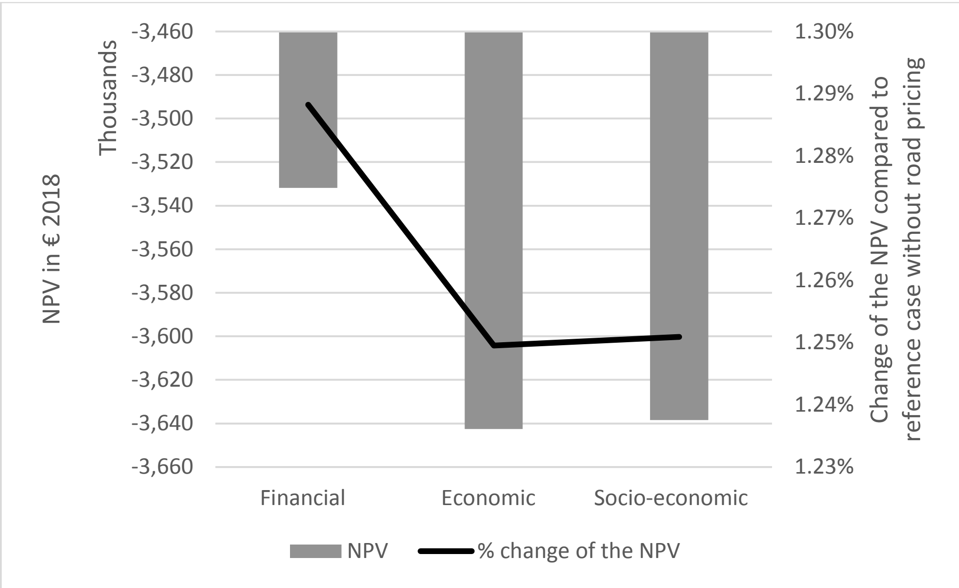
Figure 111 – Sensitivity analysis for the use of a van, dedicated freight tram



Source: Own creation

Subsequently, the effect on the ENPV is measured if road pricing, the labour cost and the time needed to cover a round trip in the reference case are increased by 1%. The ENPV increases by 0.24% if the time needed to cover a round trip is increased by 1% and by 0.07% if the labour cost is 1% higher. Concerning road pricing, there is no effect, since vans of 3.5 tonnes do not pay road pricing in Belgium anno 2019. Therefore, the effect on the project outcome if vans as well would have to pay road pricing is examined separately. Figure 112 displays the resulting NPV, as well as the change of the NPV compared to the case where vans do not pay road pricing. It is clear that adding road pricing has a positive effect on the tram-based project case, since the NPV increases for the financial, economic and socio-economic analysis compared to the reference case in which vans do not pay road pricing.

Figure 112 – NPV and NPV change if vans need to pay road pricing, dedicated freight tram

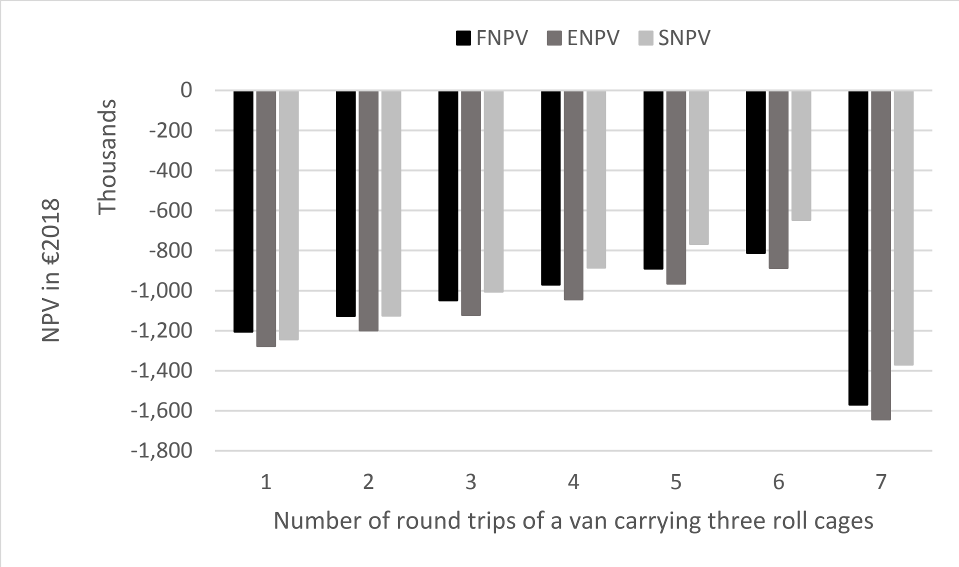


Source: Own creation

6.3.1.2 Freight wagon attached to a passenger tram

The same analysis is now done for the use of a freight wagon attached to a passenger tram. Firstly, the financial, economic and socio-economic NPV is calculated for a different number of round trips. Figure 113 shows the results. The same increasing trend is noticeable as for the use of a dedicated freight tram. The main difference is that the NPVs are more than double as high when a freight wagon is attached to a passenger tram as when a dedicated freight tram is used. Still, all NPVs remain negative, keeping the tram-based project unviable. In appendix 17, the related present value to capital ratio is provided, as well as the underlying data used in Figure 113.

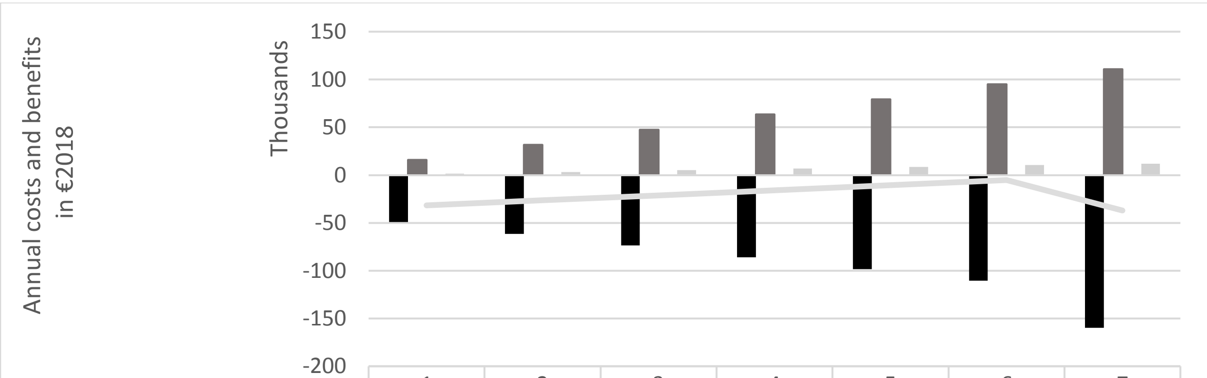
Figure 113 – NPV per number of round trips for a van carrying three roll cages, freight wagon



Source: Own creation

In order to better understand the yearly operational costs and benefits leading to the NPV, Figure 114 displays the operational costs, operational income, change of the consumer surplus and external cost savings leading to the net yearly benefits. When an additional round trip is added, all cost and benefit categories increase. The increase of the operational cost and the operational income is the most striking here. Therefore, the operational cost is examined more in detail in Figure 115.

Figure 114 – Annual costs and benefits when a van is used in the reference case, freight wagon



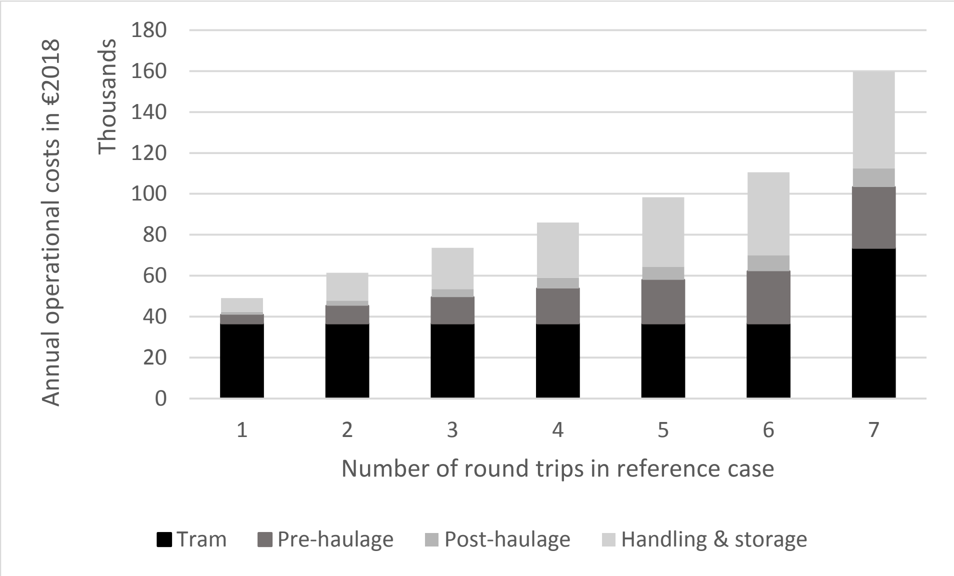
	1	2	3	4	5	6	7
Operations	-49,147	-61,441	-73,734	-86,028	-98,321	-110,615	-159,761
Operational income	15,853	31,706	47,559	63,412	79,265	95,118	110,971
Consumer surplus change	-1.18	-2.37	-3.55	-4.74	-5.92	-7.10	-8.29
External cost savings	1,461	3,256	5,051	6,847	8,642	10,437	11,898
Net benefits per year	-31,834	-26,481	-21,128	-15,774	-10,420	-5,067	-36,900

Number of round trips in reference case

Source: Own creation

When adding an additional round trip, it is clear from Figure 115 that the total operational cost increases. The tram operational costs are equal as long as maximum six round trips by road are executed in the reference case. From the seventh round trip by road, a second tram trip is necessary in order to deliver all goods at the customers in the project case. The pre-haulage costs increase per extra round trip by €4,230, the post-haulage costs by €1,298 and the handling and storage costs by €6,766.

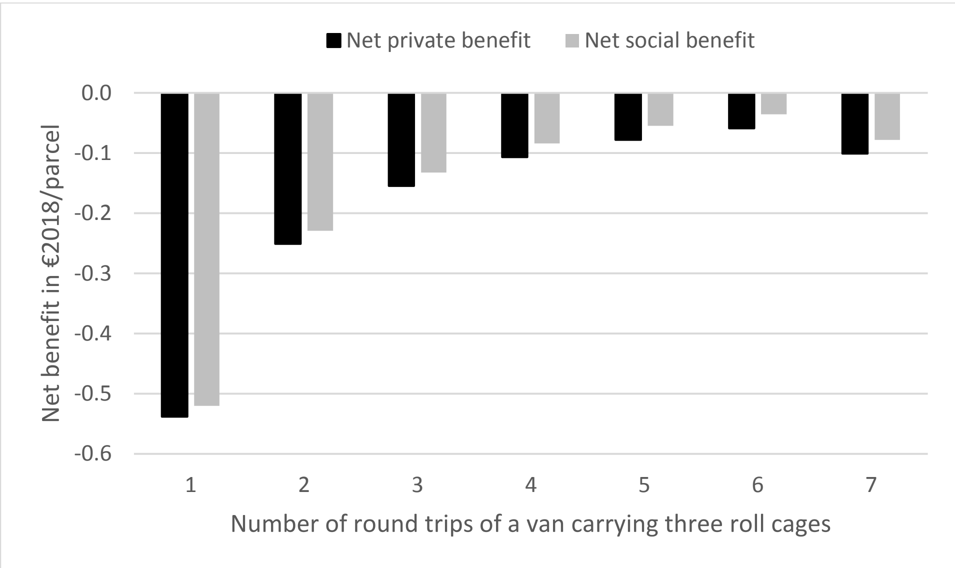
Figure 115 – Annual operational costs when a van is used in the reference case, freight wagon



Source: Own creation

When calculating the net benefits expressed in euro per parcel, the same trend as for a dedicated freight tram can be seen in Figure 116. When adding another round trip, the net private and social benefit in euro per parcel increases, but still remains negative. When six round trips are carried out, a net private cost of €0.06 and a net social cost of €0.04 are present. Although this is still a cost, the cost is lower than for a dedicated freight tram (€0.27 net private cost and €0.26 net social cost).

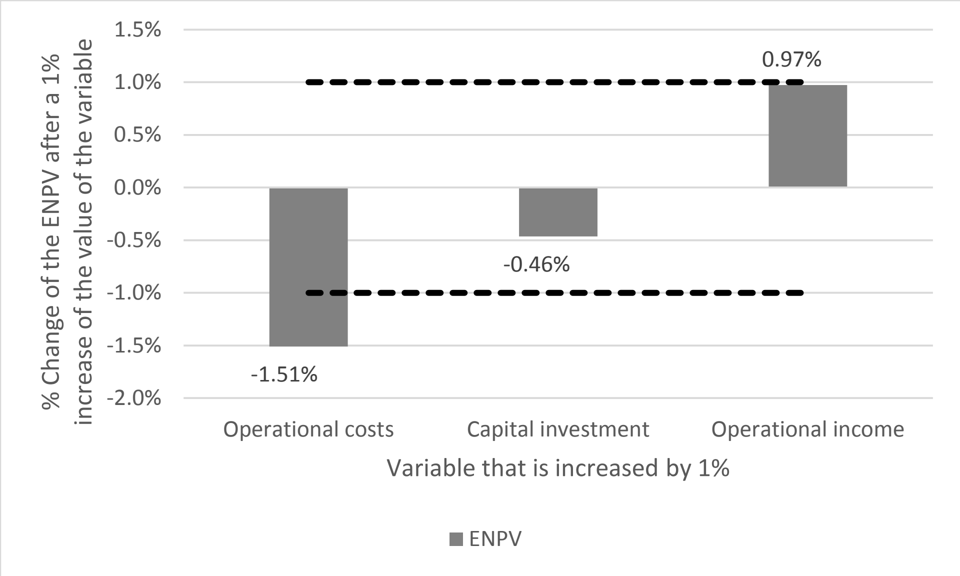
Figure 116 – Net private and social benefit for a van, freight wagon



Source: Own creation

In the next step, some sensitivity analyses are carried out for the project case in which three round trips by van are replaced by the transport of goods in a freight wagon attached to a passenger tram. The effect of the operational costs, capital investment and operational income on the project outcome is evaluated in Figure 117. The -1% and +1% tipping points at which a variable is considered to be critical are also displayed.

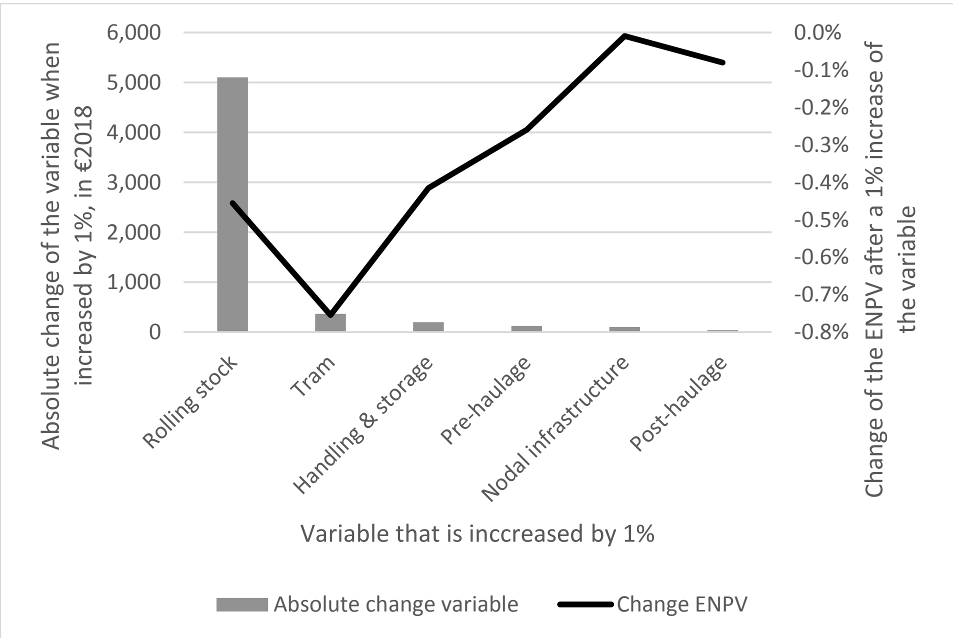
Figure 117 – Change of the ENPV when a variable is increased by 1%, van, freight wagon



Source: Own creation

It is clear from Figure 117 that the operational cost is now a critical variable affecting the viability of the tram-based project, since the ENPV alters by more than 1% when the value of the operational cost is increased by 1%. Given the fact that this variable is critical, it is elaborated on further in the scenario analysis in Section 6.3. Moreover, the effect of the different elements of the operational costs is examined together with the effect of the nodal infrastructure and rolling stock in Figure 118. From this figure, it is clear that the tram operational costs remain the most important factor of the total operational costs. With respect to the investment, the rolling stock has more effect on the ENPV than the nodal infrastructure.

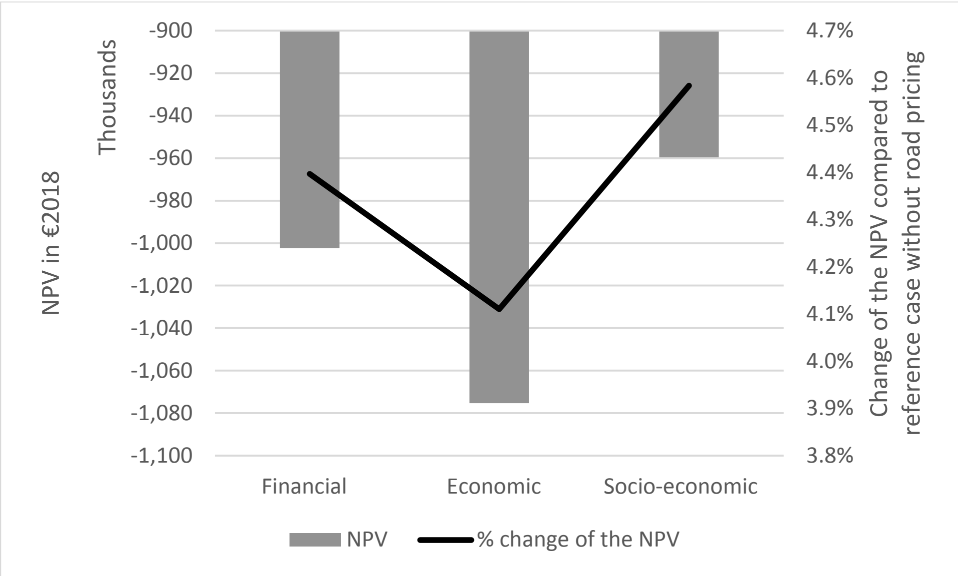
Figure 118 – Sensitivity analysis for the use of a van, freight wagon



Source: Own creation

Anno 2019, vans do not pay road pricing in Belgium[32]. The effect of a change of this policy is now investigated in Figure 119. If vans need to pay road pricing as well, the operational costs of the reference case increase and hence, the operational income of the project case also increases. As a result, the financial, economic and socio-economic NPV of the project case increase by 4.40%, 4.11% and 4.58% respectively. For the three analyses, the NPV still remains negative. As a result, the tram-based project is still not viable, although the conditions in which the project takes place are already more in favour of the project.

Figure 119 – NPV and NPV change if vans need to pay road pricing, freight wagon



Source: Own creation

In the following scenarios, the reference case in which one lorry makes one round trip is used again in order to investigate how the tram-based project can become more viable given the current project characteristics. In Section 6.3.10, the use of vans in the reference case is further elaborated on.

6.3.2 Scenario 2: Reference case: congestion on the roads

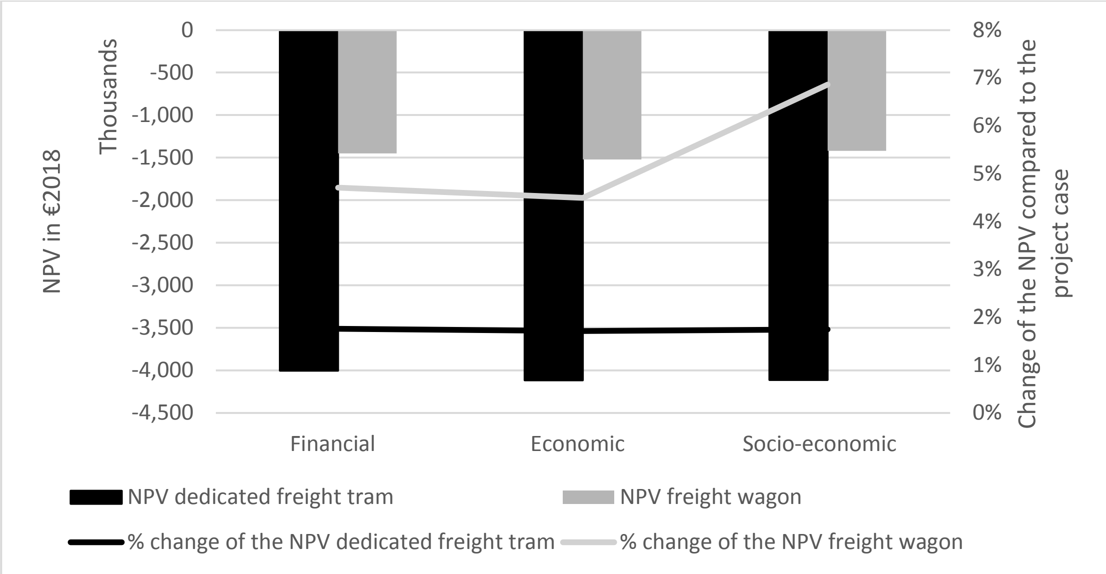
In the second scenario, the effect of road congestion around the urban area is investigated. In particular, this means that the time needed to reach the customers by road transport increases. It is assumed that the congestion delays road transport when entering the urban area and thus, the road pre-haulage used in the project case does not suffer from this congestion. Moreover, the marginal external congestion cost of the reference case increases. The unit cost for road transport during peak hour is used for the leg in the supply chain in which the urban area is entered.

In the reference case, the lorry needs half an hour to drive from the distribution centre to the first customer and hence, to enter the urban area. It is now assumed that this leg takes one hour, due to congestion. Moreover, the external costs for this leg are taken into account as peak hour external costs. Figure 120 shows the resulting NPV, as well as the relative change of the NPV compared to the NPV of the initial project case both for the project case in which a dedicated freight tram is used and for the one in which a freight wagon is attached to a passenger tram. This figure shows that the tram-based project becomes more viable when road congestion is present, since the NPV increases for the three types of analysis. However, the NPV remains negative for a dedicated freight tram as well as for

[32] See Table 38 in Section 4.1.1.2 for the road pricing scheme that is valid in Belgium in 2019.

a freight wagon. When comparing these two types of rail transport, **it is clear that the NPV when using a freight wagon is more than double the NPV when using a dedicated freight tram**.

Figure 120 – NPV and NPV change when road congestion is present



Source: Own creation

The effect of congestion on the yearly costs and benefits is noticeable for the operational income, and the saved external costs. Concerning a dedicated freight tram, the operational income increases from 17,405 €/year to 20,525 €/year, whereas the external cost savings increase from 2,469 €/year to 3,906 €/year. The latter comes from an increase of the external costs in the reference case from 5,016 €/year to 6,452 €/year. Regarding a freight wagon attached to a passenger tram, the external cost savings even increase to 4,422 €/year, because the external costs of the tram leg are lower here.

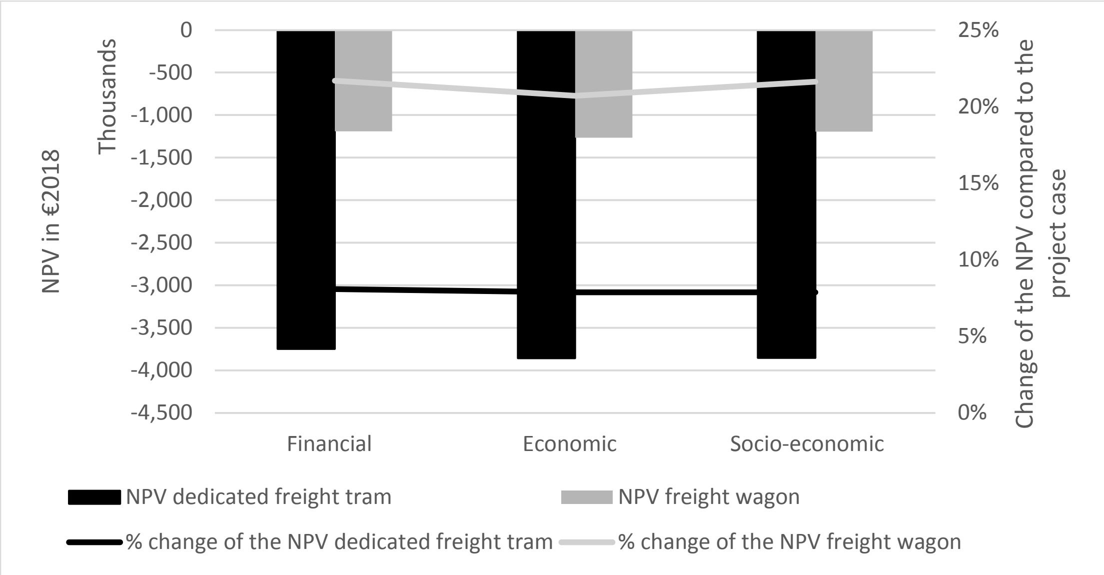
As a result, increasing congestion on the road network has a positive effect on the outcome of the tram-based project. Two scenarios in which an element of the reference case is altered are presented until so far. In the next scenarios, the tram operational costs are subjected to scenario analyses.

6.3.3 Scenario 3: Tram operational cost reduction: unaccompanied tram leg

In previous sections, it is shown that the tram operational costs are very high compared to the ones of road transport in the reference case. Therefore, it is interesting to know the effect on the project outcome if the tram operational costs are reduced. In the current scenario, the effect is investigated when the goods in the freight tram or freight wagon do not have to be accompanied by a courier. In this case, a courier picks up the goods when they arrive at a tram stop in the urban area. It is assumed that the courier is in the neighbourhood of the tram stop for another assignment, so no travel costs of the courier need to be assigned. More specifically, the time costs of the tram leg are decreased by the labour cost of the courier accompanying the goods. The time costs of the courier become zero.

Figure 121 displays the NPV for this scenario, as well as the change of the NPV compared to the NPV of the project case in which the courier accompanies the goods and this both for the use of a dedicated freight tram and a freight wagon attached to a passenger tram. It can be seen from Figure 121 that this operational change leads to an increase of the financial NPV by 8.09%, of the economic NPV by 7.88% and of the socio-economic NPV by 7.84% for a dedicated freight tram, and an increase of the financial NPV by 21.69%, the economic NPV by 20.70% and the socio-economic NPV by 21.63% for a freight wagon attached to a passenger tram. For both rail types, the NPVs remain negative, but the viability of the tram-based project is improved.

Figure 121 – NPV and NPV change if the tram leg is unaccompanied



Source: Own creation

When analysing the yearly costs and benefits for 2018, the tram operational costs decrease from 129,749 €/year to 112,372 €/year for a dedicated freight tram and from 36,854 €/year to 22,477 €/year for a freight wagon. Hence, decreasing the labour costs of the tram-based project has a positive effect on the project's outcome. In the next section, another element of the tram operational cost is tackled, being the distance covered.

6.3.4 Scenario 4: Tram operational cost reduction: shortest tram path without restrictions

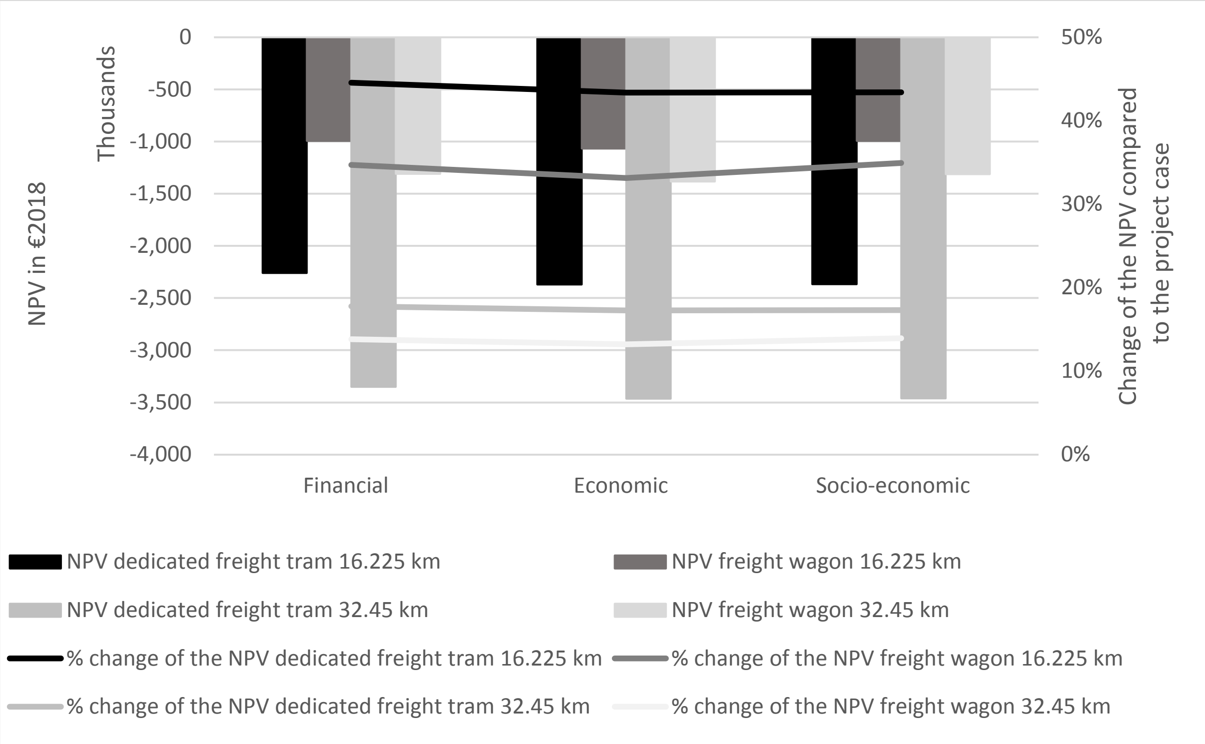
In the current project case, the tram covers a distance of 43.2 km. This long distance is related to the fact that when starting from the handling & storage point chosen in the case study under consideration, the tram passes the first tram stop, Groenplaats, in the underground. It is not possible for the tram to stop there during daytime, since this would disturb passenger traffic. Hence, to arrive at the ground level tram stop of Groenplaats, the tram needs to make a long detour (see Figure 73). This leads to high distance and time costs of the tram transport. In the current scenario, it is now assumed that a separate track is available in the underground. Hence, the tram can stop in the underground station and unload goods there without disturbing the passenger traffic. This reduces the distance to be covered by tram by 10.75 km, which is almost a quarter of the initial distance.

Moreover, it is assumed that goods are transported in the urban area in the opposite direction as in the project case. In other words, the tram does not drive back empty to P+R Melsele. Hence, the distance costs of the tram only have to be assigned to the transport in the project case in one direction. This further halves the distance to 16.225 km.

Figure 122 displays the resulting NPV when a distance of 32.45 km or one of 16.225 km is covered and the change of the NPV compared to the project case in which the tram needs to make the detour for the use of a dedicated freight tram and a freight wagon. It is clear that cutting the distance has a large positive effect on the project's outcome. The NPV increases for a dedicated freight tram by 17.75% (financial), 17.28% (economic), and 17.30% (socio-economic) when a distance of 32.45 km is covered and by 44.55% (financial), 43.37% (economic) and 43.41% (socio-economic) if only a distance of 16.225

km has to be covered instead of 43.2 km. Concerning a freight wagon attached to a passenger tram, the NPV increases by 13.84% (financial), 13.20% (economic), and 13.92% (socio-economic) when 32.45 km needs to be covered and by 34.72% (financial), 33.13% (economic) and 34.93% (socio-economic) when 16.225 km needs to be covered.

Figure 122 – NPV and NPV change if the tram takes the shortest tram path without restrictions



Source: Own creation

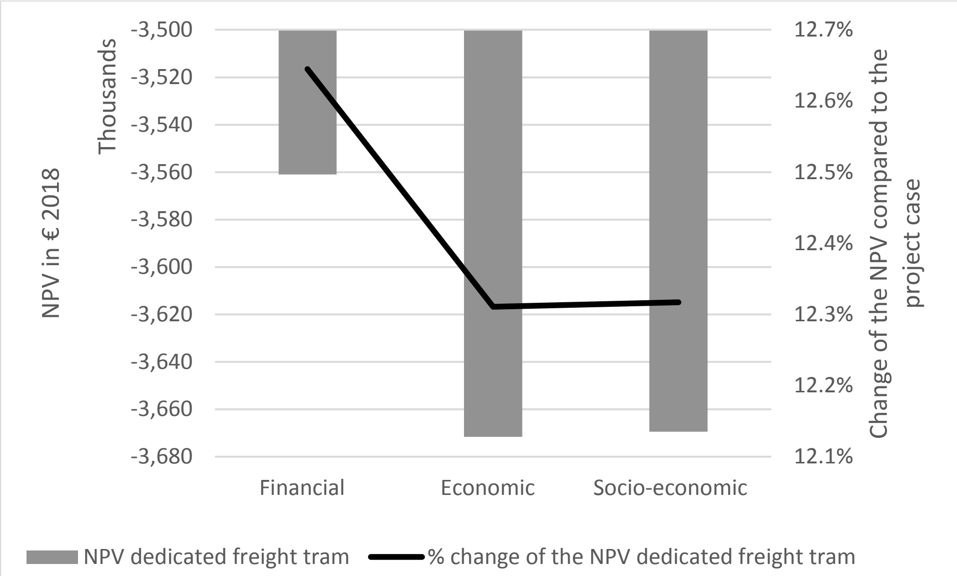
When investigating the yearly costs and benefits, the operational costs of the tram leg decrease for a dedicated freight tram from 126,749 €/year to 95,208 €/year when 32.45 km is covered and to 47,604 €/year when only 16.225 km is covered. Moreover, the external cost savings increase from 2,469 €/year to respectively 2,681 €/year (32.45 km) and 3,001 €/year (16.225 km). With respect to a freight wagon attached to a passenger tram, the tram operational costs decrease from 36,854 €/year to 27,683 €/year when 32.45 km needs to be bridged and to 13,842 €/year when only 16.225 km has to be covered. The external cost savings amount 3,069 €/year (32.45 km) and 3,195 €/year (16.225 km) respectively instead of 2,986 €/year. As a result, taking the shortest path on the tram network in terms of distance has a large positive effect on the viability of the tram-based project.

6.3.5 Scenario 5: Tram operational cost reduction: free access to tram network

Another element of the operational cost of the tram leg consists of the track access charges to use the tram infrastructure. If the freight tram operator and the infrastructure manager are one and the same company, it can be assumed that no track access charges have to be incorporated in the operational costs of the freight tram. The maintenance and repair costs of the tram infrastructure can be assigned to the passenger trams, since the share of the freight tram in total tram traffic is marginal. Moreover, in the case of a freight wagon attached to a passenger tram, no track access fee is charged.

Figure 123 shows the NPV and the change of the NPV compared to the project case of a dedicated freight tram in which track access charges have to be paid. It is clear that the tram-based project becomes more viable if no track access charges are assigned to the freight tram. The financial NPV increases by 12.64% when omitting the track access charges, whereas the economic and socio-economic NPV go up by 12.31% and 12.32% respectively. The tram operational costs in 2018 decrease from 126,749 €/year to 104,285 €/year, because the track access charges of 22,464 €/year do not have to be paid. Hence, when no track access charges are charged by the infrastructure manager, the tram-based project becomes more viable.

Figure 123 – NPV and NPV change if the access to the tram network is free of charge

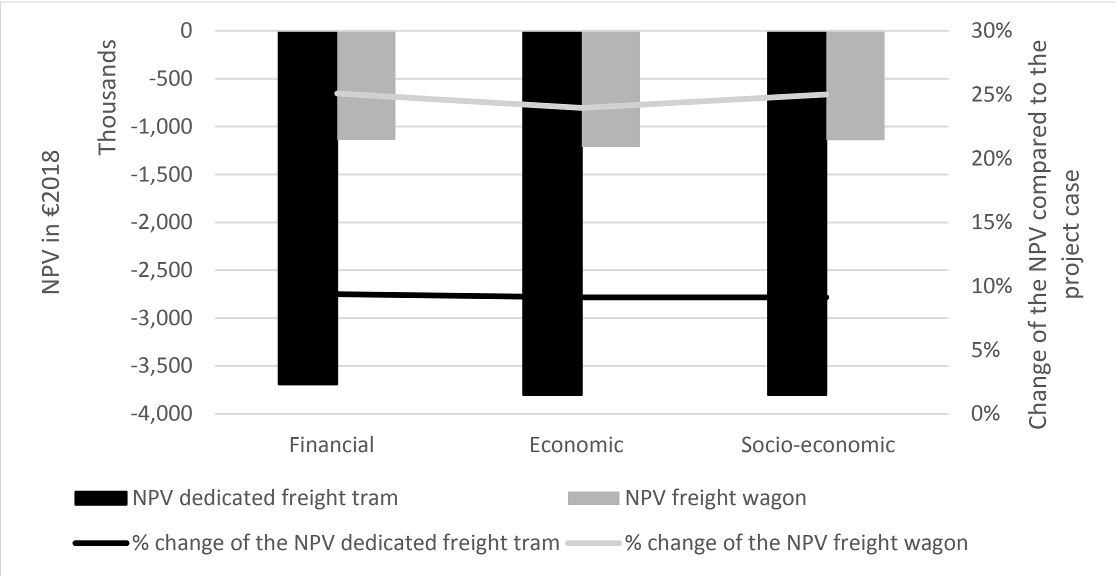


Source: Own creation

6.3.6 Scenario 6: Tram operational income increase: ancillary revenue

In the project case under consideration, it is assumed that the benefits of having additional advertisement space on the freight tram compensate for the costs of not having the lorry with advertisement for the retailer supplying the customers anymore. In the current scenario it is now assumed that the additional advertisement space available on the freight tram or freight wagon is a net benefit. This means that the operational income is increased by the ancillary revenue earned from selling the advertisement space on the tram. Figure 124 shows the resulting NPVs for a dedicated freight tram and a freight wagon, as well as the change of the NPVs compared to the project case in which no ancillary revenue is earned. The type of advertisement chosen in the calculations is a surface of 10m² on the side of the tram.

Figure 124 – NPV and NPV change ancillary revenue is earned



Source: Own creation

It can be seen from Figure 124 that adding ancillary revenue to the operational income increases the three NPVs, although they remain negative. The financial NPV increases for a dedicated freight tram by 9.37%, the economic one by 9.12% and the socio-economic one by 9.12%. For a freight wagon, the NPVs increase respectively by 25.10% (financial), 23.96% (economic) and 25.03% (socio-economic). When considering the costs and benefits for 2018, the operational income increases from 17,405 €/year to 34,045 €/year, thanks to €16,640 yearly ancillary revenue. Hence, adding ancillary revenue benefits makes the project case more viable.

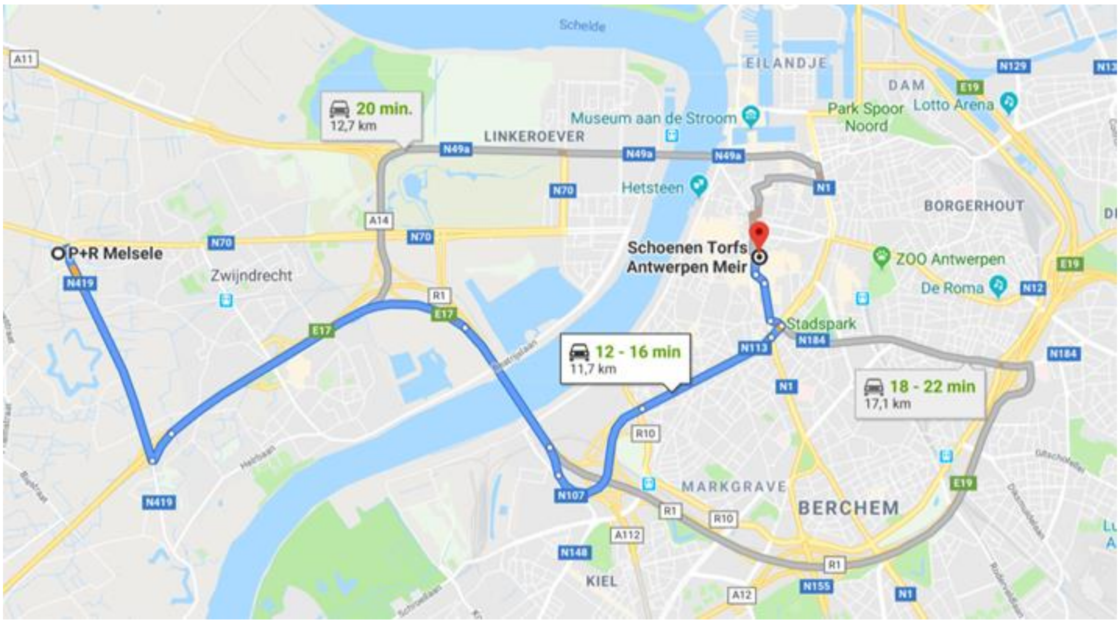
Four scenarios have been developed until now that are related to the tram leg. In the following scenario, the effect of the operational costs of the road pre- and post-haulage leg are examined.

6.3.7 Scenario 7: No pre- and/or post-haulage

Next to the tram leg, road pre- and post-haulage are needed in the case study under consideration. These two additional legs cause extra operational costs. If the distribution centre of the retailer, as well as the shops in the urban area are located next to the available tram infrastructure, no road pre-haulage and road post-haulage have to be carried out. The effect of omitting these two legs on the project outcome is investigated in the current scenario.

When no road pre-haulage is needed, two options are valid: the distribution centre of the retailer is located next to handling and storage point P+R Melsele, where the goods are now transferred from the lorry to the tram, or the tram infrastructure is extended, reaching until the distribution centre in Temse. These two cases are examined now. If the distribution centre of the retailer is located at P+R Melsele, this has an effect on the operational and external costs of the reference case. More specifically, the distance to be covered in the reference case decreases. Figure 125 shows the route to be covered. The distance equals 12 km, of which 2 km is covered in suburban area, 6 km on motorways and 4 km in the urban area. In total, the distance between the distribution centre and the shop Meir decreases by 13.5 km compared to the reference case in which road pre-haulage is needed. The time needed to cover this leg decreases from 30 minutes to 15 minutes (situation on Tuesday 15 January 2019, when leaving at 5 am – see Section 4.3.1.1).

Figure 125 – Distance between the distribution centre if located at P+R Melsele and shop Meir



Source: Own creation based on Google Maps

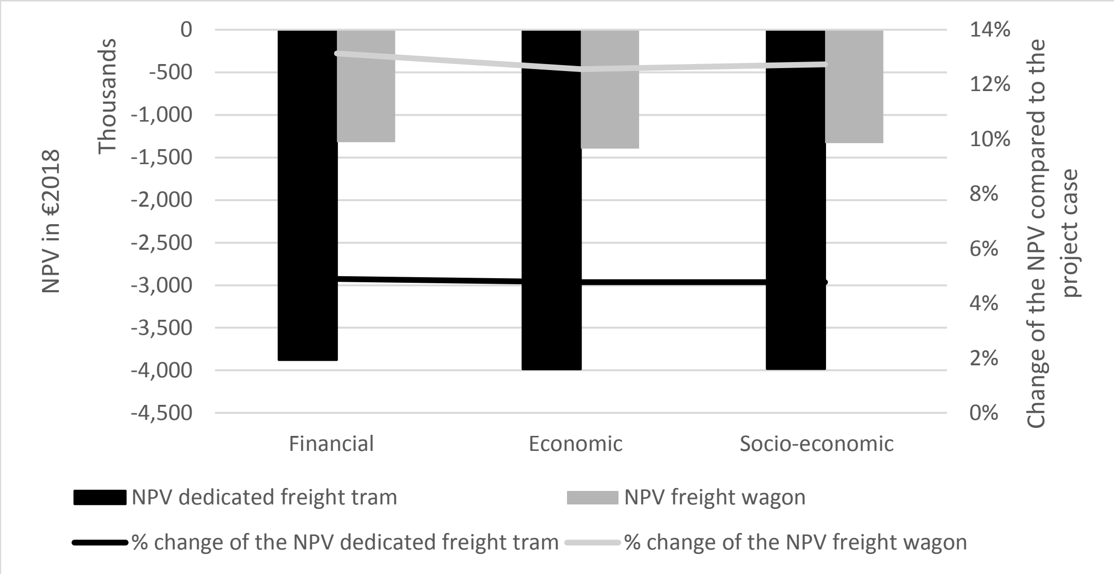
Analogously, the distance to be covered between the last shop in the round trip, being the shop at Wijnegem Shopping Centre, and the distribution centre also changes. The total distance decreases from 34 km to 20 km, including 2 km in suburban area, 13.5 km on motorways and 4.5 km in the urban area. The total time needed to cover this distance decreases from one hour if the distribution centre is located in Temse to 45 minutes if the distribution centre is located at P+R Melsele. The route to be covered is shown in Figure 126.

Figure 126 – Distance between shop Wijnegem Shopping Centre and the DC if located at P+R Melsele

Source: Own creation based on Google Maps

Since no pre-haulage takes place, no additional handling between the pre-haulage and rail leg is carried out. The external costs of the reference case are adapted based on the changed distance, and the external costs of the road pre-haulage leg disappear. The resulting changes of the NPV are displayed in Figure 127 for a dedicated freight tram and a freight wagon.

Figure 127 – NPV and NPV change when no pre-haulage is needed and the DC is relocated



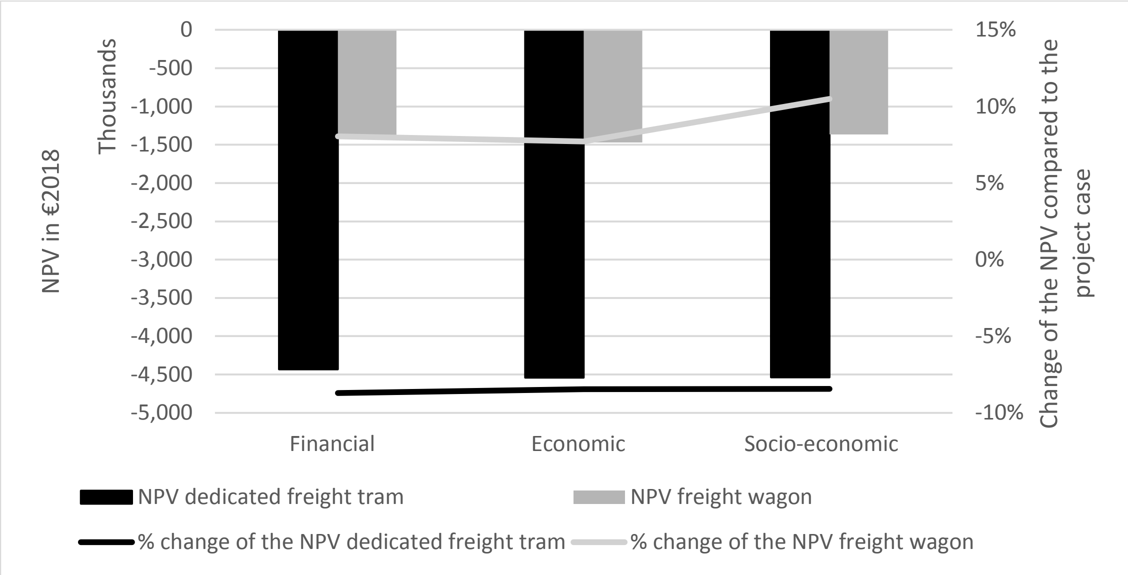
Source: Own creation

Relocating the distribution centre from Temse to P+R Melsele increases the financial NPV for a dedicated freight tram by 4.90%, the economic NPV by 4.78% and the socio-economic NPV by 4.78%. For a freight wagon, the NPV increases respectively by 13.13% (financial), 12.56% (economic) and 10.19% (socio-economic). For both tram types, it is beneficial if the distribution centre is located at the tram stop, although the NPVs remain negative.

The costs and benefits for 2018 change as follows when the distribution centre is relocated and no pre-haulage transport is needed. The investment in nodal infrastructure decreases from €9,369 to €6,246. The operational costs of the pre-haulage leg disappear and the handling and storage costs decrease from 21,931 €/year to 9,022 €/year. On the other hand, the operational income decreases from 17,405 €/year to 12,240 €/year. The reduced inventory cost increases from -9 €/year to -6.38 €/year. On the externalities side, the saved external costs are reduced from 5,016 €/year to 3,067 €/year for a dedicated freight tram and to 1,037 €/year for a freight wagon. The yearly €1,696 external costs of the road pre-haulage leg fully disappear.

Another option to omit the road pre-haulage transport, is to extend the urban tram infrastructure until the distribution centre of the retailer in Temse. When extending this infrastructure, 10 km additional tram distance has to be added at bird's-eye view. It is assumed that the extension of the tram infrastructure is part of the plans of the passenger tram network. Thus, the infrastructure investment costs are not assigned to the freight tram, but to the passenger traffic. Figure 128 displays the resulting NPV and the change of the NPV. Given the negative changes of the NPV, this scenario does not make the tram-based project more viable. This can be explained by the savings of the road pre-haulage that are lower than the additional tram operational costs. The tram operational costs are high due to the detour made by the tram, and the courier who accompanies the goods. As soon as the operational costs of the tram leg are cheaper than the ones of the pre-haulage leg, including the additional handling between the pre-haulage leg and the rail leg, it is more interesting to substitute a longer tram leg for the pre-haulage leg.

Figure 128 – NPV and NPV change when no pre-haulage is needed and the tram infrastructure is extended



Source: Own creation

The costs and benefits in 2018 of extending the tram infrastructure until the distribution centre in Temse are distributed as follows. The nodal infrastructure investment, the operational pre-haulage and handling and storage costs, and the external costs related to the pre-haulage leg change identically as when the distribution centre is relocated to P+R Melsele. The operational costs of the tram leg increase from 129,749 €/year to 156,089 €/year for a dedicated freight tram and from 36,854 €/year to 45,385 €/year for a freight wagon. The external costs of the tram leg increase from 851 €/year to 1,048 €/year for a dedicated freight tram and from 335 €/year to 412 €/year for a freight wagon.

Secondly, the effect of not having the need to use road post-haulage is investigated in this scenario. Given the fact that the three shops under consideration are located very close to a tram stop, it is assumed that the characteristics of the reference case do not change when the post-haulage leg is omitted. The operations of the project case that become superfluous include the operational costs of the post-haulage leg, and the related handling and storage, the investment in post-haulage handling equipment, and the external costs of the post-haulage leg. Figure 129 shows the resulting NPVs and the changes of the NPVs for a dedicated freight tram and for a freight wagon. When no post-haulage is needed, the tram project becomes more viable, given the increase of the three NPVs, although the NPVs remain negative.

The costs and benefits in 2018 decrease from €9,369 to €3,123 with respect to the nodal infrastructure investment. The yearly post-haulage operational costs (€12,044) disappear, and the handling costs decrease from 21,931 €/year to 9,022 €/year. Concerning the external cost savings, no changes are noticeable, because no external costs were assigned to the post-haulage transport in the project case.

In sum, the tram-based project becomes more viable if no post-haulage is needed. Concerning the pre-haulage, this depends on the way the pre-haulage leg is substituted. If the distribution centre is relocated to P+R Melsele, and this relocation does not alter the operational costs of the distribution centre, the tram project becomes more viable. If the tram infrastructure is extended until the distribution centre of the retailer in Temse, and the tram operational costs exceed the operational costs related to road pre-haulage, the project becomes less viable.

Figure 129 – NPV and NPV change when no post-haulage is needed

Source: Own creation

6.3.8 Scenario 8: Changing external costs

Given the high uncertainty on the values of the external costs, several scenarios in which other external cost values are applied, are presented here. It is chosen to halve and to double the external costs of the road and the tram transport. Figure 130 provides the results of the analysis for a dedicated freight tram and for a freight wagon. The scenarios are ranked according to a decreasing change of the socio-economic net present value compared to the project case. The scenario that is the most in favour of the tram-based project, is the one in which the external costs of the road legs are in fact double as high as estimated in the project case, and the ones of the tram leg are in reality half as high as in the project case. The second best scenario is the one in which the external costs of the road transport have to be doubled, keeping the ones of the tram leg constant. All scenarios lead to changes of the SNPV between 0.09% and -0.06% for a dedicated freight tram and between 5.25% and -3.00% for a freight wagon, which is low compared to scenarios 1-7 presented above. However, it has to be kept in mind that the share of the external costs in the SNPV of the project case is very low, due to the financial and economic factors. If the ENPV is still negative, but smaller in absolute terms, adding the external cost savings can lead to a positive SNPV. In this case, the insights provided in Figure 130 become very relevant.

Figure 130 – NPV and NPV change when external costs are halved and doubled

Source: Own creation

6.3.9 Scenario 9: Transport during peak hour or during the night

Currently, the largest part of the transport in the reference and project case occurs during off-peak hours. In the current scenario, the effect of moving the transport to mainly peak hours and to the night is examined. Transport during peak hours is possible for a dedicated freight tram and for a freight wagon. Transport during the night is only considered for a dedicated freight tram and not for a freight wagon attached to a passenger tram, since passenger trams do not operate during the full night in Antwerp anno 2019. Hence, even if the transport would start at the beginning of the night, it would not be possible to complete the full tram trip during the night. Therefore, this option is not considered here.

Firstly, it is assumed that the transport takes mainly place during peak hours. Instead of leaving at 5 am, the lorry departs at 7 am at the distribution centre in Temse. According to Google Maps estimations it takes up to one hour to arrive at the shop at Meir at this time of the day. The transport time between the shop at Meir and the shop at Groenplaats, as well as between the shop at Groenplaats and the shop at Wijnegem Shopping centre remains more or less the same. The last leg, between the shop at Wijnegem Shopping Centre and the distribution centre in Temse takes 40 minutes. With respect to the pre-haulage leg, the time needed to reach P+R Melsele becomes 30 minutes during peak hour. For the tram leg and the post-haulage no time differences are observed between peak and off-peak hours. When analysing the costs and benefits for 2018, the operational costs of the road pre-haulage increase from 4,730 €/year to 5,229 €/year. The operational income increases from 17,405 €/year to 18,449 €/year. The change of the consumer surplus increases from -9 €/year to -6 €/year for a dedicated freight tram and from -4.50 €/year to -1.35€/year for a freight wagon, whereas the external cost savings increase from 2,469 €/year to 3,283 €/year for a dedicated freight tram and to 3,799 €/year for a freight wagon.

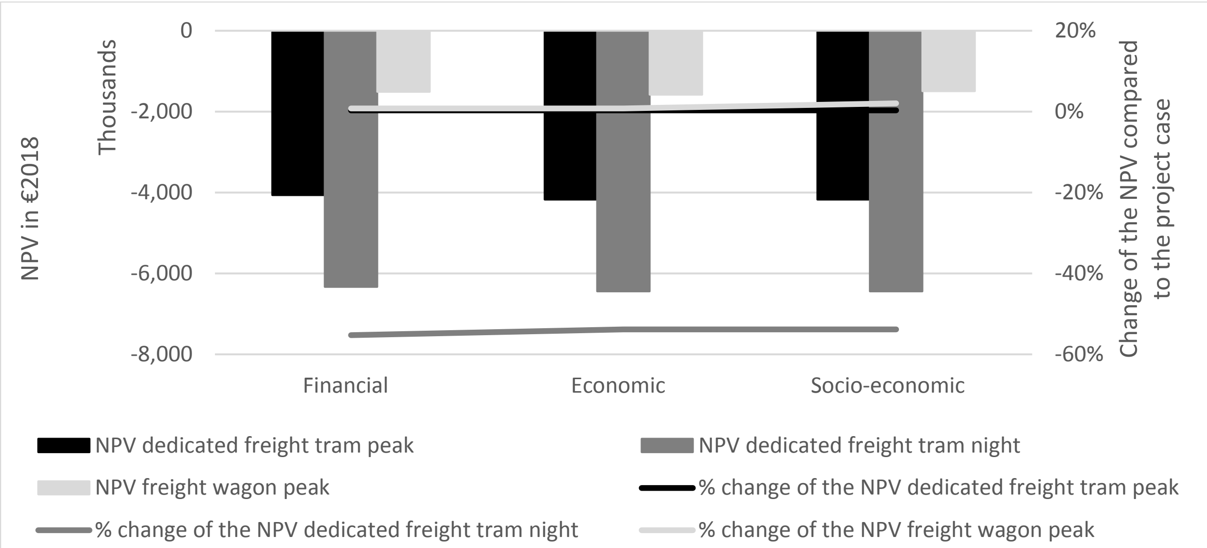
When the transport occurs during the night, the operational costs of all legs of the project and reference case change. In general, night labour is assumed to be 1.25 times as expensive as day labour (Pittoors, 2019; Van Dooren, 2017). When leaving the distribution centre in Temse at 1 am instead of 5 am, the shop at Meir is reached in 28 minutes. The time needed to move from shop Meir to shop Groenplaats remains 2 minutes, while the time needed to drive from shop Groenplaats to shop Wijnegem Shopping Centre decreases to 20 minutes. The last part of the round trip, driving back to the distribution centre, takes 30 minutes during the night.

The costs and benefits in 2018 change then tremendously. The total operational cost of a dedicated freight tram increases from 165,454 €/year to 265,943 €/year. This increase mainly comes from the cost increase of the tram leg, going from 126,749 €/year to 217,816 €/year. The road pre-haulage also increases, from 4,730 €/year to 9,129 €/year. The post-haulage increases from 12,044 €/year to 15,055 €/year and the operational handling costs climb from 21,931 €/year to 23,943 €/year. The high increase for the tram operational costs is next to the night labour factor due to the opening of the dispatch centre especially for the freight tram operations. The operational income alters slightly from 17,405 €/year to 17,698 €/year and the change of the consumer surplus decreases a bit from -9 €/year to -12 €/year. The external cost savings decrease a lot from 2,369 €/year to only 518 €/year. This is mainly due to the fact that the saved external costs almost halve from 5,016 €/year to 2,569 €/year.

The resulting NPV of executing the transport during peak hour or during the night, as well as the change of the NPV compared to the transport during off-peak hours, are shown in Figure 131. When leaving the distribution centre at 7 am instead of 5 am, most of the transport of the reference case occurs during peak hour. As shown in Figure 131, this shift still leads to a negative NPV, but the change of the NPV compared to the reference case is slightly positive. From a financial perspective, the NPV increases by 0.31%, from an economic viewpoint by 0.30% and from a socio-economic perspective by 0.32% for a dedicated freight tram and by 0.82% (financial), 0.78% (economic) and 2.05% (socio-economic) respectively for a freight wagon. When the round trip starts at 1 am instead of at 5 am, the NPV of a dedicated freight tram becomes much more negative for all three perspectives. The NPV decreases by between 53.77% (ENPV) and 55.23% (FNPV).

As a result of this scenario, moving the transport towards night time only makes the tram-based project less viable. Moving the transport from off-peak to peak hours increases the viability slightly. However, this has to be traded off against the smaller chance to find a slot in between the passenger tram traffic to make use of the public tram infrastructure. Hence, operating the freight tram during off-peak hours seems to be the best idea until now. This idea depends on the congestion level during peak hours. Scenario 2 shows that increasing road congestion improves the viability of the tram-based project. Hence, if the congestion level increases more than assumed in the current scenario, moving from off-peak hour to peak hour becomes more interesting.

Figure 131 – NPV and NPV change when the transport is executed during peak hour or during the night



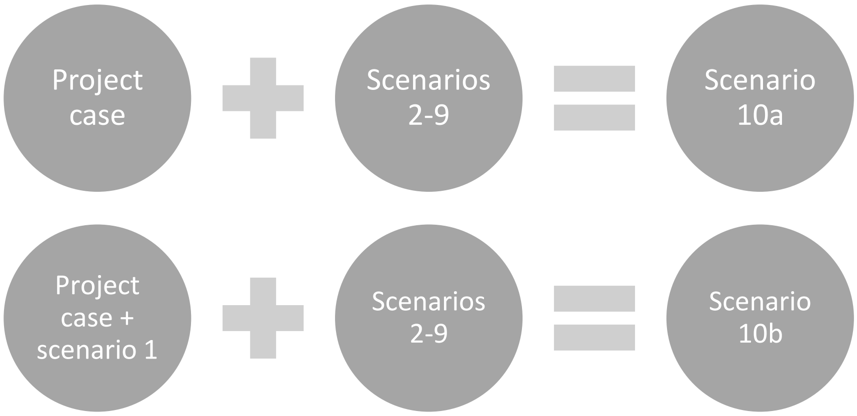
Source: Own creation

6.3.10 Scenario 10: Best-case scenario

In the last scenario, the previous scenarios are combined together. Scenario 1 concerns the type of vehicles used in the reference case. The choice for other vehicles alters the reference case a lot. Therefore, it is decided to combine scenarios 2-9 gradually with the project case, as well as with the project case on which scenario 1 is applied. Figure 132 displays this way of working graphically. Scenario 10a is obtained by combining scenarios 2-9 gradually with the project case. Scenario 10b is achieved by adding scenario 1 to the project case and combining this with scenarios 2-9. Concerning the transport of parcels alongside passengers, only scenario 10b is applicable, since the transport in the reference case is always assumed to be done by vans and not by lorries.

The analysis is firstly done for a dedicated freight tram, secondly for a freight wagon and thirdly for the transport of parcels alongside passengers.

Figure 132 – Combining scenarios 1-9



Source: Own creation

6.3.10.1 Dedicated freight tram

Firstly, scenario 10a is evaluated. Scenarios 2-9 are gradually added according to their effect on the project case. Table 85 shows the effect of each scenario on the ENPV. The ENPV is chosen here instead of the FNPV or the SNPV, because this makes it possible to see when a project is viable from a socio-economic viewpoint, even when it is not viable yet from an economic viewpoint. Moreover, the ranking based on the FNPV or SNPV would be the same in this specific case as for the ENPV.

Table 85 – Ranking of scenarios 2-9 according to a decreasing effect on the ENPV, dedicated freight tram

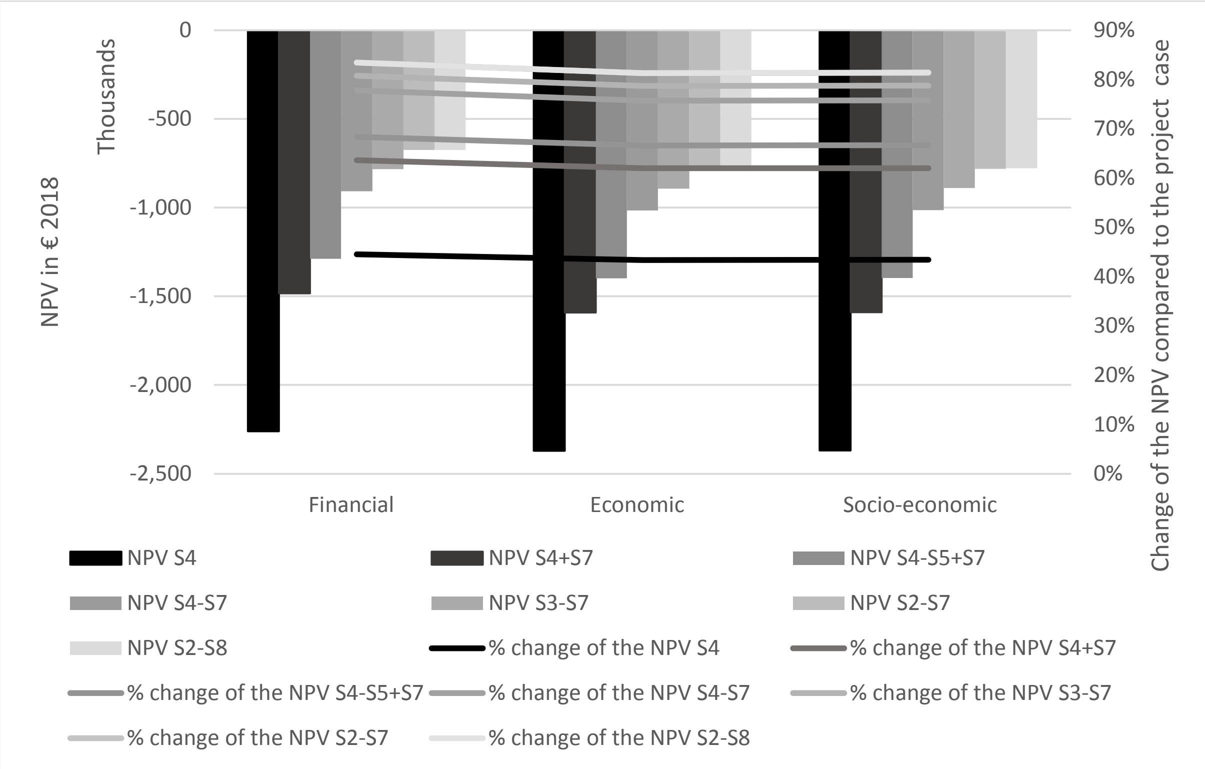
Scenario	Effect on ENPV
S4: Shortest tram path	43.37%
S7: No pre- and post-haulage	13.82% (post) and 4.78% (pre)
S5: Free access tram network	12.3%
S6: Ancillary revenue	9.12%
S3: Unaccompanied tram leg	7.88%
S2: Congestion on roads	1.71%
S9: Peak hour transport	0.30%
S8: Changing external costs	0.00%

Source: Own creation

When adding scenarios 2-9 to the project case, the following positive conditions for tram-based urban freight distribution are created. The tram can take the shortest path to reach the tram stops, without limitations. It is also assumed that goods are transported in the opposite directions too and hence, only one-way tram transport has to be paid for (scenario 4). No road pre- and post-haulage are needed, decreasing the operational costs of the project (scenario 7). Another component of the tram operational cost that is cancelled out is the track access charges (scenario 5). As part of the operational income, it is assumed that ancillary revenue is earned by selling advertisement space on the tram (scenario 6). No courier has to accompany the goods, reducing the tram operational cost (scenario 3). Road congestion is present, extending the road transport time (scenario 2). Moreover, it is assumed that the transport takes mainly place during peak hour instead of off-peak hour (scenario 9). Ultimately, the external costs of road transport are underestimated and should be doubled and likewise, the tram external costs are overestimated and should be halved (scenario 8). These positive conditions are now gradually added to the project case in order to know which conditions have to be fulfilled to make the project viable.

Figure 133 shows the NPV and the change of the NPV compared to the project case when scenarios 2-9 are gradually added according to the ranking shown in Table 85. The more scenarios added to the project case, the less negative the NPV becomes, or in other words, the higher the relative change of the NPV compared to the initial project case. It can be seen from Figure 133 that scenario 9 is not added. This is because implementing scenario 9 when scenarios 2-7 are in place reduces the NPV. Hence, scenario 9 is omitted. After adding the seven scenarios, the NPV is still negative for the three perspectives. Hence, the project is not viable. The underlying data of Figure 133 are provided in Appendix 16.

Figure 133 – NPV and NPV change in scenario 10a, dedicated freight tram



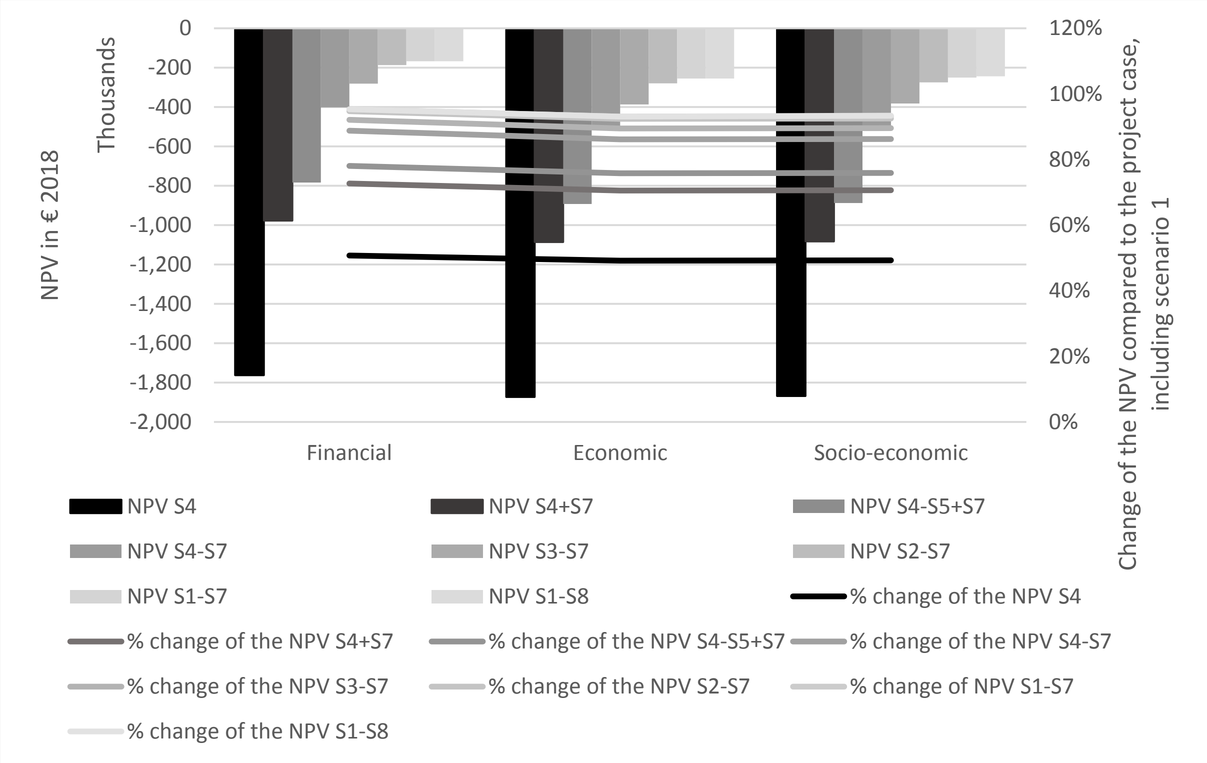
Source: Own creation

Based on scenario 10a, some conclusions can be drawn with respect to the use of a dedicated freight tram for the case study in Antwerp. The variable that has a lot of effect on the viability of the tram-based project, is the path that has to be covered by the tram. If the tram needs to make a long detour, this has a large effect on the tram operational costs. As long as the operational costs of the tram exceed the operational costs of the reference case, the tram-based project cannot succeed.

The same analysis is now done for scenario 10b, in which vans are used in the reference case. Scenario 1 is now also added. When ranking the scenarios according to a decreasing effect on the project case, in terms of change of the ENPV, scenario 1 is added after scenario 2 and before scenario 8. In Figure 134, the resulting NPVs and the changes of the NPVs are shown when scenarios 1-9 are gradually added to scenario 10b. The scenarios are added based on their change of the NPV (see Appendix 16). The scenario that increases the NPV the most, i.e. scenario 4, is added firstly. All scenarios, except scenario 9 are added. When adding scenario 9 after scenarios 1-7 are added to scenario 10b, it appears that the NPV decreases. Therefore, it is chosen not to add scenario 9.

The NPVs obtained in scenario 10b are still negative, but higher than the ones achieved by applying scenario 10a. Therefore, it is decided to conduct another sensitivity analysis for scenario 10b with respect to the amount of goods being transported.

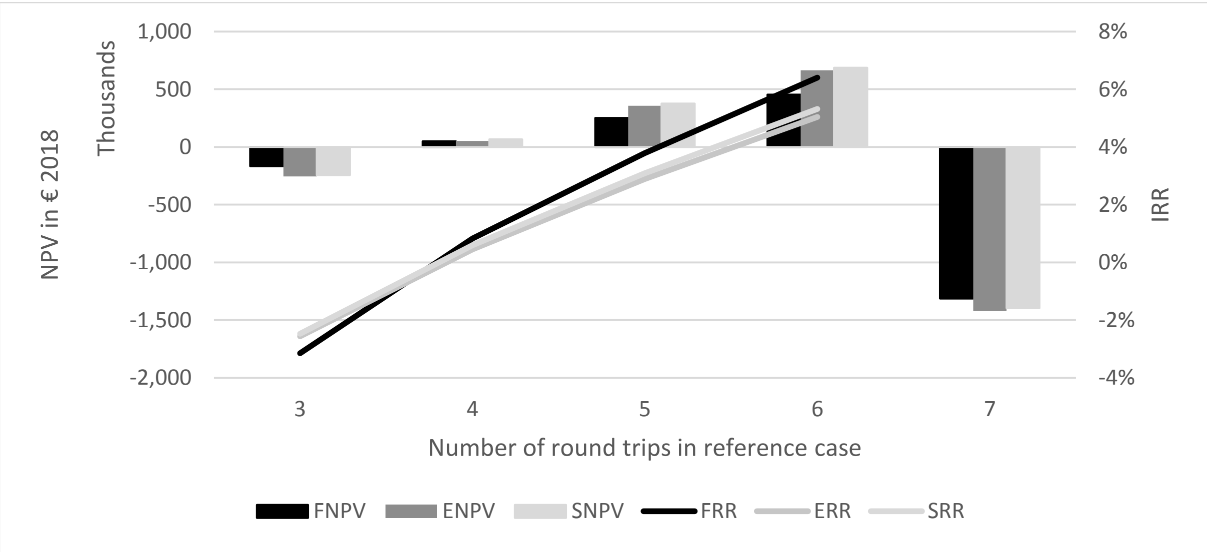
Figure 134 – NPV and NPV change in scenario 10b, dedicated freight tram



Source: Own creation

Figure 135 shows the NPVs and IRRs when more round trips are executed when scenario 10b takes place. As soon as four round trips are carried out, given scenario 1-8, the tram-based project becomes viable when considering the NPV. The present value to capital ratio (see Appendix 16) is also positive from four round trips. When analysing the IRR, Figure 135 shows that the project is not very likely to be executed. From five round trips, the IRR becomes positive, but is still much lower than the 4% discount rate used. From six round trips, the IRR exceeds the discount rate.

Figure 135 – NPV and IRR for different numbers of round trips, scenario 10b



Source: Own creation

6.3.10.2 Freight wagon attached to a passenger tram

The second type of rail transport considered in this research is the use of a freight wagon attached to a passenger tram. As for a dedicated freight tram, scenarios 2-9 are ranked according to a decreasing ENPV. The ranking is shown in Table 86. Scenario 5, concerning the track access charges is not presented in Table 86. This is because a freight wagon attached to a passenger tram does not pay track access charges in the project case. Hence, scenario 5 is not applicable here.

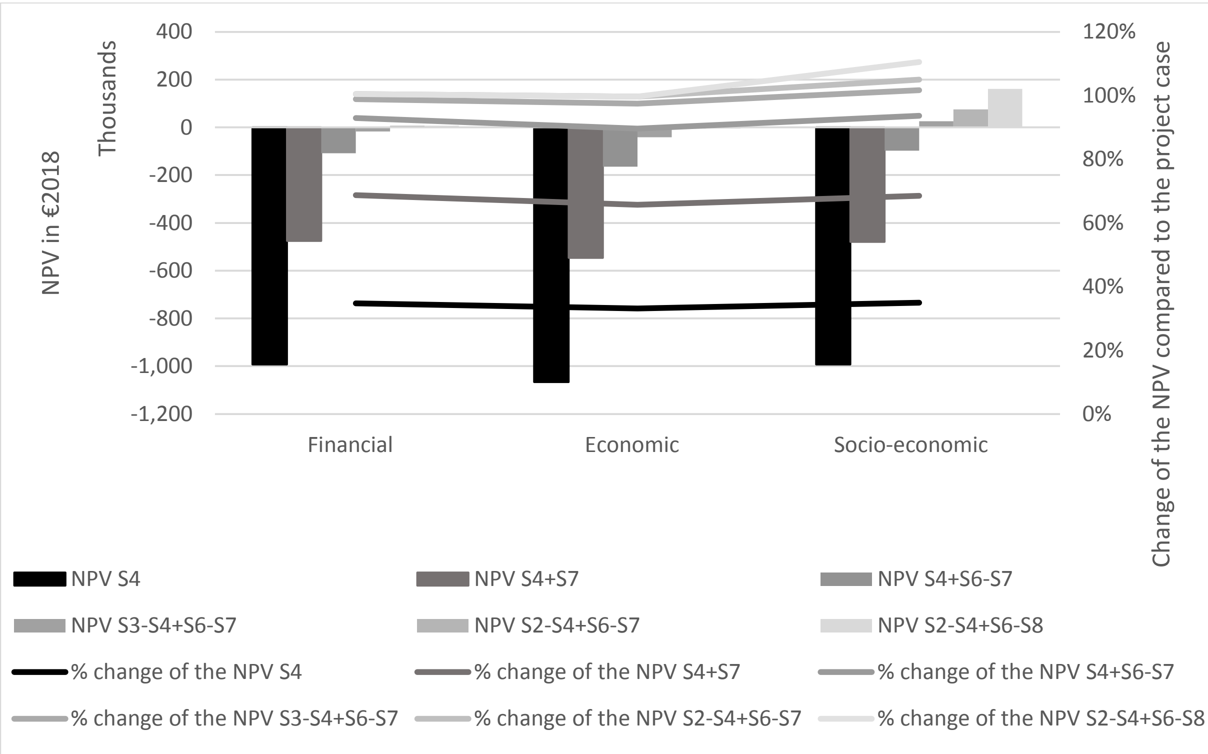
Table 86 – Ranking of scenarios 2-9 according to a decreasing effect on the ENPV, freight wagon

Scenario	Effect on ENPV
S4: Shortest tram path	33.13%
S7: No pre- and post-haulage	24.28% (post) and 12.56% (pre)
S6: Ancillary revenue	23.96%
S3: Unaccompanied tram leg	20.70%
S2: Congestion on roads	4.49%
S9: Peak hour transport	0.78%
S8: Changing external costs	0.00%

Source: Own creation

Scenarios 2-9 are now gradually added to the project case in which a freight wagon is attached to a passenger tram. Figure 136 shows the resulting NPVs, and the NPV changes. From the seven scenarios shown in Table 86, only six scenarios are applied in Figure 136. Adding scenario 9 when scenarios 2-7 are in place, decreases the NPV and hence, it is decided to omit scenario 9.

Figure 136 – NPV and NPV change in scenario 10a, freight wagon

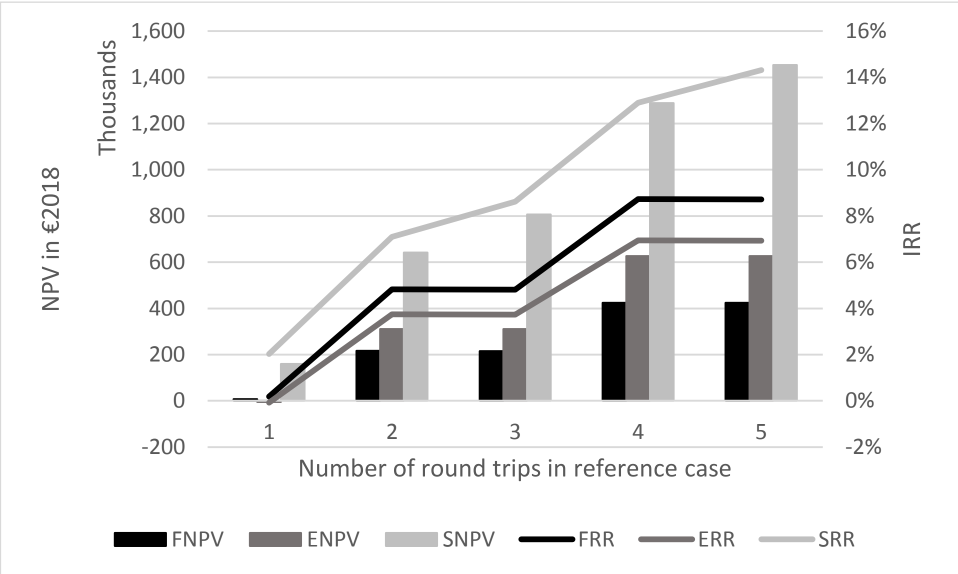


Source: Own creation

It is clear from Figure 136 that when gradually adding the scenarios, the tram-based project becomes viable from a financial and socio-economic perspective. As soon as scenario 4, 7, 6 and 3 are applied, using the freight wagon instead of the current road transport is viable from a socio-economic perspective when only considering the net present value. The SNPV is equal to €26,051 at this point. However, the SRR only equals 0.35%, which is much lower than the social discount rate of 4% used. When adding more scenarios, the NPV increases further, to an SNPV of €160,632 after applying all scenarios. The related SRR equals 2.04% and the present value to capital ratio amounts 0.315.

In the next step, it is investigated if the project could become viable also from the perspective of the internal rate of return when more goods are transported. This is examined in Figure 137, where the number of round trips is increased until five. Figure 137 displays the NPV and IRR for scenario 10a. When one round trip is executed, the ENPV is still negative. As soon as two daily round trips take place, the three NPVs are positive, with the SNPV having the highest value. The internal rate of return equals 3.75% from an economic perspective and 7.09% from a socio-economic perspective. As soon as four round trips are executed per day, the internal rate of return exceeds the financial and social discount rate of 4% for the financial, economic and socio-economic analysis. Hence, the tram-based project is viable and should be executed. This is in favour of the project leader, i.e. the government, the project users, and the impactees. The background data of Figure 137 are provided in Appendix 16.

Figure 137 – NPV and IRR for different number of round trips, scenario 10a, freight wagon

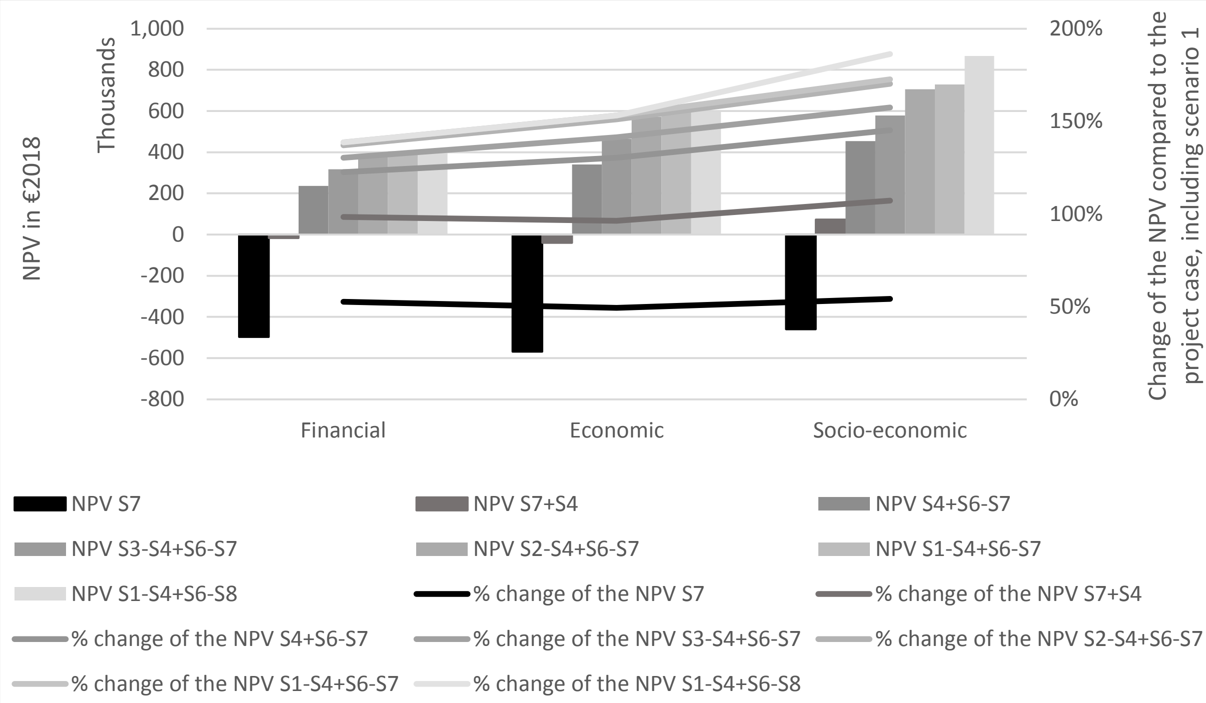


Source: Own creation

The same analysis is now performed for scenario 10b, in which the reference case is executed by vans instead of lorries. Scenario 1 is added to the analysis, being the introduction of road pricing for vans. When ranking the ENPV of scenarios 1-9, applying scenario 7 provides the highest increase of the ENPV, followed by scenario 4, 6, 3, 2, 1, 9 and 8. Hence, the only difference with scenario 10a is the position of scenarios 7 and 4. Figure 138 displays the resulting NPVs and changes of the NPVs when applying scenarios 1-9 gradually. Again, it is visible that scenario 9 is not applied, because it decreases the NPV when applied after the other scenarios. Thus, seven scenarios are applied and displayed in Figure 138. When only scenario 7 is applied, the NPV is still negative for the three analyses. After applying scenario 7 and scenario 4, the SNPV becomes positive. Hence, when only considering the NPV, applying the project would be beneficial from a socio-economic perspective. However, the SRR amounts 0.96% at this moment, which is lower than the social discount rate of 4%.

By adding scenario 6 to scenarios 7 and 4, the NPV is positive from a financial, economic and socio-economic perspective. The present value to capital ratio equals 0.462 (financial), 0.668 (economic) and 0.891 (socio-economic), and the internal rate of return exceeds the social discount rate, being equal to 5.21%, 4.07% and 5.25% respectively. In other words, as soon as scenarios 7, 4 and 6 are applied, the implementation of the project is advantageous for the society. Adding more scenarios increases the NPV and IRR. When all considered scenarios are applied, an FNPV of €404,355, an ENPV of €596,616 and an SNPV of €867,108 are obtained. A corresponding internal rate of return of 8.37% (FRR), 6.65% (ERR) and 9.18% (SRR) are achieved, as well as a present value to capital ratio of 0.792 (financial), 1.169 (economic) and 1.699 (socio-economic).

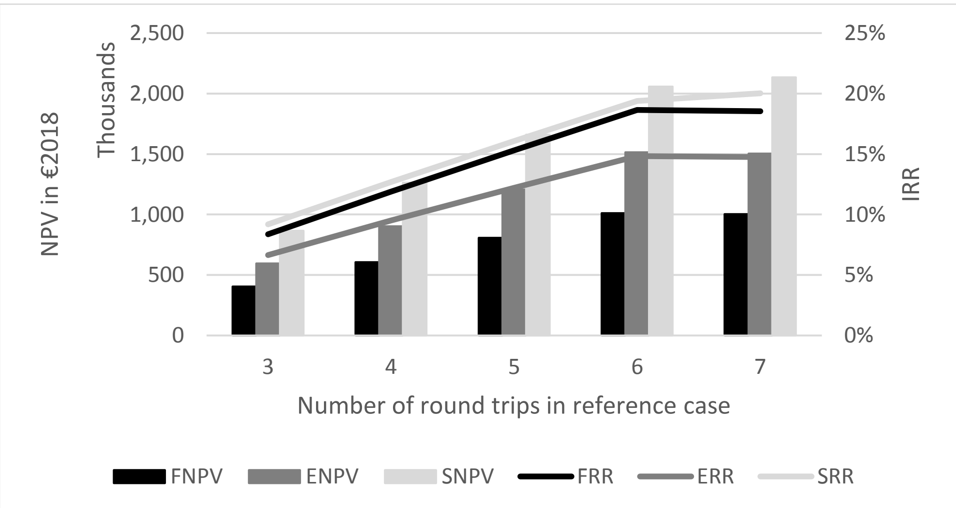
Figure 138 – NPV and NPV change in scenario 10b, freight wagon



Source: Own creation

Ultimately, the viability of scenario 10b is evaluated when the amount of goods to be transported is altered. Figure 139 displays the NPV and IRR for three to seven daily round trips when all scenarios of Figure 138 are in place. When adding more round trips, the NPVs and IRRs increase.

Figure 139 – NPV and IRR for different numbers of round trips, scenario 10b, freight wagon

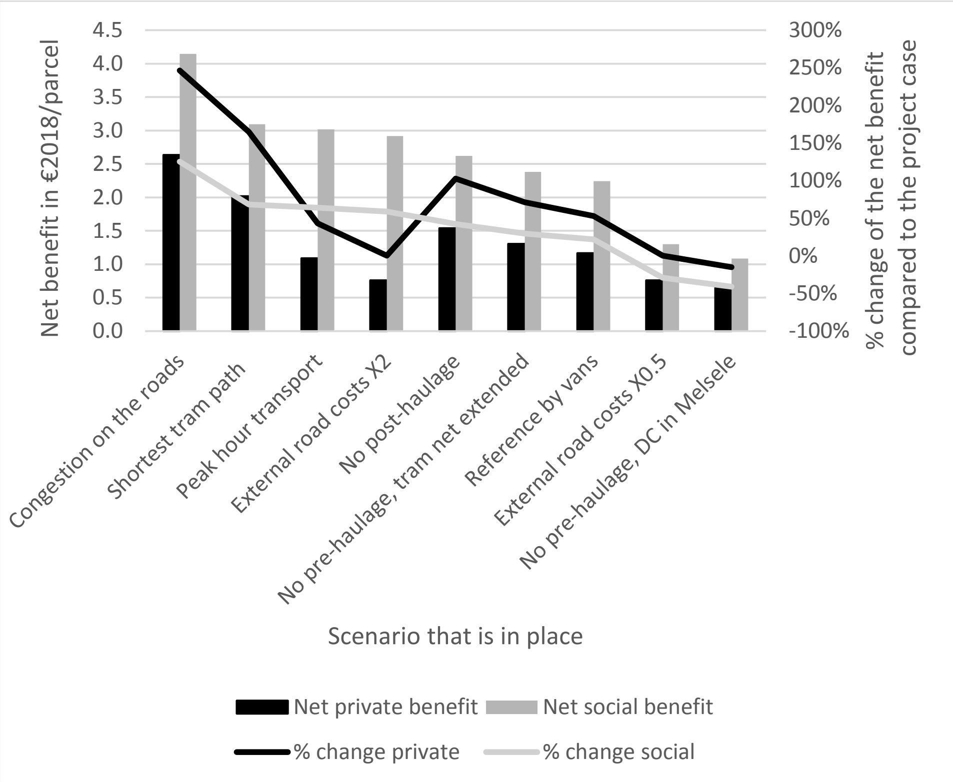


Source: Own creation

6.3.10.3 Freight alongside passengers

Ultimately, the transport of freight alongside passengers is examined. For this type of transport, the net private and social benefits are calculated. Therefore, the effect of applying a certain scenario to the transport of parcels alongside passengers is also measured in terms of the effect on the net private and social benefit. Scenarios 3, 5 and 6 cannot be applied for this type of rail transport. The tram leg cannot be unaccompanied, since it is the courier carrying the goods (scenario 3). Track access charges do not have to be paid in the project case (scenario 5), and no significant ancillary revenue can be earned (scenario 6). Therefore, scenarios 1, 2, 4, 7, 8 and 9 are investigated here. Figure 140 displays these scenarios and the resulting net benefit if the scenario is applied, as well as the change of the net benefit compared to the project case in which the scenario is not applied. The scenarios are ranked according to a decreasing net social benefit.

Figure 140 – Net benefit for different scenarios, freight alongside passengers



Source: Own creation

It is clear that the net social benefit increases if any of the scenarios is applied, except scenario 8 (external road costs are halved) and 7 (distribution centre of Torfs is located in Melsele). Concerning the net private benefit, all scenarios but scenario 7 (distribution centre in Melsele) have a positive effect. Scenario 8 does not influence the net private benefits.

6.4 Conclusion

Dealing with risk and uncertainty is an important aspect when developing a social cost-benefit framework. This chapter examines the effect of the project characteristics on the project outcome for three types of rail transport. Firstly, sensitivity analyses are carried out, focusing on the amount of goods transported, the financial and social discount rate, the capital investment, operational costs and operational income. In general, the annual operational costs of a dedicated freight tram and freight wagon are very high compared to the operational income. Especially the tram operational costs are elevated.

Secondly, based on the knowledge gathered through the sensitivity analyses, scenarios analyses are carried out. Ten scenarios are developed and evaluated. The scenarios focus on altering characteristics of the reference and/or project case. The analysis reveals that the success of the tram-based project highly depends on the project characteristics and the type of rail transport used. With respect to a dedicated freight tram, the project case cannot be made viable given the current project characteristics and the scenarios examined. However, when it is assumed that the transport in the reference case takes place by vans instead of a lorry, the NPVs become positive after applying all scenarios, and after adding another round trip. When also including the IRR in the analysis, the project is only viable when six round trips are carried out daily. Concerning the use of a freight wagon attached to a passenger tram, the project becomes viable from a socio-economic perspective after applying scenarios 4, 7, 6 and 3. When two daily round trips are executed, the project is also viable from a financial and economic perspective. The internal rate of return exceeds the discount rate from four daily round trips onwards. If the transport in the reference case takes place by vans instead of a lorry, the project is viable after implementing scenarios 7, 4 and 6. By adding multiple round trips, the NPV and IRR increase. Regarding the transport of parcels alongside passengers, applying all scenarios, except scenario 8 (halving the road external costs) and scenario 7 (the distribution centre is moved to Melsele), increases the net social benefit.

Based on the insights gathered from the sensitivity and scenario analyses, strategic levers can now be developed and applied by the project leader. Examples of strategic levers are the development of cheaper rolling stock, the elaboration on the technology for autonomous driving and the construction of longer trams and the adaptation of the tram network for these longer trams. All these strategic levers can result in lower tram operational costs, increasing the viability of the tram-based projects. Given the importance of allowing that the goods are not accompanied by a courier during the rail leg in the case study discussed in this chapter, elaborating on autonomous driving technologies seems to be a most promising avenue to make the use of rail for urban freight distribution more viable.

7. What role for rail in urban freight distribution: a conclusion

Urban freight distribution by road transport is becoming more challenging due to sustainability measures taken by authorities and growing passenger and vehicle movements on the roads. Moreover, it leads to several unwanted effects, such as air pollution and congestion. In this context, the present doctoral thesis investigates the potential role of rail in urban freight distribution from a financial, economic and socio-economic perspective. An SCBA-framework is developed, complemented by sensitivity analyses, scenario analyses and a decision framework. The framework is used to investigate three types of rail transport in Antwerp: a dedicated freight tram, a freight wagon attached to a passenger tram, and a courier transporting some parcels in a passenger tram. Based on the framework and its application, the conditions under which the use of rail for urban freight distribution becomes viable are identified.

The current chapter provides an answer to the research questions (Section 7.1). Furthermore, the transferability of the developed model to other case studies, other urban areas and other types of rail transport is explained (Section 7.2). Subsequently, the main contributions of this research and its implications to scholarly theory, policy and practice are discussed (Section 7.3). Ultimately, some interesting avenues for further research are highlighted (Section 7.4).

7.1 What did we learn?

The most important findings of this research are summarised in this section in a way that they reply to the research questions proposed in Chapter 1. Firstly, the main success and failure factors of urban rail freight are distinguished. Secondly, the potential of urban rail freight is explained from a financial and economic viewpoint and thirdly, from a socio-economic perspective. Ultimately, the main question of this research is answered, being what role for rail in urban freight distribution.

7.1.1 What are the success and failure factors of urban rail freight distribution?

The first research question relates to the main success and failure factors that are identified with respect to the use of urban rail freight distribution. Not all success and failure factors can respectively be applied to or solved in a new case, but it is mandatory to avoid using the same factors that repetitively lead to a failure of the project. Success and failure factors are derived from the literature and then evaluated based on the application of the developed social cost-benefit framework to the case study for Antwerp.

Firstly, the most important success factors based on the literature include the good environmental performance of rail transport and the presence of congestion in the urban area. Other factors that influence the success are the use of a just in time strategy, the transport of non-time-sensitive, low value commodities, the use of standard units, the presence of time gains compared to the former road-based solution, the provision of value added services, the introduction of other urban freight distribution measures, the opportunity of extra ancillary revenue, synergies by sharing a warehouse with commercial activities and the low fatality risk that is associated with rail transport.

The positive effect of the good environmental performance of rail transport, the presence of congestion to enter the urban area, the additional operational income related to ancillary revenue and the low fatality risk of rail on the project outcome are approved in the case study for Antwerp. A just in time strategy is applied in the case study, the goods transported in the case study are not very time-sensitive and do not have a very high value, and standard units are used. No time gains are present for the transport by dedicated freight tram or by freight wagon, leading to higher in-transit inventory costs and hence, no value added services. Ultimately, synergies are present in the case study in the sense that if storage is needed, existing storage space is used.

Secondly, the main failure factors emerging from the literature refer to the interference with passenger traffic, resistance from different stakeholders, the initial investment that is needed and the commitment of different stakeholders. Moreover, the involvement of politicians is crucial, as well as the amount of goods transported, the costs compared to road transport and the applied technology. The issue of interference with the passenger traffic is tackled in the case study by assuming that the transport takes place during off-peak hours. When the tram transport would shift to peak hours, this is not beneficial to the project outcome and it would be more challenging to not disturb the passenger transport.

Furthermore, it is assumed that the stakeholders involved are not resistant to the tram-based freight transport. If tram operators or local authorities are resistant to the project, some cost components, such as track access charges or investment costs of transit platforms respectively could become more expensive, potentially leading to the failure of the project. From the sensitivity analyses, it appears that the operational costs are critical for the viability of the tram-based project. When the tram operational costs decrease, the viability of the tram-based project increases. Concerning the technology used, it is assumed that the tram cannot leave the tracks and hence, road post-haulage transport is sometimes needed. It is demonstrated that the viability of the tram-based project increases when no pre- and post-haulage is needed. Ultimately, in the best-case scenario, adding more goods increases the success chances of the project.

7.1.2 What is the potential of urban rail freight from a financial and economic viewpoint?

Urban freight distribution by means of a dedicated freight tram is not viable for the considered case study, even not in the best-case scenario and when increasing the amount of goods being transported. Especially the tram operational costs are a hurdle for the tram-based project. Therefore, scenarios are developed in which the tram operational costs decrease by respectively omitting the need for a courier to accompany the goods during the tram leg, allowing the tram to take the shortest path in the urban area, and assuming that the tram does not need to pay track access charges. When adding more round trips to the best-case scenario, the tram-based solution becomes interesting for the project leader as soon as six daily round trips take place. The financial and economic NPV is positive and the IRR exceeds the financial discount rate.

The use of a freight wagon attached to a passenger tram can become viable if several conditions are fulfilled. These conditions include congestion on the road network, favourable tram operational conditions such as no need to accompany the goods and no route restrictions, additional earnings from ancillary revenue, no need for pre- and post-haulage, and a minimum daily amount of goods to be transported. If the transport in the reference case is executed by vans instead of lorries, the conditions turning the project viable are less restrictive and only include the fact that the tram can take the shortest route, the additional earnings from ancillary revenue and the elimination of the need for road pre- and post-haulage.

Transporting parcels in a passenger tram provides a net benefit when shifting from lorry to tram. Hence, it seems viable to shift from road to rail. Two remarks have to be made here. Firstly, when transporting only some parcels, it is assumed that the transport in the reference case is executed by vans instead of by lorry. Secondly, the sensitivity and scenario analyses show that the net benefit, and thus the success of this project, depends a lot on, amongst other factors, the time of the door-to-door route by tram versus the same route by van. If the tram schedule is not reliable, or the trams are delayed due to congestion, the time to enter the urban area by tram is more uncertain and could take longer.

In sum, when comparing the use of a dedicated freight tram and a freight wagon attached to a passenger tram, the freight wagon shows the most potential under the condition that relevant passenger services are operated. This higher potential is related to the lower tram operational costs, since no track access charges have to be paid and no tram driver costs have to be assigned to the goods. The transport of parcels in a passenger tram also reveals some potential, but this is only an option for small quantities of goods.

7.1.3 What is the potential of urban rail freight from a socio-economic viewpoint?

The effects on the project users are now incorporated as the change of the consumer surplus, whereas the consequences on impactees, such as inhabitants of the urban area, are reflected in the external cost savings when shifting from road to rail. The additional consumer surplus consists of the reduced inventory carrying cost because of potential time savings. For all three types of rail transport considered, the change of the consumer surplus is negative and hence, is a cost instead of a benefit. However, this is very small and hence, negligible. The external cost savings on the other hand are much higher. Thus, the external cost savings are the main element that plays a role in the socio-economic analysis.

For a dedicated freight tram, the initial project case is not viable and it remains unviable in the best-case scenario. If the tram external costs are halved and the road external costs are doubled, the SNPV does not alter a lot. The explanation for this small effect of the external cost changes on the SNPV lies here in the high absolute negative value of the ENPV. The operational costs of the initial project case are so high, that even when taking into account the external cost savings, the project does not become viable. If four daily round trips take place in the best-case scenario, the ENPV and SNPV of the tram solution are positive, with the SNPV exceeding the ENPV. In other words, the benefit for society related to the shift from road to rail is higher than the benefit for the project leader. By shifting from road to rail, the project leader creates benefits for society as a whole.

Concerning a freight wagon attached to a passenger tram, the initial project case is not viable, but the tram-based solution becomes interesting as soon as the goods do not have to be accompanied during the tram leg, the tram can follow the shortest route on the tram network, ancillary revenue is earned and no pre- and post-haulage are needed. At this stage, the ENPV is still negative, but the SNPV is positive. In other words, under these conditions, the project leader experiences a net cost, but if the effects on the project users and on the impactees are included, the project should be implemented, because it provides net benefits to society. If the project leader would not be the government, but a private stakeholder, such as a private tram operator, the government could decide to compensate the private stakeholder for its net private cost, since society as a whole wins if the project is executed. If the transport in the reference case is carried out by vans instead of lorries, and the tram can follow the shortest route and no pre- and post-haulage transport are needed, the ENPV is negative, but the SNPV is positive. For this reference case, it becomes interesting to shift from road to tram.

The transport of parcels alongside passengers provides net private benefits for the case study under consideration. When doing the same analysis from a socio-economic viewpoint, it is clear that the net social benefits are even higher. This is as for the other two types of rail transport related to the external cost savings.

7.1.4 What role for rail in urban freight distribution?

Finally, the main question of this research can be answered: what role for rail in urban freight distribution? The application of the developed model to a case study in Antwerp shows that there can be a role for rail in urban freight distribution. However, this role depends on several conditions that need to be fulfilled, which is demonstrated in the literature review by the many urban rail freight initiatives that failed or have not been put in practice. Moreover, the application of the model to a case study in Antwerp shows that several assumptions had to be made, and scenarios had to be developed to make the project viable.

The most important conditions to make the use of rail viable from an economic perspective are the following. Firstly, the availability of urban rail infrastructure and the configuration of the urban rail network is critical. If the rail vehicle cannot take the shortest path in the urban area to reach the customer, the rail operational costs become too high. Secondly, rail transport seems the most valuable for transport flows in which no road pre- and post-haulage is needed to complement the rail leg. This limits the potential of rail for urban freight flows to customers that are located at walking distance from the public urban rail network. Thirdly, in order to make the use of rail profitable from an economic viewpoint, ancillary revenue has to be earned by for example selling advertisement space on the rail vehicle. Fourthly, the rail operational costs have to be lowered by allowing the goods to be unaccompanied during the rail leg. Fifthly, a certain amount of transported goods is required to make the rail-based urban freight solution profitable. Sixthly, the presence of congestion in the urban area is an important factor, increasing the lead times by road transport and hence, the operational costs when the transport is done by road transport.

When adopting the socio-economic perspective, the conditions to make the use of rail for urban freight distribution successful are less strict. The reason is that the external costs of road and rail are now included in the analysis and that the external costs of road transport exceed the ones of rail transport. Hence, the tipping point where the use of rail becomes viable from a socio-economic perspective, is subject to less strict conditions as from an economic perspective.

In sum, in order to make rail a viable alternative for urban freight distribution, mainly conditions that are external to shippers and receivers have to be fulfilled. Firstly, in urban areas where no congestion is present, transport by rail often takes too long compared to road transport to make the use of rail for urban freight distribution viable. Secondly, other conditions can only be created if different key stakeholders cooperate. Policy makers should create a level playing field by charging all transport modes for the external costs they cause. Rail infrastructure managers should consider freight activities when extending the urban rail network and passenger services, so that rail freight vehicles or wagons can take the shortest path in the urban area. Rail operators should think of freight distribution next to passenger transport in the first place, and only in a second step focus on ancillary revenue creation. Ultimately, a certain amount of goods is needed from the shippers and receivers, preferably consisting of freight flows that do not need road pre- and post-haulage.

7.2 Transferability of the findings and the SCBA-framework

The social cost-benefit framework is in this research applied to analyse a case study in Antwerp. Hence, the main findings are based on this case study. In this section, it is explained how the findings can be generalised. Moreover, the social cost-benefit framework is developed as a generic framework that can be applied to other case studies, other urban areas and other types of rail transport as well. This section also demonstrates how the framework can be adapted to other projects.

7.2.1 Generalisation of the main findings

Although the main findings formulated in Section 7.1 come from an application of the social cost-benefit framework, most of them can be generalised towards other cases, other environments and other rail types. The reason is that the rail-based project can be reduced to a couple of characteristics of the transport flows, the urban area and the rail transport. In line with Quandt & Baumol (1966), the success or failure of rail-based urban freight distribution can be determined based on the characteristics of the concept. In other words, a certain set of combinations of characteristics is needed for a rail-based urban freight distribution concept to be viable. This set of characteristics can be present in any case study, environment and for any rail type.

The set of combinations of characteristics leading to a successful urban rail freight project is presented in Table 87. The characteristics of the case study are divided in characteristics related to the freight flows, the urban area and the rail transport. Concerning the freight flows, a certain minimum amount of goods needs to be transported by rail. The exact amount needed to operate break-even depends on the other case study characteristics. Increasing the amount of goods as such when the other project characteristics are not favourable, does not turn the project viable. Moreover, the need for road pre- and/or post-haulage leads to additional operational costs, reducing the viability of the rail-based concept. If the transport in the reference case is executed by vans, this offers more opportunities for the rail-based solution than when the transport in the reference case takes place by lorries. The reason is that the loading capacity of the rail vehicle is higher than the capacity of the vans, whereas this is not always the case for lorries.

Table 87 – Characteristics of a successful urban rail freight project

Freight flows	Urban area	Rail transport
•Certain minimum amount of goods •No pre- and post-haulage needed •Transport in reference case by vans	•Congestion on the road network •High external road costs and low external tram costs •Short rail distance	•Ancillary revenue possible •Freight wagon attached to a passenger vehicle or parcels alongside passengers •Unaccompanied rail leg if freight wagon is used

Source: Own creation

With respect to the urban area, congestion on the roads is in favour of shifting from road to rail. Due to congestion, the transport takes longer on the road network, and the external congestion costs also increase. If the external road costs become more elevated, this is in favour of the rail-based transport. Furthermore, the shorter the distance on the public rail network to be covered, the better for the operational costs of the rail leg. If restrictions are present, obliging the rail vehicle to make a detour to reach its destination, the distance to be covered by rail becomes too high compared to the distance to be covered by road.

Regarding the rail transport, it is beneficial if some ancillary revenue can be earned by selling advertisement space on the rail vehicle. The type of rail transport that is the most promising is either attaching a freight wagon to a passenger vehicle, or transporting parcels in a passenger vehicle. The use of a dedicated rail vehicle is less viable, since this type of rail transport is characterised by high operational rail costs. These costs include amongst others the labour cost of the driver of the rail vehicle and track access charges to use the public rail infrastructure. Related to this, it is in favour of rail transport if the goods in the freight wagon do not have to be accompanied by a courier, but can just be collected by a courier at the rail stops.

In sum, for case studies characterised by similar features as the ones displayed in Table 87, rail transport can play a role for urban freight distribution. In the following sections, the transferability of the developed social cost-benefit framework to another case study in the same environment (Section 7.2.2), another urban area (Section 7.2.3) and another type of rail transport (Section 7.2.4) is discussed.

7.2.2 Transferability to another case study in Antwerp

In order to apply the developed model to another case study in the same environment, being the urban area of Antwerp, only a few data have to be collected. Table 88 shows which data are needed to investigate the role of rail transport for another case study in Antwerp. In other words, this table shows the cost of adapting the model to another case study. The data needed concern first of all some characteristics of the transport in the reference case. In other words, some features of the current transport by road have to be indicated. These features include the distances to be covered and the time needed to cover the distances, the timing of the transport, the freight type carried, the location of the customers to be supplied, the weight of the goods delivered per customer and some vehicle characteristics, such as the fuel type, the euro standard, the gross tonnage and whether the vehicle is rigid or articulated. In other words, the developed model can be applied to evaluate the potential of rail for the distribution of different freight types. The type of freight to be transported affects several characteristics of the reference and project case, and thus, the costs and benefits of using rail instead of road. Transferring construction materials from a pre-haulage lorry to a rail vehicle for instance, requires more handling equipment than transferring some roll cages.

Moreover, some decisions with respect to the project case have to be made. Concerning handling and storage, it has to be decided which handling and storage point is chosen where the goods are loaded on and unloaded from the rail vehicle and whether storage takes place at these points. Furthermore, it has to be indicated whether road pre-haulage is needed and if so, the distance to be covered. The same is valid for the road post-haulage leg, with the additional choice how the post-haulage transport takes place. A shop employee can pick up the goods at the rail stop, a courier can deliver the goods at the shop by walking, or a cargo bike or LGV service can be used. Ultimately, with respect to the rail leg it has to be indicated whether a siding to the existing rail infrastructure has to be constructed, what rail type is chosen, whether advertisement space is sold and what type of rolling stock is invested in.

By collecting the data summed up in Table 88, the social cost-benefit framework can immediately be applied to another case study in Antwerp. In other words, the developed model is generic. In the following section, it is explained how the framework can also be applied to another case study environment.

Table 88 – Input data needed to apply the social cost-benefit framework to another case study in Antwerp

Case	Leg	To be provided
Reference case	Road	Distance between DC and customer n-1, customer n-1 and customer n, customer n and DC on motorways, in urban areas and in suburban areas Time to cover the mentioned distance, or average speed Timing of the transport: night, off-peak, peak hour Freight type: cooled food, frozen food, non-cooled food, non-food Location of the customers (to know the rent prices of the shop) Weight of goods delivered per customer Fuel type of the vehicle used (diesel/petrol) Euro standard of the vehicle used (0-6) Gross tonnage of the vehicle used Rigid or articulated vehicle used
Project case	Handling and storage	Which handling and storage point is chosen at the edge of the urban area, and does it serve as a transit platform or distribution centre Which rail stop is chosen to supply each customer, and does it serve as a transit platform or distribution centre
	Pre-haulage	Pre-haulage needed? If yes, how many kilometres on motorways and in suburban areas
	Post-haulage	Post-haulage needed? If yes, how is it executed per customer (employee, courier, cargo bike, LGV) If LGV: euro standard and fuel type (diesel, electric, petrol)
	Rail	Are sidings to the existing rail infrastructure needed? Type of rail transport: dedicated vehicle, freight wagon, parcels alongside passengers Is advertisement space sold? Type of rolling stock used

Source: Own creation

7.2.3 Transferability to other urban areas

Besides using the developed framework for another case study in Antwerp, the objective is to transfer the rail-based concept to another environment. In order to apply the developed tool to another urban area within Belgium, the following additional data have to be collected:

- the distances to be covered on the rail network;
- the involvement of the relevant stakeholders;
- the location and number of customers;
- the locations for handling and storage points;
- the real estate price;
- the storage policy of the customers;
- the type of road and rail vehicles used;
- the urban freight distribution measures;
- the way the customers are currently supplied.

In order to apply the tool in an urban area outside Belgium, labour cost and external cost figures have to be adapted for the country in which the urban area is located. The next section devotes some attention to the transferability of the framework to other rail types.

7.2.4 Transferability to other rail types

In the case study under consideration, the social cost-benefit framework is applied for the use of tram transport in Antwerp. As pointed out in this research, the model is also valid for the use of trains. However, some adaptations to the model still have to be made due to some crucial differences between tram and train transport. The main differences concern the connection to the rail infrastructure, the challenges to find loading and unloading locations, and the potential to use the idle time of the locomotives and the train drivers.

Next to these differences, some additional data have to be collected to apply the developed framework to light rail. These data include the external costs of trains, the cost of train rolling stock, the cost of train line infrastructure, and the operational costs of a train. Moreover, when applying the framework to for instance underground freight transport, the additional costs related to the transfer of the goods to the ground level need to be added to the calculations.

7.3 Contributions and implications

This research contributes to the existing body of knowledge in several ways. Firstly, the existing scholarly theory is extended. Secondly, contributions to and implications for policy makers are present. Thirdly, the research adds valuable knowledge for practitioners.

7.3.1 Scholarly theory

There are two important areas where this research makes an original contribution to. Firstly, the key strength of the present research is the development of a generic social cost-benefit framework that serves as a tool which can easily be applied to different cases. A unique characteristic of this research is the fact that the social cost-benefit framework is developed for an urban rail freight context. Existing cost-benefit models focus either on rail transport, or on the urban context, but the combination of these two in one model is innovative. Moreover, the model fits in recent open network paradigms such as Crowd Logistics, Freight as a Service and Physical Internet, which have as a common characteristic the objective of cost reduction and resource sharing. By making use of the existing public rail network, and for the use of a freight wagon and the transport of freight alongside passengers also of existing public transport trips, existing urban transport resources are utilised more efficiently and logistics costs can be reduced.

Secondly, the viewpoint of the framework is the one of the project leader, which is in this research the government. This is novel compared to existing case studies on using rail for urban freight distribution, in which the viewpoint is always the rail operator or the retailer. By adopting the viewpoint of the government, both the private and external costs of the rail-based urban freight solution are taken into account for the rail leg, the road pre- and post-haulage leg and handling and storage.

7.3.2 Policy

The development of the social cost-benefit framework from the perspective of the government provides a tool for policy makers through which they can determine which urban rail freight projects are beneficial to the society. The tool provides policy makers the boundaries for an adapted policy towards for example subsidies. In other words, authorities can decide on compensating private stakeholders for their potential loss when shifting from road to rail if this is favourable for the society as a whole. The results of the developed framework show the socio-economic net benefit and the financial and economic net benefit. The net socio-economic benefit of a certain urban rail freight project could be used by authorities to compensate private stakeholders for their potential net economic cost.

Moreover, authorities can use the insights from the current research in their sustainable urban logistics plans (SULPs). The main findings show that shifting from road to rail is under certain conditions beneficial for society. Policy makers are in the position to create part of the beneficial conditions for rail transport. For example, one of the findings shows that the operational costs of the tram leg become too high compared to the costs of road transport if the tram needs to make a long detour. Authorities could foresee loading and unloading spaces in the urban area where trams can be unloaded. This could reduce the distance to be covered. Moreover, policy makers could create a level playing field by making all transport modes pay for the externalities they cause. Given the higher external costs caused by road transport compared to rail transport, this decision would increase the private cost of road transport relatively more than the one of rail transport. As a result, the usage of rail for urban freight distribution becomes more attractive.

7.3.3 Practice

Some of the insights provided in this research are particularly valuable for specific stakeholders. Firstly, rail operators can be assisted in understanding how they can extend the scope of their activities. Idle time of rolling stock or drivers could be used to supply retailers in the urban area. Hence, economies of scope could be obtained. Secondly, rail infrastructure managers can learn how the configuration of their rail network can be valuable for freight transport as well. This is something they have to keep in mind when extending the existing rail infrastructure. Thirdly, the findings of the social cost-benefit framework help suppliers and retailers to understand under which conditions shifting from road to rail can become interesting for them.

7.4 Suggestions for further research

Several interesting avenues for further research exist. Firstly, a natural progression of this work is to further extend the social cost-benefit framework by applying the framework to light rail, and by investigating the demand for potential rail transport in an urban context. In order to capture the potential demand, stated preference techniques such as discrete choice models, can be applied. Conducting a freight demand analysis is amongst others recommended by Nuzzolo et al. (2007). This is not examined in the current research, since before asking potential users about their willingness-to-pay for a certain project, the project has to be made clear. The latter is done in the current research. Hence, the willingness-to-pay of project users can now be investigated. Next to the generalised cost used as a proxy of the willingness-to-pay, other factors can affect the amount users want to pay for making use of rail instead of road. An example is the risk that the rail traffic is disturbed compared to the risk that the road traffic is disturbed. Other possible extensions comprise the transport of waste away from the urban area.

Secondly, further research in this field would be of great help in elaborating on how goods can be unloaded, and possibly also loaded, from a freight wagon within 30 seconds. In the current research, it is assumed that such a technology exists, but research is still needed to fully understand whether this is technically possible, or what has to be changed to make it technically possible. The current research shows that transporting goods in a freight wagon attached to a passenger tram is the most promising way of using the tram. This finding can serve as a valuable rationale why technical research on developing such an unloading technology could be ground-breaking.

Thirdly, studies regarding the optimisation of certain variables used in the current social cost-benefit framework would be worthwile. Examples of variables that can be optimised are the location of the handling and storage point and the route covered by the tram if multiple customers have to be served in the urban area. At the moment, certain tram routes are chosen in order to supply the customers from a given handling and storage point. However, optimisation tools could assist in determining which customer should optimally be supplied first.

Ultimately, further research should focus on including future trends such as automation, autonomous vehicles, digitalisation, modular transport and innovative standard freight units. These future trends can strongly advance the introduction of rail transport for urban freight distribution.

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Appendices

Appendix 1 : Different terms for delivering goods in urban areas using rail transport

Term	Authors	Scope of the expression
City logistics	Kortschak (1995)	Tram for distribution within the city centre
	Dorner (2001)	Tram/train to and within the city centre
	Taniguchi et al. (2001b)	Underground rail, scope not specified
	Genta et al. (2006)	Tram for distribution within the city centre
	Mortimer (2008)	Tram for distribution within the city centre
	Maes & Vanelslander (2011)	Train from outside the city to the city centre
	Delaître & De Barbeyrac (2012)	Train from outside the city to the city centre
	Kikuta et al. (2012)	Subway between suburb and centre
	Arvidsson & Browne (2013)	Tram from outside the city to the city centre
	Regué & Bristow (2013)	Tram for distribution within the city centre
	Diziain et al. (2014)	Train and tram to and within urban areas
	Filippi & Campagna (2014)	Train from outside the city to the city centre
	Gorçun (2014)	Light rail, train, tram, underground rail to and within the city centre
	Macário (2014)	Light rail, train, tram, underground rail to and within the city centre
	Cleophas et al. (2018)	Train and tram to and within urban areas
	Ozturk & Patrick (2018)	Train and tram to and within urban areas
Urban logistic(s)	Ebrardt (2001)	Train from outside the city to the city centre
	Maes & Vanelslander (2011)	Train from outside the city to the city centre
	Regué & Bristow (2013)	Tram for distribution within the city centre
	Diziain et al. (2014)	Train and tram to and within urban areas
	Gonzalez-Feliu (2014, 2016)	Train from outside the city to the city centre
	Gorçun (2014)	Light rail, train, tram, underground rail to and within the city centre
	Macário (2014)	Light rail, train, tram, underground rail to and within the city centre
	Strale (2014)	Tram transport, scope not specified
	Cleophas et al. (2018)	Train and tram to and within urban areas
	Ozturk & Patrick (2018)	Train and tram to and within urban areas
City distribution	Dorner (2001)	Tram/train to and within the city centre
	WSP (2008)	Tram, scope not specified
	Maes & Vanelslander (2011)	Train from outside the city to the city centre
Urban distribution	Dorner (2001)	Tram/train to and within the city centre
	Dinwoodie (2006)	Train from outside the city to the city centre
	Maes & Vanelslander (2011)	Train from outside the city to the city centre
(Urban) freight distribution	Dinwoodie (2006)	Train from outside the city to the city centre
	Genta et al. (2006)	Tram within the city centre
	Nuzzolo et al. (2007)	Train from outside the city to the city centre
	Arvidsson (2010)	Tram/train to and within the city centre
	Alessandrini et al. (2012)	Train from outside the city to the city centre
	Arvidsson & Browne (2013)	Tram from outside the city to the city centre
	Filippi & Campagna (2014)	Train from outside the city to the city centre
	Macário (2014)	Light rail, train, tram, underground rail to and within the city centre

Term	Authors	Scope of the expression
	Nuzzolo & Comi (2014)	Tram within the city centre
	Woodburn (2014)	Light rail, train, tram, underground rail to and within the city centre
Urban goods distribution	Regué & Bristow (2013)	Tram for distribution within the city centre
	Strale (2014)	Tram transport, scope not specified
	Behiri et al. (2018)	Train, tram and underground rail to and within urban areas
Urban (freight) transport(ation)	Dorner (2001)	Tram/train to and within the city centre
	Ruesch (2001)	Train from outside the city to the city centre
	Arvidsson (2010)	Tram/train to and within the city centre
	Issenman et al. (2010)	Train, tram and underground rail to and within urban areas
	Behrends (2012a)	Train from outside the city to the city centre
	Diziain et al. (2014)	Train and tram to and within urban areas
	Filippi & Campagna (2014)	Train from outside the city to the city centre
	Gorçun (2014)	Light rail, train, tram, underground rail to and within the city centre
	Stale (2014)	Tram transport, scope not specified
	Woodburn (2014)	Light rail, train, tram, underground rail to and within the city centre
	Behiri et al. (2018)	Train, tram and underground rail to and within urban areas
	Cleophas et al. (2018)	Train and tram to and within urban areas
	Ozturk & Patrick (2018)	Train and tram to and within urban areas
Urban (goods) transport	Strale (2014)	Tram transport, scope not specified
	Behiri et al. (2018)	Train, tram and underground rail to and within urban areas
(Urban) freight movement	Sivakumaran et al. (2010)	Train between airport and transfer terminals
	Marinov et al. (2013)	Train and tram to and within urban areas
	Cleophas et al. (2018)	Train and tram to and within urban areas
(Urban) goods movement	Sivakumaran et al. (2010)	Train between airport and transfer terminals
	Cochrane et al. (2017)	Train from outside the city to the city centre
	Ozturk & Patrick (2018)	Train and tram to and within urban areas
No specific term	Bous (2001)	Underground rail, within the city centre
	Foyer (2001)	Rail type and scope not specified
	Taniguchi et al. (2001a)	Underground rail, in the city
	Robinson & Mortimer (2004a)	Train, tram and underground rail to and within urban areas

Source: Own creation

Appendix 2: Terms to describe urban areas

Author(s) (year)	City	City-region	Metropolitan area	Metropolitan centre	Metropolis	Town	Urban area	Urban centre	Urbanised area	Urban place	Urban space	Urban zone
Clark (1982)	X			X	X	X						
Krugman (1993)	X			X	X			X				
Kortschak (1995)	X						X					
Rien & Roggenkamp (1995)	X						X					
Dorner (2001)	X											
Robinson & Mortimer (2004a)	X			X			X					
Parr (2005)		X										
Tsai (2005)	X		X	X								
Dinwoodie (2006)	X						X					
Genta et al. (2006)	X						X					
Nuzzolo et al. (2007)			X				X	X				
Parr (2007)	X		X			X	X		X			
Mortimer (2008)	X						X					X
Cladera et al. (2009)			X		X							
Arvidsson (2010)	X		X				X					
Dessemontet et al. (2010)	X		X				X					
Issenman et al. (2010)	X											
Pflieger & Rozenblat (2010)	X				X						X	
Maes & Vanelslander (2011)	X											
Alessandrini et al. (2012)	X						X					
Allen et al. (2012)	X					X	X					
Kikuta et al. (2012)	X						X					
Arvidsson & Browne (2013)	X						X					
Hesse (2013)	X					X				X		
Regué & Bristow (2013)	X						X					
Diziain et al. (2014)	X		X				X					
Filippi & Campagna (2014)	X						X					
Gonzalez-Feliu (2014, 2016)	X		X									
Gorçun (2014)	X		X			X						
Macário (2014)	X						X					
Nuzzolo & Comi (2014)			X				X					
Strale (2014)	X						X					
Woodburn (2014)							X					
Zych (2014)	X						X					
Cochrane et al. (2017)	X						X					
Behiri et al. (2018)	X		X				X					
Cleophas et al. (2018)	X						X					
Ozturk & Patrick (2018)	X		X				X					

Source: Own creation

Appendix 3 : Overview discount rates in transport projects

Year	Discount rate	Project	Area	Source
1988	5% real rate	Extension Brussels metro network	Brussels	Blauwens (1988)
2006	4% (instead of 8% before)	Transport	France	International Transport Forum (2011)
2008	4.2% real rate	Belgian infrastructure projects	Belgium	Verbruggen (2008)
	6%-10% marginal rate of return on private-sector investment, used as real discount rate	Urban railway development projects	US, New Zealand, Canada, Hong Kong, Republic of Korea	Gwee et al. (2008)
	3.5% social discount rate	Evaluation periods of 0-30 years, urban railway development projects	UK	
	3.0%	Evaluation periods of 31-75 years, urban railway development projects		
	2.5%	Evaluation periods of >75 years, urban railway development projects		
	4% real rate	Government's borrowing rate in Australia, urban railway development projects	Australia	
2010	5%	High-speed rail network	Spain	Campos & Hernández (2010)
2011	3%-6%	Transport	UK, France	International Transport Forum (2011)
2012	4%-6%	Urban logistics intermodal terminals	n.a.	Raicu et al. (2012)
2013	4% real discount rate, sensitivity analysis between 2.5% and 5.5%	Transport infrastructure	Belgium	Rebel (2013)
	3.5%	Freight Tram	Barcelona	Regué & Bristow (2013)
2014	4.5%, sensitivity analysis between 3% and 6%	Longer and heavier vehicles	Spain	Ortega et al. (2014)
2015	4% real rate	Transport infrastructure projects	EU	Sartori et al. (2015)
	3.375% nominal rate	Federal water resource projects	USA	Vadali et al. (2017)
2016	4% real rate	General SCBA	Average of different countries	Blauwens et al. (2016)
	4%	Urban freight tramway	France	Gonzalez-Feliu (2016)
2017	4% real rate	Cargo bikes	Belgium	Maes (2017)
n.a.	3% real rate, 5% nominal rate	Pipeline projects	USA	Vadali et al. (2017)

Source: Own creation

Appendix 4 : Overview social discount rates in different countries

Country	Author (year)	Subject	Basis	Constant rate	Declining real rate	r_f (real)	r_e (real)
Belgium	Federaal Planbureau (2017)	Energy	/	4-5%	/	/	/
EU (cohesion countries[33])	Sartori et al. (2015)	Investment project	/	5%	/	/	/
EU (other countries)	Sartori et al. (2015)	Investment project	/	3%	/	/	/
France	Limon & Crozet (2017)	High speed rail	Robien	/	Until 2014: 4% (0-30y); 3.5% (31-50y); 3% (>50y); B = 2	Until 2014: 1%	Until 2014: 1.5%
	Limon & Crozet (2017), Ni (2017)	Public investment projects	Quinet (2013)	/	From 2014: 4.5% or 2.5%+β*2%; β for freight is 1.4	From 2014: 2.5% (0-60y); gradually declining to 1.5% (>60y)	From 2014: 2% (0-60y); 3% (>60y)
Germany	Goldman (2017)	Rail freight infrastructure	Weitzman (2012)	/	3.5% -> 2.7% over 50 years	1.3%	5%
	Limon & Crozet (2017)	High speed rail	Quinet (2013)	3%	/	/	/
the Netherlands	Limon & Crozet (2017)	High speed rail	Quinet (2013)	4%	/	/	/
Sweden	Hultkrantz et al. (2014)	Rail freight project (theoretical)	Weitzman (2012)	/	6.2%, declining until 5.5% after 60 years		
	Limon & Crozet (2017)	High speed rail	Quinet (2013)	3.5%	/	/	/
US	Ni (2017)	Public investment projects	/	3% (low) and 7% (high)	/	/	/
UK	HM Treasury (2018) (Green book)	Public investment projects	Ramsey (1928), Freeman et al. (2018)	/	Since 2003: 3.5% (0-30y); 3.0% (31-75y); 2.5% (76-125y); 2.0% (126-200y); 1.5% (201-300y); 1.0 % (>300 y)	/	/

Source: Own creation

[33] The cohesion countries are Greece, Ireland, Portugal and Spain.

Appendix 5: Overview presentations during the expert meeting

Presenter(s)	Topic	Discussant, company
De Langhe (2014)	Designing a research strategy for assessing the role of rail in urban freight distribution	Mr. Marc Goossenaerts, Bpost
Gonzalez-Feliu (2014)	Costs and benefits of railway urban logistics: a prospective social cost-benefit analysis	Dr. Roel Gevaers, University of Antwerp
Filippi & Campagna (2014)	Making urban logistics in big cities more sustainable: a rail transport solution for Rome	Ms. Marina Knegtel, Carrefour
Woodburn (2014)	The role of rail in urban freight distribution: lessons from the British Experience	Ms. Marleen Verheyen, Infrabel
Nuzzolo & Comi (2014)	Modelling the demand for rail in an urban context: some methodological aspects	Dr. Jack Doomernik, Lloyd's Register
Macário (2014)	Changing public policy to enhance the role of railways in urban logistics	Mr. Marc Nuytemans, De Lijn

Source: Own creation

Appendix 6: Overview interviews

Date	Company	Function	Topic
21 November 2013	Infrabel	Engineer Project leader	Working of Infrabel and potential of urban rail freight
24 June 2014	Waasland Shopping Centre Sint-Niklaas	Facility manager	Delivery profile shopping centre
9 September 2014	De Lijn	Mobility developer Policy manager	Capacity Antwerp tram network
11 September 2014	Grand Bazar Shopping Centre Antwerp	Shopping centre manager Facility manager	Delivery profile shopping centre
3 July 2015	City of Antwerp	Consultant technics	Potential use of freight tram by the City
24 August 2015	City of Antwerp Hogeschool Amsterdam	Consultant technics Lector City logistics	CityCargo Amsterdam, potential of a freight tram for Antwerp
10 February 2016	B Logistics[34]	Intermodal transportation and inland terminals director Business developer modal shift	Potential of urban rail freight
4 April 2016	VITO	Senior researcher in transport and environmental economics	External costs
3 April 2017	Bombardier	Head of projects and product flexity 2 light rail vehicles	Data and view of Bombardier on potential of urban rail freight
10 May 2017	Bombardier	Executive director	Data and view of Bombardier on potential of urban rail freight
15 May 2017	Lineas	Business developer modal shift	Feedback on SCBA model
7 January 2019	De Lijn Kernteam Antwerpse Mobiliteit	Head of strategy Mobility developer Coordinator public transport processes	Feedback on SCBA model
9 January 2019	Torfs	Warehouse manager	Case study Torfs

Source: Own creation

[34] Lineas is the new name of the former rail freight operator B Logistics and this name is in use since 27 April 2017.

Appendix 7 : Comparison between Antwerp and Lyon

The figures used in this research that are based on Ayadi (2014) are derived for urban freight distribution in Lyon in France. This Appendix explains why it can be assumed that the conditions in which the figures are derived in Lyon are similar to the conditions in Antwerp and hence, why the figures can be applied in this research.

Appendix 7.1: Speed on the road network

In order to know whether the average speed values in the region of Lyon can also be applied to the region of Antwerp in Belgium, two elements have to be compared: the maximum speed allowed at the roads in Lyon and in Antwerp and the congestion level in both cities. In Table 89, the additional travel times in Lyon and Antwerp compared to a free flow situation are displayed. The average additional travel time in Lyon amounts to 29%, whereas this is 31% for Antwerp. These two figures are very close to each other. The other, more detailed, additional travel times are also close to each other for Lyon and Antwerp, with a maximum difference of 9% during the morning peak hour and on highways.

Table 89 – Additional travel times in Lyon and Antwerp compared to a free flow situation, valid for 2018

Timing/area	Antwerp	Lyon
On average	31%	29%
During the morning peak	54%	63%
During the evening peak	61%	59%
On highways	32%	23%
On non-highways	30%	33%
Peak hour, morning, time per 30 min trip	16 min	19 min
Peak hour, evening, time per 30 min trip	18 min	18 min

Source: Own creation based on TomTom (2019)

The maximum allowed speed in Lyon and in Antwerp under normal weather conditions is shown in Table 90. In built-up areas, the maximum speed is both in Antwerp and in Lyon equal to 50 km/h. On public roads outside the built-up areas, there is a difference of 20 km/h, since the maximum speed in Flanders was reduced from 90 km/h to 70 km/h on 1 January 2017 (Vlaamse Overheid, 2019a), where this is 90 km/h in France. In Flanders, the maximum speed on public roads with at least four lanes, of which at least two per direction, equals 120 km/h if the road is separated by something else besides road marks. The same speed is allowed on motorways. In France, a distinction is made between these two types of road, leading to a maximum speed of 110 km/h for the first type and a maximum of 130 km/h for the second type. As a result, it can be assumed that the average speed of lorries in Flanders is similar to the one in France for traffic in the urban area, but the average speed for regional traffic outside the city will be slightly lower due to the maximum speed on the public roads outside the built-up area.

Table 90 – Maximum speed per road type for Antwerp and Lyon under normal weather conditions

Road type	Antwerp	Lyon
Built-up area	50 km/h	50 km/h
Public road outside the built-up area	70 km/h	90 km/h
Public roads with ≥4 lanes (≥2 per direction) if separated by more than road marks	120 km/h	110 km/h
Motorways	120 km/h	130 km/h

Source: Own creation based on fgov (1975) for Antwerp and Ministère de l’intérieur (2017) for Lyon

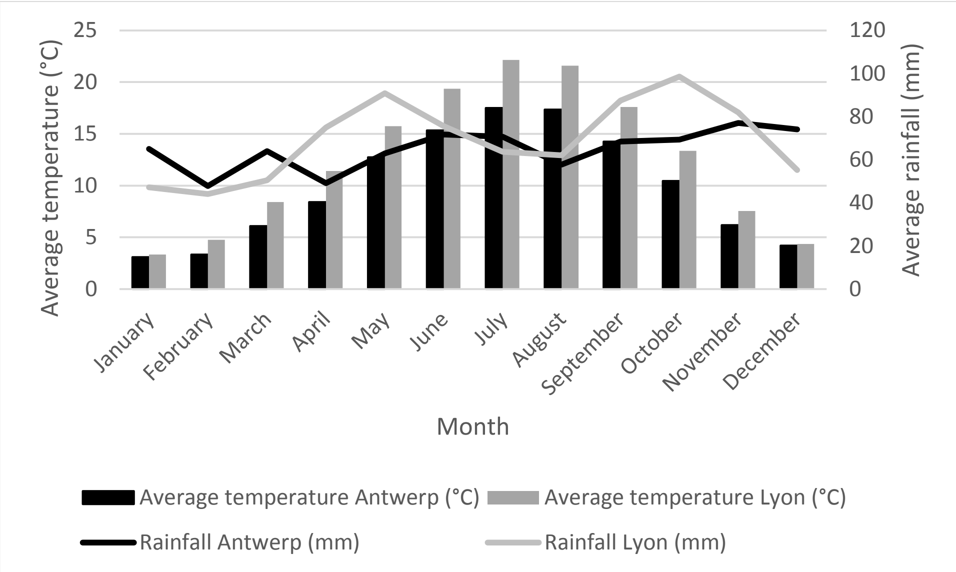
Appendix 7.2: Operational costs in distribution centres

Ayadi (2014) provides operational costs for storing goods in distribution centres in the Lyon region. Labour and heating and cooling are part of these operational costs. Therefore, it is important to consider the labour and weather conditions in which these costs are derived before applying these figures to Antwerp.

Firstly, the hourly labour cost of Belgium was in 2017 equal to €39.6, whereas the one of France was equal to €36.0. Hence, the labour costs in Belgium are a bit higher than in France (Eurostat, 2018). This means that the part of the operational costs of a distribution centre that is related to labour costs is a bit higher in Belgium than the figures for France.

Secondly, the heating and cooling costs are compared. Figure 141 shows the average temperature in Antwerp (black bar) and the one in Lyon (grey bar). When comparing these average temperatures, it is clear that the average temperature is a bit higher in Lyon than in Antwerp. In order to obtain the average temperature, the minimum and maximum temperatures are combined, since heating and cooling of warehouses is done during the day and during the night.

Figure 141 – Climatogram of Antwerp and Lyon



Source: Own creation based on Météo France (2017)

The average year temperature in Lyon equals 12°C, whereas the one in Antwerp is equal to 10°C. Heating in this research is taken into account to the extent that the average temperature in the warehouses is equal to 5°C. As displayed in Figure 141, the average temperature in Antwerp and Lyon is only below 5°C in the months of January, February and December. In these months, the average temperature in these two cities is not very different. Table 91 displays the minimum and maximum temperatures for Antwerp and Lyon for the months of December, January and February. It is clear that all maximum temperatures are above 5°C on average, so at these temperatures, it can be assumed that no heating is needed. Concerning the minimum temperatures, the only difference is in the month of February, where the average minimum temperature of Antwerp is 0°C, while this is 1.1°C in Lyon. This means that only for one month a year and only during the night, more heating is needed on average in Antwerp compared to Lyon to maintain an average temperature of 5°C in the warehouses.

Table 91 – Minimum and maximum temperatures in Antwerp and Lyon for some months expressed in °C

Month	Antwerp		Lyon	
	Min. temperature	Max. temperature	Min. temperature	Max. temperature
December	1.6	6.8	1.6	7.1
January	0.3	5.9	0.3	6.4
February	0.0	6.7	1.1	8.4

Source: Own creation based on Météo France (2017)

On the other hand, cooling is needed for cooled and frozen retail products. The average year temperature of Lyon lies 2°C above the one of Antwerp. Hence, it can be assumed that on average more cooling is needed in Lyon than in Antwerp to keep cooled and frozen goods at the correct temperature.

Combining the higher labour and heating cost in Antwerp and the higher cooling cost in Lyon, it is assumed that the operational costs provided by Ayadi (2014) for the Lyon area, can be applied to Antwerp. The effect of a change of these costs is tested in Chapter 6 by sensitivity analyses.

Appendix 8: Electricity production in Belgium

Concerning the emissions of logistics buildings, the electricity production of the country in which the logistics building is located is relevant. It has to be examined how the electricity in the specific country is generated. The emissions of using electricity are derived by the mix of energy sources used by a certain country (Ayadi, 2014).

In general, the minimum and maximum emission factors of different energy sources are displayed in Table 92. The emission factors displayed in this table include the emissions during all production stages, such as the extraction of the source, the final storage of potential waste, the construction, operation and deconstruction of installations. The forks of the minimum and maximum values are often very large. The reason for this is that the figures take into account a large range of possible technologies, including old ones that are still used, and new developed ones. However, this makes it difficult to choose one specific value. Ayadi (2014) uses in his research a figure of 90 g CO_2 per kWh for France. This figure does not take into account energy losses due to the transport of the current between the electricity central and the retailer. In general, retailers use electricity on middle and high tension. This has a result that the losses do not exceed 3%. In other words, if the retailer consumes 1 kWh, 1.03 kWh was sent by the electricity central to the retailer. Hence, the daily emissions of a logistic building equal the product of the daily electricity consumption per square metre, the loss coefficient which is equal to 1.03 and the emissions for production of one kWh in the country under observation.

Table 92 – Emission factors of different energy sources (for 2012)

Energy source	Minimum g CO_2/kWh	Maximum g CO_2/kWh
Coal	754	1124
Oil	545	900
Gas	388	688
Solar energy	13	280
Hydraulic energy	4	90
Wind turbine	9	48
Nuclear	3	40

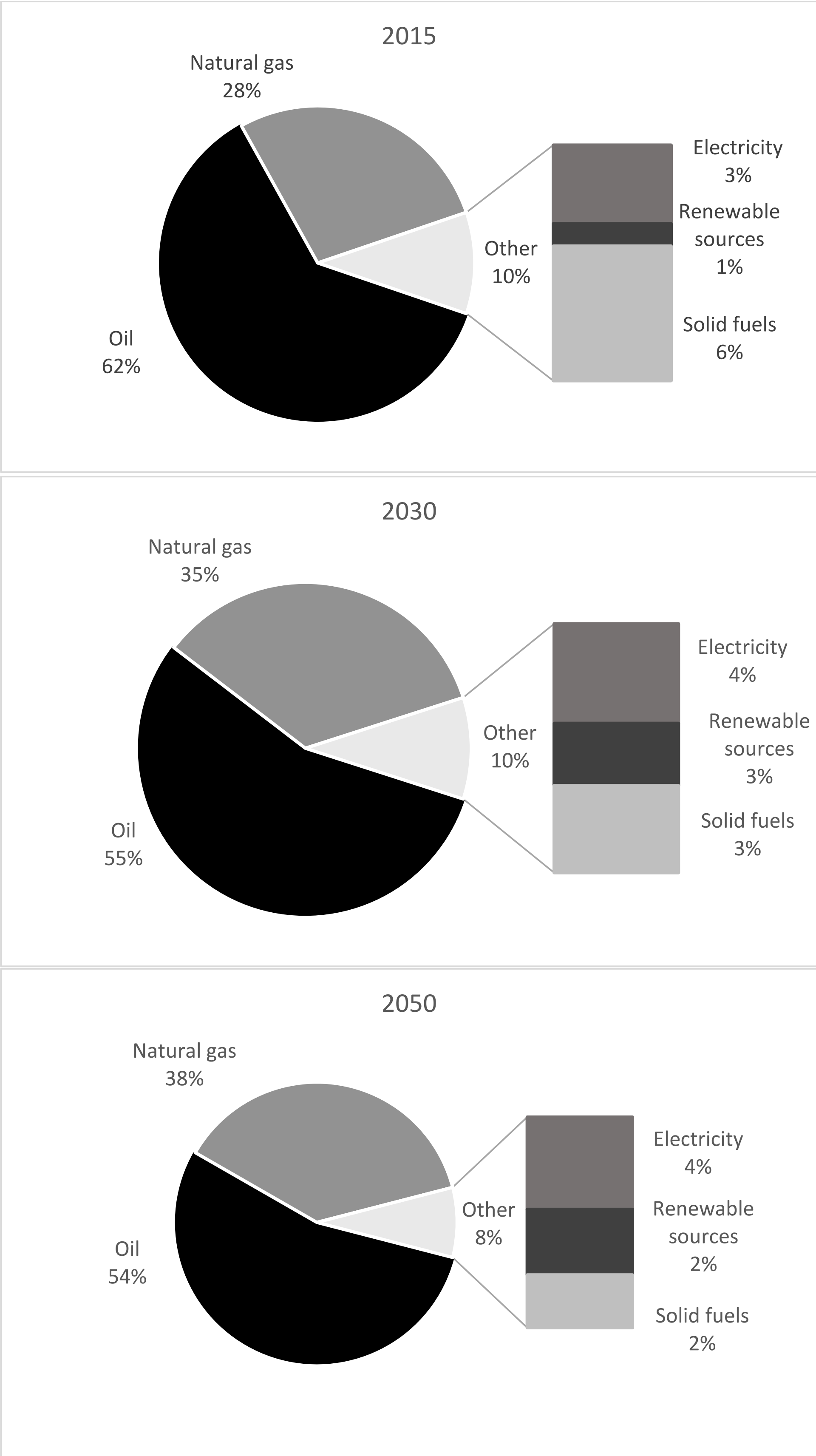
Source: Ayadi (2014)

Gusbin & Devogelaer (2017) provide an overview of the net energy import of Belgium. The net import equals all import of energy minus all export of energy. In 2015, Belgium was for 84% dependent on imported energy, whereas it is assumed this will reach 91% by 2030 and will then decrease again to 88% by 2050. The net imported energy mix of Belgium is displayed for 2015, 2030 and 2050 in Figure 142. The main observation is the decrease of oil as energy source and the increase of natural gas. The use of renewable sources triples by 2030, but is expected to experience a decrease of 1% by 2050 again. The use of solid fuels, mainly coals[35], is halved by 2030 and is reduced to two-thirds by 2050. Electricity is for a large part imported. Between 2020 and 2030 this will even increase, due to the phase-out of nuclear energy[36]. By 2050, renewable energy will produce 47% of the electricity production, whereas the remaining 53% will be produced by natural gas. In 2015, the electricity sector emitted 194 tonnes CO_2 per GWh, by 2030 this increases to 198 ton CO_2, while this will be reduced to 165 tonnes by 2050.

[35] The last coal central in Belgium was closed in 2016 (Gusbin & Devogelaer, 2017).

[36] The nuclear reactor of Doel 1 will stop producing energy on 15 February 2025, the one of Doel 2 on 1 December 2025. In total, Belgium possesses two nuclear plants, being Doel and Tihange, consisting of in total seven nuclear reactors (Gusbin & Devogelaer, 2017).

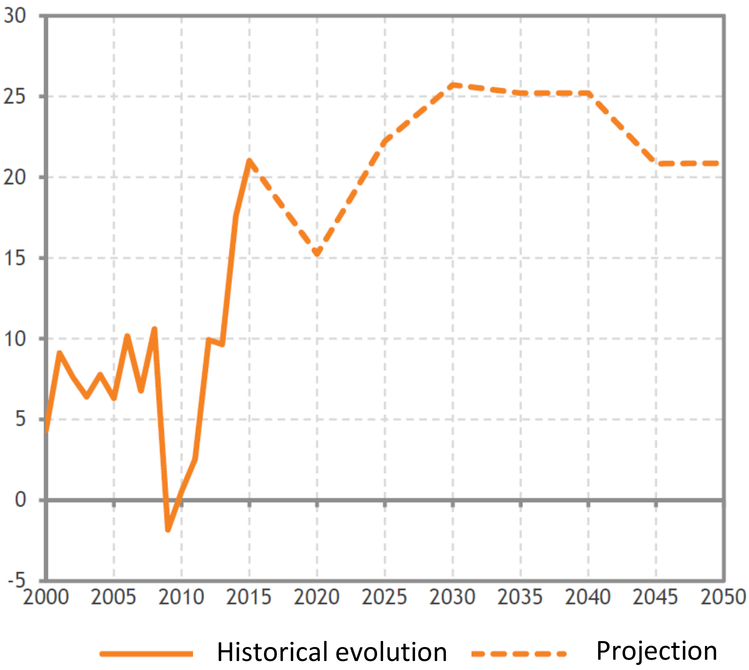
Figure 142 – Net imported energy mix of Belgium for 2015, 2030 and 2050



Source: Own creation based on Gusbin & Devogelaer (2017)

Specifically electricity is interesting to discuss a bit more in detail in this research. Figure 143 shows the evolution of the net electricity import in Belgium between 2000 and 2050. Between 2000 and 2015, the evolution is based on historical data, between 2016 and 2050, the evolution is forecasted using the PRIMES model. Until 2020, cross-border flows depend on net transfer capacity, whereas from 2020 on it is assumed that electricity transmission in Europe will evolve as if there is only one central transmission net provider. The strong increase of net electricity import in 2012-2015 can be explained by the temporary unavailability of the nuclear plant of Doel (reactor D3) and Tihange (reactor T2) and the closing of reactor D1 in Doel due to a Belgian law on reducing nuclear energy generation. However, in 2016, this law was revisited, leading to the restarting of these three reactors. As a result, the net import was decreasing from 2016 on. The strong increase between 2020 and 2030 can be explained by the fact that the generation of nuclear energy will be reduced in Belgium and should be zero by 2025 (Gusbin & Devogelaer, 2017).

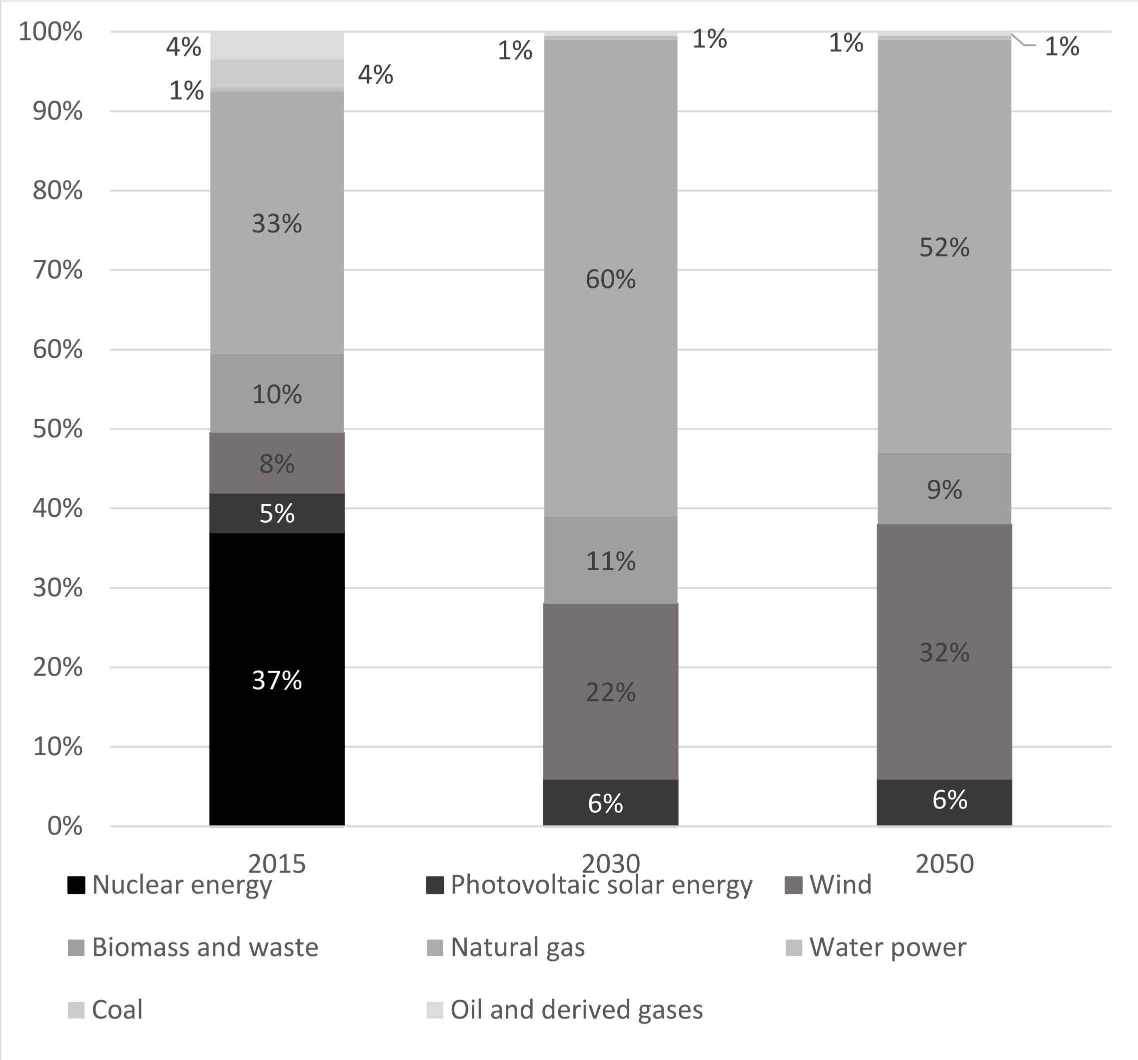
Figure 143 – Net electricity import in Belgium expressed in TWh



Source: Gusbin & Devogelaer (2017)

Figure 144 gives an overview of the net electricity production in Belgium for the years 2015, 2030 and 2050. The electricity production mix of Belgium changes over these three years. When comparing the mix of 2015 and the one of 2030, it is visible that the nuclear energy and coal-based energy disappear, leading to more generation by natural gas (60% in 2030) and renewable sources, especially wind energy (22% by 2030). When comparing the mix of 2030 by the one of 2050 it is clear that the share of wind energy further increases to 32%. The reason for this is a facilitating policy and a decrease of the investment cost (Gusbin & Devogelaer, 2017).

Figure 144 – Net electricity production in Belgium



Source: Own creation based on Gusbin & Devogelaer (2017)

Appendix 9: Financial analysis project case dedicated freight tram

Year	0	1	2	3	4	5	6	7	8	9	10
Own public + private equity	394,416										
Loan over 30 years	393,416	380,302	367,188	354,074	340,960	327,847	314,733	301,619	288,505	275,391	262,277
Loan over 15 years	1,000	933	867	800	733	667	600	533	467	400	333
Interest		5,325	5,147	4,969	4,791	4,613	4,435	4,257	4,079	3,901	3,723
Loan repayment		13,181	13,181	13,181	13,181	13,181	13,181	13,181	13,181	13,181	13,181
Depreciation rolling stock		17,142	17,142	17,142	17,142	17,142	17,142	17,142	17,142	17,142	17,142
Depreciation nodal infrastructure		312	312	312	312	312	312	312	312	312	312
Depreciation line infrastructure		8,906	8,906	8,906	8,906	8,906	8,906	8,906	8,906	8,906	8,906
Total financial cost	**394,416**	**18,505**	**18,327**	**18,149**	**17,971**	**17,793**	**17,615**	**17,438**	**17,260**	**17,082**	**16,904**
Tram		126,749	129,664	132,647	135,697	138,818	142,011	145,278	148,619	152,037	155,534
Road pre-haulage		4,730	4,839	4,950	5,064	5,180	5,299	5,421	5,546	5,673	5,804
Road post-haulage		12,044	12,321	12,604	12,894	13,191	13,494	13,805	14,122	14,447	14,779
Handling & storage		21,931	22,435	22,951	23,479	24,019	24,571	25,137	25,715	26,306	26,911
Replacement costs		0	0	0	0	0	0	0	0	0	0
Total operational + replacement cost		**165,454**	**169,259**	**173,152**	**177,134**	**181,209**	**185,376**	**189,640**	**194,002**	**198,464**	**203,028**
Operational income		17,405	17,805	18,214	18,633	19,062	19,500	19,949	20,408	20,877	21,357
Residual value		0	0	0	0	0	0	0	0	0	0
Total inflows	0	**17,405**	**17,805**	**18,214**	**18,633**	**19,062**	**19,500**	**19,949**	**20,408**	**20,877**	**21,357**
EBITDA		-148,049	-151,454	-154,937	-158,501	-162,147	-165,876	-169,691	-173,594	-177,587	-181,671
Operational result		-174,410	-177,815	-181,299	-184,862	-188,508	-192,237	-196,052	-199,955	-203,948	-208,032
EBT		-179,735	-182,962	-186,267	-189,653	-193,121	-196,672	-200,309	-204,034	-207,849	-211,755
TAXES		0	0	0	0	0	0	0	0	0	0
Net result after taxes		-179,735	-182,962	-186,267	-189,653	-193,121	-196,672	-200,309	-204,034	-207,849	-211,755
Cash flow	**-394,416**	**-153,374**	**-156,601**	**-159,906**	**-163,292**	**-166,759**	**-170,311**	**-173,948**	**-177,673**	**-181,488**	**-185,394**
Free cash flow		-166,554	-169,781	-173,087	-176,472	-179,940	-183,491	-187,129	-190,854	-194,668	-198,575
Discounted free cash flow	**-394,416**	**-160,148**	**-156,972**	**-153,874**	**-150,849**	**-147,898**	**-145,016**	**-142,202**	**-139,455**	**-136,771**	**-134,150**
Cumulative discounted free cash flow	-394,416	-554,564	-711,536	-865,410	-1,016,259	-1,164,157	-1,309,173	-1,451,375	-1,590,830	-1,727,601	-1,861,751

Year	11	12	13	14	15	16	17	18	19	20
Own public + private equity										
Loan over 30 years	249,163	236,050	222,936	209,822	196,708	183,594	170,480	157,366	144,253	131,139
Loan over 15 years	267	200	133	67	0	0	0	0	0	0
Interest	3,545	3,367	3,189	3,011	2,833	2,656	2,479	2,301	2,124	1,947
Loan repayment	13,181	13,181	13,181	13,181	13,181	13,114	13,114	13,114	13,114	13,114
Depreciation rolling stock	17,142	17,142	17,142	17,142	17,142	17,142	17,142	17,142	17,142	17,142
Depreciation nodal infrastructure	312	312	312	312	312	312	312	312	312	312
Depreciation line infrastructure	8,906	8,906	8,906	8,906	8,906	8,906	8,906	8,906	8,906	8,906
Total financial cost	**16,726**	**16,548**	**16,370**	**16,192**	**16,014**	**15,769**	**15,592**	**15,415**	**15,238**	**15,061**
Tram	159,111	162,771	166,515	170,344	174,262	178,270	182,371	186,565	190,856	195,246
Road pre-haulage	5,937	6,074	6,214	6,357	6,503	6,652	6,805	6,962	7,122	7,286
Road post-haulage	15,119	15,467	15,823	16,187	16,559	16,940	17,329	17,728	18,136	18,553
Handling & storage	27,530	28,163	28,811	29,474	30,152	30,845	31,555	32,280	33,023	33,782
Replacement costs	0	0	0	0	2,000	0	0	0	0	0
Total operational + replacement cost	**207,698**	**212,475**	**217,362**	**222,361**	**229,476**	**232,708**	**238,060**	**243,535**	**249,137**	**254,867**
Operational income	21,849	22,351	22,865	23,391	23,929	24,479	25,042	25,618	26,208	26,810
Residual value	0	0	0	0	0	0	0	0	0	0
Total inflows	**21,849**	**22,351**	**22,865**	**23,391**	**23,929**	**24,479**	**25,042**	**25,618**	**26,208**	**26,810**
EBITDA	-185,850	-190,124	-194,497	-198,970	-205,547	-208,228	-213,018	-217,917	-222,929	-228,056
Operational result	-212,211	-216,485	-220,858	-225,331	-231,908	-234,589	-239,379	-244,278	-249,290	-254,417
EBT	-215,756	-219,852	-224,047	-228,343	-234,741	-237,245	-241,857	-246,580	-251,415	-256,365
TAXES	0	0	0	0	0	0	0	0	0	0
Net result after taxes	-215,756	-219,852	-224,047	-228,343	-234,741	-237,245	-241,857	-246,580	-251,415	-256,365
Cash flow	**-189,395**	**-193,491**	**-197,686**	**-201,982**	**-208,380**	**-210,884**	**-215,496**	**-220,218**	**-225,053**	**-230,004**
Free cash flow	-202,575	-206,672	-210,867	-215,162	-221,561	-223,998	-228,610	-233,332	-238,167	-243,118
Discounted free cash flow	**-131,589**	**-129,087**	**-126,641**	**-124,251**	**-123,025**	**-119,594**	**-117,362**	**-115,179**	**-113,044**	**-110,956**
Cumulative discounted free cash flow	-1,993,340	-2,122,427	-2,249,068	-2,373,319	-2,496,344	-2,615,938	-2,733,301	-2,848,480	-2,961,524	-3,072,480

Year	21	22	23	24	25	26	27	28	29	30
Own public + private equity										
Loan over 30 years	118,025	104,911	91,797	78,683	65,569	52,455	39,342	26,228	13,114	0
Loan over 15 years	0	0	0	0	0	0	0	0	0	0
Interest	1,770	1,593	1,416	1,239	1,062	885	708	531	354	177
Loan repayment	13,114	13,114	13,114	13,114	13,114	13,114	13,114	13,114	13,114	13,114
Depreciation rolling stock	17,142	17,142	17,142	17,142	17,142	17,142	17,142	17,142	17,142	17,142
Depreciation nodal infrastructure	312	312	312	312	312	312	312	312	312	312
Depreciation line infrastructure	8,906	8,906	8,906	8,906	8,906	8,906	8,906	8,906	8,906	8,906
Total financial cost	**14,884**	**14,707**	**14,530**	**14,353**	**14,176**	**13,999**	**13,822**	**13,645**	**13,468**	**13,291**
Tram	199,736	204,330	209,030	213,838	218,756	223,787	228,934	234,200	239,586	245,097
Road pre-haulage	7,453	7,625	7,800	7,980	8,163	8,351	8,543	8,739	8,940	9,146
Road post-haulage	18,979	19,416	19,863	20,319	20,787	21,265	21,754	22,254	22,766	23,290
Handling & storage	34,559	35,354	36,167	36,999	37,850	38,721	39,611	40,522	41,454	42,408
Replacement costs	0	0	0	0	0	0	0	0	0	0
Total operational + replacement cost	**260,729**	**266,725**	**272,860**	**279,136**	**285,556**	**292,124**	**298,843**	**305,716**	**312,748**	**319,941**
Operational income	27,427	28,058	28,703	29,363	30,039	30,730	31,436	32,159	32,899	33,656
Residual value	0	0	0	0	0	0	0	0	0	0
Total inflows	**27,427**	**28,058**	**28,703**	**29,363**	**30,039**	**30,730**	**31,436**	**32,159**	**32,899**	**33,656**
EBITDA	-233,302	-238,668	-244,157	-249,773	-255,517	-261,394	-267,406	-273,557	-279,849	-286,285
Operational result	-259,663	-265,029	-270,518	-276,134	-281,878	-287,755	-293,767	-299,918	-306,210	-312,646
EBT	-261,433	-266,622	-271,934	-277,373	-282,941	-288,641	-294,476	-300,449	-306,564	-312,823
TAXES	0	0	0	0	0	0	0	0	0	0
Net result after taxes	-261,433	-266,622	-271,934	-277,373	-282,941	-288,641	-294,476	-300,449	-306,564	-312,823
Cash flow	**-235,072**	**-240,261**	**-245,573**	**-251,012**	**-256,580**	**-262,279**	**-268,115**	**-274,088**	**-280,203**	**-286,462**
Free cash flow	-248,186	-253,375	-258,687	-264,126	-269,693	-275,393	-281,228	-287,202	-293,316	-299,576
Discounted free cash flow	**-108,912**	**-106,913**	**-104,956**	**-103,041**	**-101,167**	**-99,331**	**-97,535**	**-95,775**	**-94,052**	**-92,365**
Cumulative discounted free cash flow	-3,181,392	-3,288,305	-3,393,261	-3,496,303	-3,597,469	-3,696,800	-3,794,335	-3,890,110	-3,984,163	-4,076,528

Source: Own creation

Appendix 10: Economic analysis project case dedicated freight tram

Year	0	1	2	3	4	5	6	7	8	9	10
Initial investment	**788,832**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Tram		126,749	129,664	132,647	135,697	138,818	142,011	145,278	148,619	152,037	155,534
Road pre-haulage		4,730	4,839	4,950	5,064	5,180	5,299	5,421	5,546	5,673	5,804
Road post-haulage		12,044	12,321	12,604	12,894	13,191	13,494	13,805	14,122	14,447	14,779
Handling & storage		21,931	22,435	22,951	23,479	24,019	24,571	25,137	25,715	26,306	26,911
Replacement costs		0	0	0	0	0	0	0	0	0	0
Total operational + replacement cost		**165,454**	**169,259**	**173,152**	**177,134**	**181,209**	**185,376**	**189,640**	**194,002**	**198,464**	**203,028**
Operational income		17,405	17,805	18,214	18,633	19,062	19,500	19,949	20,408	20,877	21,357
Residual value		0	0	0	0	0	0	0	0	0	0
Total inflows		**17,405**	**17,805**	**18,214**	**18,633**	**19,062**	**19,500**	**19,949**	**20,408**	**20,877**	**21,357**
Net result		-148,049	-151,454	-154,937	-158,501	-162,147	-165,876	-169,691	-173,594	-177,587	-181,671
Cash flow	**-788,832**	**-148,049**	**-151,454**	**-154,937**	**-158,501**	**-162,147**	**-165,876**	**-169,691**	**-173,594**	**-177,587**	**-181,671**
Discounted cash flow	**-788,832**	**-142,355**	**-140,028**	**-137,739**	**-135,487**	**-133,273**	**-131,094**	**-128,951**	**-126,843**	**-124,770**	**-122,731**
Cumulative discounted cash flow	-788,832	-931,187	-1,071,214	-1,208,953	-1,344,441	-1,477,713	-1,608,807	-1,737,759	-1,864,602	-1,989,372	-2,112,103

Year	11	12	13	14	15	16	17	18	19	20
Initial investment	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Tram	159,111	162,771	166,515	170,344	174,262	178,270	182,371	186,565	190,856	195,246
Road pre-haulage	5,937	6,074	6,214	6,357	6,503	6,652	6,805	6,962	7,122	7,286
Road post-haulage	15,119	15,467	15,823	16,187	16,559	16,940	17,329	17,728	18,136	18,553
Handling & storage	27,530	28,163	28,811	29,474	30,152	30,845	31,555	32,280	33,023	33,782
Replacement costs	0	0	0	0	2,000	0	0	0	0	0
Total operational + replacement cost	**207,698**	**212,475**	**217,362**	**222,361**	**229,476**	**232,708**	**238,060**	**243,535**	**249,137**	**254,867**
Operational income	21,849	22,351	22,865	23,391	23,929	24,479	25,042	25,618	26,208	26,810
Residual value	0	0	0	0	0	0	0	0	0	0
Total inflows	**21,849**	**22,351**	**22,865**	**23,391**	**23,929**	**24,479**	**25,042**	**25,618**	**26,208**	**26,810**
Net result	-185,850	-190,124	-194,497	-198,970	-205,547	-208,228	-213,018	-217,917	-222,929	-228,056
Cash flow	**-185,850**	**-190,124**	**-194,497**	**-198,970**	**-205,547**	**-208,228**	**-213,018**	**-217,917**	**-222,929**	**-228,056**
Discounted cash flow	**-120,724**	**-118,751**	**-116,810**	**-114,900**	**-114,133**	**-111,175**	**-109,358**	**-107,570**	**-105,812**	**-104,082**
Cumulative discounted cash flow	-2,232,827	-2,351,578	-2,468,388	-2,583,288	-2,697,421	-2,808,596	-2,917,953	-3,025,523	-3,131,335	-3,235,417

Year	21	22	23	24	25	26	27	28	29	30
Initial investment	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Tram	199,736	204,330	209,030	213,838	218,756	223,787	228,934	234,200	239,586	245,097
Road pre-haulage	7,453	7,625	7,800	7,980	8,163	8,351	8,543	8,739	8,940	9,146
Road post-haulage	18,979	19,416	19,863	20,319	20,787	21,265	21,754	22,254	22,766	23,290
Handling & storage	34,559	35,354	36,167	36,999	37,850	38,721	39,611	40,522	41,454	42,408
Replacement costs	0	0	0	0	0	0	0	0	0	0
Total operational + replacement cost	**260,729**	**266,725**	**272,860**	**279,136**	**285,556**	**292,124**	**298,843**	**305,716**	**312,748**	**319,941**
Operational income	27,427	28,058	28,703	29,363	30,039	30,730	31,436	32,159	32,899	33,656
Residual value	0	0	0	0	0	0	0	0	0	0
Total inflows	**27,427**	**28,058**	**28,703**	**29,363**	**30,039**	**30,730**	**31,436**	**32,159**	**32,899**	**33,656**
Net result	-233,302	-238,668	-244,157	-249,773	-255,517	-261,394	-267,406	-273,557	-279,849	-286,285
Cash flow	**-233,302**	**-238,668**	**-244,157**	**-249,773**	**-255,517**	**-261,394**	**-267,406**	**-273,557**	**-279,849**	**-286,285**
Discounted cash flow	**-102,381**	**-100,707**	**-99,061**	**-97,442**	**-95,849**	**-94,282**	**-92,741**	**-91,225**	**-89,734**	**-88,267**
Cumulative discounted cash flow	-3,337,798	-3,438,505	-3,537,566	-3,635,007	-3,730,856	-3,825,138	-3,917,879	-4,009,104	-4,098,838	-4,187,105

Source: Own creation

Appendix 11: Financial analysis project case freight wagon attached to passenger tram

Year	0	1	2	3	4	5	6	7	8	9	10
Own public + private equity	259,821										
Loan over 30 years	259,821	251,161	242,500	233,839	225,178	216,518	207,857	199,196	190,536	181,875	173,214
Interest		3,508	3,391	3,274	3,157	3,040	2,923	2,806	2,689	2,572	2,455
Loan repayment		8,661	8,661	8,661	8,661	8,661	8,661	8,661	8,661	8,661	8,661
Depreciation rolling stock		17,009	17,009	17,009	17,009	17,009	17,009	17,009	17,009	17,009	17,009
Depreciation nodal infrastructure		312	312	312	312	312	312	312	312	312	312
Total financial cost	**259,821**	**12,168**	**12,051**	**11,934**	**11,818**	**11,701**	**11,584**	**11,467**	**11,350**	**11,233**	**11,116**
Tram		36,854	37,702	38,569	39,456	40,363	41,292	42,241	43,213	44,207	45,224
Road pre-haulage		4,730	4,839	4,950	5,064	5,180	5,299	5,421	5,546	5,673	5,804
Road post-haulage		4,593	4,698	4,806	4,917	5,030	5,146	5,264	5,385	5,509	5,636
Handling & storage		18,043	18,458	18,883	19,317	19,761	20,216	20,681	21,156	21,643	22,141
Replacement costs		0	0	0	0	0	0	0	0	0	0
Total operational + replacement cost		**64,219**	**65,697**	**67,208**	**68,753**	**70,335**	**71,952**	**73,607**	**75,300**	**77,032**	**78,804**
Operational income		17,405	17,805	18,214	18,633	19,062	19,500	19,949	20,408	20,877	21,357
Residual value		0	0	0	0	0	0	0	0	0	0
Total inflows	**0**	**17,405**	**17,805**	**18,214**	**18,633**	**19,062**	**19,500**	**19,949**	**20,408**	**20,877**	**21,357**
EBITDA		-46,815	-47,892	-48,993	-50,120	-51,273	-52,452	-53,658	-54,892	-56,155	-57,447
Operational result		-64,136	-65,213	-66,314	-67,441	-68,594	-69,773	-70,980	-72,214	-73,476	-74,768
EBT		-67,644	-68,604	-69,588	-70,598	-71,634	-72,696	-73,786	-74,903	-76,049	-77,223
TAXES		0	0	0	0	0	0	0	0	0	0
Net result after taxes		-67,644	-68,604	-69,588	-70,598	-71,634	-72,696	-73,786	-74,903	-76,049	-77,223
Cash flow	**-259,821**	**-50,322**	**-51,282**	**-52,267**	**-53,277**	**-54,313**	**-55,375**	**-56,464**	**-57,582**	**-58,727**	**-59,902**
Free cash flow		-58,983	-59,943	-60,928	-61,937	-62,973	-64,036	-65,125	-66,242	-67,388	-68,563
Discounted free cash flow	**-259,821**	**-56,715**	**-55,421**	**-54,164**	**-52,944**	**-51,759**	**-50,608**	**-49,490**	**-48,403**	**-47,346**	**-46,318**
Cumulative discounted free cash flow	-259,821	-316,536	-371,956	-426,121	-479,065	-530,825	-581,433	-630,923	-679,325	-726,671	-772,990

Year	11	12	13	14	15	16	17	18	19	20
Own public + private equity										
Loan over 30 years	164,553	155,893	147,232	138,571	129,911	121,250	112,589	103,928	95,268	86,607
Interest	2,338	2,221	2,105	1,988	1,871	1,754	1,637	1,520	1,403	1,286
Loan repayment	8,661	8,661	8,661	8,661	8,661	8,661	8,661	8,661	8,661	8,661
Depreciation rolling stock	17,009	17,009	17,009	17,009	17,009	17,009	17,009	17,009	17,009	17,009
Depreciation nodal infrastructure	312	312	312	312	312	312	312	312	312	312
Total financial cost	**10,999**	**10,882**	**10,765**	**10,648**	**10,531**	**10,415**	**10,298**	**10,181**	**10,064**	**9,947**
Tram	46,264	47,328	48,416	49,530	50,669	51,834	53,027	54,246	55,494	56,770
Road pre-haulage	5,937	6,074	6,214	6,357	6,503	6,652	6,805	6,962	7,122	7,286
Road post-haulage	5,765	5,898	6,034	6,172	6,314	6,459	6,608	6,760	6,916	7,075
Handling & storage	22,650	23,171	23,704	24,249	24,807	25,377	25,961	26,558	27,169	27,794
Replacement costs	0	0	0	0	0	0	0	0	0	0
Total operational + replacement cost	**80,616**	**82,471**	**84,367**	**86,308**	**88,293**	**90,324**	**92,401**	**94,526**	**96,700**	**98,924**
Operational income	21,849	22,351	22,865	23,391	23,929	24,479	25,042	25,618	26,208	26,810
Residual value	0	0	0	0	0	0	0	0	0	0
Total inflows	**21,849**	**22,351**	**22,865**	**23,391**	**23,929**	**24,479**	**25,042**	**25,618**	**26,208**	**26,810**
EBITDA	-58,768	-60,120	-61,502	-62,917	-64,364	-65,844	-67,359	-68,908	-70,493	-72,114
Operational result	-76,089	-77,441	-78,824	-80,238	-81,685	-83,166	-84,680	-86,229	-87,814	-89,436
EBT	-78,428	-79,662	-80,928	-82,226	-83,556	-84,919	-86,317	-87,749	-89,217	-90,722
TAXES	0	0	0	0	0	0	0	0	0	0
Net result after taxes	-78,428	-79,662	-80,928	-82,226	-83,556	-84,919	-86,317	-87,749	-89,217	-90,722
Cash flow	**-61,106**	**-62,341**	**-63,607**	**-64,904**	**-66,235**	**-67,598**	**-68,996**	**-70,428**	**-71,896**	**-73,400**
Free cash flow	-69,767	-71,002	-72,268	-73,565	-74,895	-76,259	-77,656	-79,089	-80,557	-82,061
Discounted free cash flow	**-45,319**	**-44,347**	**-43,402**	**-42,482**	**-41,587**	**-40,715**	**-39,867**	**-39,040**	**-38,236**	**-37,452**
Cumulative discounted free cash flow	-818,309	-862,656	-906,058	-948,540	-990,127	-1,030,842	-1,070,709	-1,109,749	-1,147,985	-1,185,436

Year	21	22	23	24	25	26	27	28	29	30
Own public + private equity										
Loan over 30 years	77,946	69,286	60,625	51,964	43,304	34,643	25,982	17,321	8,661	0
Interest	1,169	1,052	935	818	702	585	468	351	234	117
Loan repayment	8,661	8,661	8,661	8,661	8,661	8,661	8,661	8,661	8,661	8,661
Depreciation rolling stock	17,009	17,009	17,009	17,009	17,009	17,009	17,009	17,009	17,009	17,009
Depreciation nodal infrastructure	312	312	312	312	312	312	312	312	312	312
Total financial cost	**9,830**	**9,713**	**9,596**	**9,479**	**9,362**	**9,245**	**9,128**	**9,011**	**8,895**	**8,778**
Tram	58,076	59,412	60,778	62,176	63,606	65,069	66,566	68,097	69,663	71,265
Road pre-haulage	7,453	7,625	7,800	7,980	8,163	8,351	8,543	8,739	8,940	9,146
Road post-haulage	7,237	7,404	7,574	7,748	7,926	8,109	8,295	8,486	8,681	8,881
Handling & storage	28,433	29,087	29,756	30,440	31,141	31,857	32,589	33,339	34,106	34,890
Replacement costs	0	0	0	0	0	0	0	0	0	0
Total operational + replacement cost	**101,200**	**103,527**	**105,908**	**108,344**	**110,836**	**113,386**	**115,993**	**118,661**	**121,390**	**124,182**
Operational income	27,427	28,058	28,703	29,363	30,039	30,730	31,436	32,159	32,899	33,656
Residual value	0	0	0	0	0	0	0	0	0	0
Total inflows	**27,427**	**28,058**	**28,703**	**29,363**	**30,039**	**30,730**	**31,436**	**32,159**	**32,899**	**33,656**
EBITDA	-73,773	-75,470	-77,205	-78,981	-80,798	-82,656	-84,557	-86,502	-88,491	-90,527
Operational result	-91,094	-92,791	-94,527	-96,302	-98,119	-99,977	-101,878	-103,823	-105,813	-107,848
EBT	-92,263	-93,843	-95,462	-97,121	-98,821	-100,562	-102,346	-104,174	-106,047	-107,965
TAXES	0	0	0	0	0	0	0	0	0	0
Net result after taxes	-92,263	-93,843	-95,462	-97,121	-98,821	-100,562	-102,346	-104,174	-106,047	-107,965
Cash flow	**-74,942**	**-76,522**	**-78,141**	**-79,800**	**-81,499**	**-83,241**	**-85,025**	**-86,853**	**-88,725**	**-90,644**
Free cash flow	-83,603	-85,183	-86,801	-88,460	-90,160	-91,901	-93,685	-95,513	-97,386	-99,304
Discounted free cash flow	**-36,688**	**-35,943**	**-35,218**	**-34,510**	**-33,820**	**-33,148**	**-32,492**	**-31,852**	**-31,227**	**-30,617**
Cumulative discounted free cash flow	-1,222,124	-1,258,067	-1,293,285	-1,327,795	-1,361,615	-1,394,763	-1,427,255	-1,459,106	-1,490,333	-1,520,951

Source: Own creation

Appendix 12: Economic analysis project case freight wagon attached to passenger tram

Year	0	1	2	3	4	5	6	7	8	9	10
Initial investment	**519,642**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Tram		36,854	37,702	38,569	39,456	40,363	41,292	42,241	43,213	44,207	45,224
Road pre-haulage		4,730	4,839	4,950	5,064	5,180	5,299	5,421	5,546	5,673	5,804
Road post-haulage		4,593	4,698	4,806	4,917	5,030	5,146	5,264	5,385	5,509	5,636
Handling & storage		18,043	18,458	18,883	19,317	19,761	20,216	20,681	21,156	21,643	22,141
Replacement costs		0	0	0	0	0	0	0	0	0	0
Total operational + replacement cost		**64,219**	**65,697**	**67,208**	**68,753**	**70,335**	**71,952**	**73,607**	**75,300**	**77,032**	**78,804**
Operational income		17,405	17,805	18,214	18,633	19,062	19,500	19,949	20,408	20,877	21,357
Residual value		0	0	0	0	0	0	0	0	0	0
Total inflows		**17,405**	**17,805**	**18,214**	**18,633**	**19,062**	**19,500**	**19,949**	**20,408**	**20,877**	**21,357**
Net result		-46,815	-47,892	-48,993	-50,120	-51,273	-52,452	-53,658	-54,892	-56,155	-57,447
Cash flow	-519,642	-46,815	-47,892	-48,993	-50,120	-51,273	-52,452	-53,658	-54,892	-56,155	-57,447
Discounted cash flow	-519,642	-45,014	-44,278	-43,555	-42,843	-42,142	-41,454	-40,776	-40,109	-39,454	-38,809
Cumulative discounted cash flow	-519,642	-564,657	-608,935	-652,490	-695,333	-737,475	-778,928	-819,704	-859,814	-899,268	-938,076

Year	11	12	13	14	15	16	17	18	19	20
Initial investment	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Tram	46,264	47,328	48,416	49,530	50,669	51,834	53,027	54,246	55,494	56,770
Road pre-haulage	5,937	6,074	6,214	6,357	6,503	6,652	6,805	6,962	7,122	7,286
Road post-haulage	5,765	5,898	6,034	6,172	6,314	6,459	6,608	6,760	6,916	7,075
Handling & storage	22,650	23,171	23,704	24,249	24,807	25,377	25,961	26,558	27,169	27,794
Replacement costs	0	0	0	0	0	0	0	0	0	0
Total operational + replacement cost	**80,616**	**82,471**	**84,367**	**86,308**	**88,293**	**90,324**	**92,401**	**94,526**	**96,700**	**98,924**
Operational income	21,849	22,351	22,865	23,391	23,929	24,479	25,042	25,618	26,208	26,810
Residual value	0	0	0	0	0	0	0	0	0	0
Total inflows	**21,849**	**22,351**	**22,865**	**23,391**	**23,929**	**24,479**	**25,042**	**25,618**	**26,208**	**26,810**
Net result	-58,768	-60,120	-61,502	-62,917	-64,364	-65,844	-67,359	-68,908	-70,493	-72,114
Cash flow	-58,768	-60,120	-61,502	-62,917	-64,364	-65,844	-67,359	-68,908	-70,493	-72,114
Discounted cash flow	-38,174	-37,550	-36,937	-36,333	-35,739	-35,155	-34,580	-34,015	-33,459	-32,912
Cumulative discounted cash flow	-976,251	-1,013,801	-1,050,738	-1,087,071	-1,122,810	-1,157,965	-1,192,545	-1,226,560	-1,260,019	-1,292,930

Year	21	22	23	24	25	26	27	28	29	30
Initial investment	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Tram	58,076	59,412	60,778	62,176	63,606	65,069	66,566	68,097	69,663	71,265
Road pre-haulage	7,453	7,625	7,800	7,980	8,163	8,351	8,543	8,739	8,940	9,146
Road post-haulage	7,237	7,404	7,574	7,748	7,926	8,109	8,295	8,486	8,681	8,881
Handling & storage	28,433	29,087	29,756	30,440	31,141	31,857	32,589	33,339	34,106	34,890
Replacement costs	0	0	0	0	0	0	0	0	0	0
Total operational + replacement cost	**101,200**	**103,527**	**105,908**	**108,344**	**110,836**	**113,386**	**115,993**	**118,661**	**121,390**	**124,182**
Operational income	27,427	28,058	28,703	29,363	30,039	30,730	31,436	32,159	32,899	33,656
Residual value	0	0	0	0	0	0	0	0	0	0
Total inflows	**27,427**	**28,058**	**28,703**	**29,363**	**30,039**	**30,730**	**31,436**	**32,159**	**32,899**	**33,656**
Net result	-73,773	-75,470	-77,205	-78,981	-80,798	-82,656	-84,557	-86,502	-88,491	-90,527
Cash flow	-73,773	-75,470	-77,205	-78,981	-80,798	-82,656	-84,557	-86,502	-88,491	-90,527
Discounted cash flow	-32,374	-31,845	-31,324	-30,812	-30,309	-29,813	-29,326	-28,846	-28,375	-27,911
Cumulative discounted cash flow	-1,325,304	-1,357,149	-1,388,473	-1,419,286	-1,449,594	-1,479,407	-1,508,733	-1,537,580	-1,565,954	-1,593,866

Source: Own creation

Appendix 13: Socio-economic analysis project case dedicated freight tram

Year	0	1	2	3	4	5	6	7	8	9	10
Residual value		0	0	0	0	0	0	0	0	0	0
Initial investment	**788,832**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Tram		126,749	129,664	132,647	135,697	138,818	142,011	145,278	148,619	152,037	155,534
Road pre-haulage		4,730	4,839	4,950	5,064	5,180	5,299	5,421	5,546	5,673	5,804
Road post-haulage		12,044	12,321	12,604	12,894	13,191	13,494	13,805	14,122	14,447	14,779
Handling & storage		21,931	22,435	22,951	23,479	24,019	24,571	25,137	25,715	26,306	26,911
Replacement costs		0	0	0	0	0	0	0	0	0	0
Total operational + replacement cost		**165,454**	**169,259**	**173,152**	**177,134**	**181,209**	**185,376**	**189,640**	**194,002**	**198,464**	**203,028**
Operational income		17,405	17,805	18,214	18,633	19,062	19,500	19,949	20,408	20,877	21,357
Consumer surplus existing users		-9	-9	-9	-9	-10	-10	-10	-10	-11	-11
Consumer surplus new users		0	0	0	0	0	0	0	0	0	0
External cost savings		2,469	2,526	2,584	2,644	2,705	2,767	2,830	2,896	2,962	3,030
Total inflows		19,865	17,796	18,205	18,624	19,052	19,490	19,939	20,397	20,866	21,346
Net result		-145,588	-151,463	-154,947	-158,511	-162,156	-165,886	-169,701	-173,604	-177,597	-181,682
Cash flow	**-788,832**	**-145,588**	**-151,463**	**-154,947**	**-158,511**	**-162,156**	**-165,886**	**-169,701**	**-173,604**	**-177,597**	**-181,682**
Discounted cash flow	**-788,832**	**-139,989**	**-140,036**	**-137,747**	**-135,495**	**-133,281**	**-131,102**	**-128,959**	**-126,851**	**-124,777**	**-122,738**
Cumulative discounted cash flow	-788,832	-928,821	-1,068,857	-1,206,604	-1,342,099	-1,475,380	-1,606,482	-1,735,441	-1,862,292	-1,987,070	-2,109,807

Year	11	12	13	14	15	16	17	18	19	20
Residual value	0	0	0	0	0	0	0	0	0	0
Initial investment	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Tram	159,111	162,771	166,515	170,344	174,262	178,270	182,371	186,565	190,856	195,246
Road pre-haulage	5,937	6,074	6,214	6,357	6,503	6,652	6,805	6,962	7,122	7,286
Road post-haulage	15,119	15,467	15,823	16,187	16,559	16,940	17,329	17,728	18,136	18,553
Handling & storage	27,530	28,163	28,811	29,474	30,152	30,845	31,555	32,280	33,023	33,782
Replacement costs	0	0	0	0	2,000	0	0	0	0	0
Total operational + replacement cost	**207,698**	**212,475**	**217,362**	**222,361**	**229,476**	**232,708**	**238,060**	**243,535**	**249,137**	**254,867**
Operational income	21,849	22,351	22,865	23,391	23,929	24,479	25,042	25,618	26,208	26,810
Consumer surplus existing users	-11	-11	-12	-12	-12	-12	-13	-13	-13	-14
Consumer surplus new users	0	0	0	0	0	0	0	0	0	0
External cost savings	3,100	3,171	3,244	3,319	3,395	3,473	3,553	3,635	3,719	3,804
Total inflows	21,837	22,340	22,853	23,379	23,917	24,467	25,030	25,605	26,194	26,797
Net result	-185,861	-190,136	-194,509	-198,982	-205,559	-208,241	-213,030	-217,930	-222,942	-228,070
Cash flow	**-185,861**	**-190,136**	**-194,509**	**-198,982**	**-205,559**	**-208,241**	**-213,030**	**-217,930**	**-222,942**	**-228,070**
Discounted cash flow	**-120,732**	**-118,758**	**-116,817**	**-114,907**	**-114,140**	**-111,181**	**-109,364**	**-107,576**	**-105,818**	**-104,088**
Cumulative discounted cash flow	-2,230,539	-2,349,297	-2,466,114	-2,581,021	-2,695,161	-2,806,342	-2,915,706	-3,023,283	-3,129,101	-3,233,189

Year	21	22	23	24	25	26	27	28	29	30
Residual value	0	0	0	0	0	0	0	0	0	0
Initial investment	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Tram	199,736	204,330	209,030	213,838	218,756	223,787	228,934	234,200	239,586	245,097
Road pre-haulage	7,453	7,625	7,800	7,980	8,163	8,351	8,543	8,739	8,940	9,146
Road post-haulage	18,979	19,416	19,863	20,319	20,787	21,265	21,754	22,254	22,766	23,290
Handling & storage	34,559	35,354	36,167	36,999	37,850	38,721	39,611	40,522	41,454	42,408
Replacement costs	0	0	0	0	0	0	0	0	0	0
Total operational + replacement cost	**260,729**	**266,725**	**272,860**	**279,136**	**285,556**	**292,124**	**298,843**	**305,716**	**312,748**	**319,941**
Operational income	27,427	28,058	28,703	29,363	30,039	30,730	31,436	32,159	32,899	33,656
Consumer surplus existing users	-14	-14	-15	-15	-15	-16	-16	-16	-17	-17
Consumer surplus new users	0	0	0	0	0	0	0	0	0	0
External cost savings	3,892	3,981	4,073	4,166	4,262	4,360	4,460	4,563	4,668	4,775
Total inflows	27,413	28,044	28,689	29,348	30,023	30,714	31,420	32,143	32,882	33,639
Net result	-233,316	-238,682	-244,172	-249,788	-255,533	-261,410	-267,422	-273,573	-279,865	-286,302
Cash flow	**-233,316**	**-238,682**	**-244,172**	**-249,788**	**-255,533**	**-261,410**	**-267,422**	**-273,573**	**-279,865**	**-286,302**
Discounted cash flow	**-102,387**	**-100,713**	**-99,067**	**-97,447**	**-95,855**	**-94,288**	**-92,747**	**-91,230**	**-89,739**	**-88,272**
Cumulative discounted cash flow	-3,335,576	-3,436,289	-3,535,356	-3,632,803	-3,728,658	-3,822,945	-3,915,692	-4,006,922	-4,096,662	-4,184,934

Source: Own creation

Appendix 14: Socio-economic analysis project case freight wagon attached to passenger tram

Year	0	1	2	3	4	5	6	7	8	9	10
Residual value		0	0	0	0	0	0	0	0	0	0
Initial investment	**519,642**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Tram		36,854	37,702	38,569	39,456	40,363	41,292	42,241	43,213	44,207	45,224
Road pre-haulage		4,730	4,839	4,950	5,064	5,180	5,299	5,421	5,546	5,673	5,804
Road post-haulage		4,593	4,698	4,806	4,917	5,030	5,146	5,264	5,385	5,509	5,636
Handling & storage		18,043	18,458	18,883	19,317	19,761	20,216	20,681	21,156	21,643	22,141
Replacement costs		0	0	0	0	0	0	0	0	0	0
Total operational + replacement cost		**64,219**	**65,697**	**67,208**	**68,753**	**70,335**	**71,952**	**73,607**	**75,300**	**77,032**	**78,804**
Operational income		17,405	17,805	18,214	18,633	19,062	19,500	19,949	20,408	20,877	21,357
Consumer surplus existing users		-5	-5	-5	-5	-5	-5	-5	-5	-5	-6
Consumer surplus new users		0	0	0	0	0	0	0	0	0	0
External cost savings		2,986	3,054	3,125	3,196	3,270	3,345	3,422	3,501	3,581	3,664
Total inflows		**20,386**	**20,855**	**21,334**	**21,825**	**22,327**	**22,841**	**23,366**	**23,903**	**24,453**	**25,015**
Net result		-43,834	-44,842	-45,873	-46,928	-48,008	-49,112	-50,241	-51,397	-52,579	-53,788
Cash flow	**-519,642**	**-43,834**	**-44,842**	**-45,873**	**-46,928**	**-48,008**	**-49,112**	**-50,241**	**-51,397**	**-52,579**	**-53,788**
Discounted cash flow	**-519,642**	**-42,148**	**-41,459**	**-40,781**	**-40,115**	**-39,459**	**-38,814**	**-38,179**	**-37,555**	**-36,941**	**-36,338**
Cumulative discounted cash flow	-519,642	-561,790	-603,249	-644,030	-684,145	-723,603	-762,417	-800,597	-838,152	-875,093	-911,431

Year	11	12	13	14	15	16	17	18	19	20
Residual value	0	0	0	0	0	0	0	0	0	0
Initial investment	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Tram	46,264	47,328	48,416	49,530	50,669	51,834	53,027	54,246	55,494	56,770
Road pre-haulage	5,937	6,074	6,214	6,357	6,503	6,652	6,805	6,962	7,122	7,286
Road post-haulage	5,765	5,898	6,034	6,172	6,314	6,459	6,608	6,760	6,916	7,075
Handling & storage	22,650	23,171	23,704	24,249	24,807	25,377	25,961	26,558	27,169	27,794
Replacement costs	0	0	0	0	0	0	0	0	0	0
Total operational + replacement cost	**80,616**	**82,471**	**84,367**	**86,308**	**88,293**	**90,324**	**92,401**	**94,526**	**96,700**	**98,924**
Operational income	21,849	22,351	22,865	23,391	23,929	24,479	25,042	25,618	26,208	26,810
Consumer surplus existing users	-6	-6	-6	-6	-6	-6	-6	-7	-7	-7
Consumer surplus new users	0	0	0	0	0	0	0	0	0	0
External cost savings	3,748	3,834	3,922	4,013	4,105	4,199	4,296	4,395	4,496	4,599
Total inflows	**25,591**	**26,179**	**26,782**	**27,397**	**28,028**	**28,672**	**29,332**	**30,006**	**30,697**	**31,403**
Net result	-55,026	-56,291	-57,586	-58,910	-60,265	-61,651	-63,069	-64,520	-66,004	-67,522
Cash flow	**-55,026**	**-56,291**	**-57,586**	**-58,910**	**-60,265**	**-61,651**	**-63,069**	**-64,520**	**-66,004**	**-67,522**
Discounted cash flow	**-35,744**	**-35,159**	**-34,585**	**-34,019**	**-33,463**	**-32,916**	**-32,378**	**-31,849**	**-31,328**	**-30,816**
Cumulative discounted cash flow	-947,174	-982,334	-1,016,918	-1,050,937	-1,084,401	-1,117,317	-1,149,695	-1,181,544	-1,212,872	-1,243,688

Year	21	22	23	24	25	26	27	28	29	30
Residual value	0	0	0	0	0	0	0	0	0	0
Initial investment	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Tram	58,076	59,412	60,778	62,176	63,606	65,069	66,566	68,097	69,663	71,265
Road pre-haulage	7,453	7,625	7,800	7,980	8,163	8,351	8,543	8,739	8,940	9,146
Road post-haulage	7,237	7,404	7,574	7,748	7,926	8,109	8,295	8,486	8,681	8,881
Handling & storage	28,433	29,087	29,756	30,440	31,141	31,857	32,589	33,339	34,106	34,890
Replacement costs	0	0	0	0	0	0	0	0	0	0
Total operational + replacement cost	**101,200**	**103,527**	**105,908**	**108,344**	**110,836**	**113,386**	**115,993**	**118,661**	**121,390**	**124,182**
Operational income	27,427	28,058	28,703	29,363	30,039	30,730	31,436	32,159	32,899	33,656
Consumer surplus existing users	-7	-7	-7	-8	-8	-8	-8	-8	-9	-9
Consumer surplus new users	0	0	0	0	0	0	0	0	0	0
External cost savings	4,705	4,813	4,924	5,037	5,153	5,271	5,393	5,517	5,644	5,773
Total inflows	**32,125**	**32,864**	**33,620**	**34,393**	**35,184**	**35,993**	**36,821**	**37,668**	**38,534**	**39,420**
Net result	-69,075	-70,664	-72,289	-73,952	-75,652	-77,393	-79,173	-80,993	-82,856	-84,762
Cash flow	**-69,075**	**-70,664**	**-72,289**	**-73,952**	**-75,652**	**-77,393**	**-79,173**	**-80,993**	**-82,856**	**-84,762**
Discounted cash flow	**-30,312**	**-29,817**	**-29,330**	**-28,850**	**-28,379**	**-27,915**	**-27,458**	**-27,010**	**-26,568**	**-26,134**
Cumulative discounted cash flow	-1,274,000	-1,303,817	-1,333,147	-1,361,997	-1,390,376	-1,418,290	-1,445,749	-1,472,758	-1,499,326	-1,525,460

Source: Own creation

Appendix 15: Overview of all equations

All equations used in this research are the following:

(1) $GC = fee_{user} + VoT_{unit} * time$

(2) $\int_{GC_{project}}^{GC_{reference}} D(GC)dGC \approx \frac{1}{2} * (GC_{reference} - GC_{project}) * (Q_{reference} + Q_{project})$

(3) $\Delta CS_{generated} = \frac{1}{2} * (GC_{reference} - GC_{project}) * (Q_{project} - Q_{reference})$

(4) $k_t = k_s * \frac{CPI_t}{CPI_s}$

(5) $PPI_{st} = \frac{GDP_t}{GDP_s} * \frac{POP_s}{POP_t}$

(6) $r = \frac{i - m}{1 + m}$

(7) $NPV = \sum_{t=0}^{T} \frac{NB_t}{(1+i)^t}$

(8) $FNPV = \sum_{j=t_p-t_r}^{j=t_n-t_r} \frac{-\Delta I_j + \Delta R_j - \Delta C_j - \Delta F_j}{(1+r)^j} + \frac{K_{t_n}}{(1+r)^{t_n-t_r}}$

(9) $ENPV = \sum_{j=t_p-t_r}^{j=t_n-t_r} \frac{-\Delta I_j + \Delta R_j - \Delta C_j}{(1+r)^j} + \frac{K_{t_n}}{(1+r)^{t_n-t_r}}$

(10) $SNPV = \sum_{j=t_p-t_r}^{j=t_n-t_r} \frac{-\Delta I_j + \Delta R_j - \Delta C_j - \Delta E_j}{(1+s)^j} + \frac{K_{t_n}}{(1+s)^{t_n-t_r}}$

(11) $\Delta R_p - \Delta C_p + S_p > x$

(12) $\Delta B_s - \Delta C_s + S_s > y$

(13) $investment = \mathrm{infra}_{line} + \mathrm{infra}_{nodal} + rollingstock$

(14) $\mathrm{infra}_{line} = track + switch$

(15) $\mathrm{infra}_{nodal} = \mathrm{infra}_{nodal,pre} + \mathrm{infra}_{nodal,post}$

(16) $\mathrm{infra}_{nodal,pre} = \beta * \sum_{m=1}^{4} (tp_{const,m} * pallets_{tp,m} * surf_m)$

(17) $\mathrm{infra}_{nodal,post} = \sum_{q=1}^{4} (\gamma_q) * \sum_{m=1}^{4} (tp_{const,m} * pallets_{tp,m} * surf_m)$

(18) $rollingstock = number_{railveh} * railveh$

(19) $operation_{total} = operation_{rail} + operation_{pre} + operation_{post} + operation_{handling}$

(20) $operation_{rail} = \mathrm{dcost}_{rail} + t\mathrm{cost}_{rail}$

(21) $\mathrm{dcost}_{rail} = D_{rail} * d_{rail}$

(22) $D_{rail} = \sum_{i=1}^{j} (D_{rail,i} + D_{rail,i,i+1} + D_{rail,j,1})$

(23) $railtrips_{technical} = \max(railtrips_{weight}, railtrips_{volume})$

(24) $railtrips = \max(railtrips_{technical}, railtrips_{organisational})$

(25) $\mathrm{tcost}_{rail} = \sum_{i=1}^{j}\left(U_{rail,i} * \left(\iota_i * u_{rail,day} + (1-\iota_i) * (u_{rail,night})\right)\right) + (1-\iota) * 3 * u_{rail,dispatch})$

(26) $\mathrm{U}_{rail,i} = \sum_{i=1}^{j} \frac{D_{rail,i} + D_{rail,i,i+1} + D_{rail,j,1}}{speed_{rail}}$

(27) $operation_{pre} = \mathrm{dcost}_{pre} + t\mathrm{cost}_{pre}$

(28) $\mathrm{dcost}_{pre} = \sum_{k=1}^{l}(\beta_k * d_{pre,k} * D_{pre,k})$

(29) $D_{pre} = \sum_{k=1}^{l}(D_{pre,k,m} + D_{pre,k,sub})$

(30) $\mathrm{tcost}_{pre} = \sum_{k=1}^{l}\beta_k * (u_{pre,day,k} * (U_{pre,peak,k} + U_{pre,off-peak,k}) + u_{pre,night,k} * U_{pre,night,k})$

(31) $operation_{post} = posth_{employee} + posth_{courier} + posth_{bike} + posth_{LGV}$

(32) $posth_{employee,n} = \frac{(D_{post,\gamma 1,peak} + D_{post,\gamma 1,off-peak}) * u_{post,employee,day} + D_{post,\gamma 1,night} * u_{post,employee,night}}{speed_{walk}}$

(33) $posth_{courier,n} = \frac{(D_{post,\gamma 2,peak} + D_{post,\gamma 2,off-peak}) * u_{post,courier,day} + D_{post,\gamma 2,night} * u_{post,courier,night}}{speed_{walk}}$

(34) $posth_{bike,n} = \frac{(D_{post,\gamma 3,peak} + D_{post,\gamma 3,off-peak}) * u_{post,bike,day} + D_{post,\gamma 3,night} * u_{post,bike,night}}{speed_{bike}} + \mathrm{dcost}_{bike,n}$

(35) $\mathrm{dcost}_{bike} = D_{post,\gamma 3} * (0.07€ / km + \lambda * 0.0002€ / km)$

(36) $posth_{LGV,n} = \frac{(D_{post,\gamma 4,peak} + D_{post,\gamma 4,off-peak}) * u_{post,LGV,day} + D_{post,\gamma 4,night} * u_{post,LGV,night}}{speed_{LGV}} + \mathrm{dcost}_{LGV,n}$

(37) $operation_{handling} = operation_{handling,pre} + operation_{handling,post}$

(38) $operation_{handling,pre} = \sum_{m=1}^{4}\sum_{k=1}^{l}\beta_k * (operation_{tp,m} * pallets_{tp,m} + operation_{dc,m} * pallets_{dc,m})$

(39) $operation_{handling,post} = \sum_{m=1}^{4}\sum_{q=1}^{4}\sum_{n=1}^{o}(\gamma_{q,n} * (operation_{tp,m} * pallets_{tp,m} + operation_{dc,m} * pallets_{dc,m}) + \mathrm{tcost}_{\gamma 2,n,operation})$

(40) $\mathrm{tcost}_{\gamma 2,operation} = \iota * U_{post,\gamma 2,day} * u_{rail,day} + (1-\iota) * U_{post,\gamma 2,night} * u_{rail,night}$

(41) $income_{oper} = fee + ancillary$

(42) $fee = \mathrm{dcost}_{reference} + \mathrm{tcost}_{reference} + rest_{reference}$

(43) $D_{reference} = \sum_{n=1}^{o}\sum_{k=1}^{l}\sum_{s=1}^{t}(D_{reference,\mathrm{s,n\text{-}1},k} + D_{reference,n-1,n,k} + D_{reference,n,s,k})$

(44) $U_{reference} = \frac{D_{reference}}{speed_{reference}}$

(45) $Netbenefit_{tram,private} = \Delta R_p - \Delta C_p$

(46) $\Delta R_p = fee + ancillary$

(47) $\Delta C_p = investment + operation_{total}$

(48) $timesav = h * pallets * \frac{U_{reference} - U_{project}}{24}$

(49) $MSC = C_{p,rail} + C_{p,road} + C_{p,h\&s} + C_{e,rail} + C_{e,road} + C_{e,h\&s}$

(50) $C_{e,saved} = C_{e,reference} - C_{e,project}$

(51) $C_{e,reference} = acc_{reference} + air_{reference} + \mathrm{clim}_{reference} + cong_{reference} + \mathrm{infra}_{reference} + noise_{reference}$

(52) $C_{e,project} = C_{e,rail} + C_{e,pre} + C_{e,post} + C_{e,h\&s}$

(53) $C_{e,rail} = acc_{rail} + air\,\&\,\mathrm{clim}_{rail} + cong_{rail} + \mathrm{infra}_{rail} + noise_{rail}$

(54) $C_{e,pre} = acc_{pre} + air\,\&\,\mathrm{clim}_{pre} + cong_{pre} + \mathrm{infra}_{pre} + noise_{pre}$

(55) $C_{e,post} = acc_{post} + air\,\&\,\mathrm{clim}_{post} + cong_{post} + \mathrm{infra}_{post} + noise_{post}$

(56) $C_{e,h\&s} = air\,\&\,\mathrm{clim}_{h\&s}$

(57) $air\,\&\,\mathrm{clim}_{e} = \frac{€}{g} * \frac{g}{kWh} * \frac{kWh}{tramkm}$

(58) $benefits_{social,net} = \Delta B_s - \Delta C_s$

(59) $\Delta B_s = external_{reference} = timesav + C_{e,reference}$

(60) $\Delta C_s = external_{project} = external_{rail} + external_{pre} + external_{post} + external_{h\&s}$

Appendix 16: Sensitivity and scenario analyses for a dedicated freight tram

This appendix provides additional sensitivity analyses to the ones that are carried out in Chapter 6, as well as the underlying data for the figures presented in Chapter 6. Firstly, data and analyses when a lorry of 12 tonnes is used, are provided. In Appendix 16.2, data and analyses are shown in case a van of 3.5 tonnes is used in the reference case.

Appendix 16.1: Outcome if a lorry of 12 tonnes is used in the reference case

In this section, costs and benefits are displayed in case a lorry with a gross weight of 12 tonnes is used in the reference case and hence, in the road pre-haulage leg of the project case. Firstly, the underlying data of Figure 90 are provided. Table 93 displays the financial, economic and socio-economic NPV per number of round trips performed and per number of roll cages transported in the lorry.

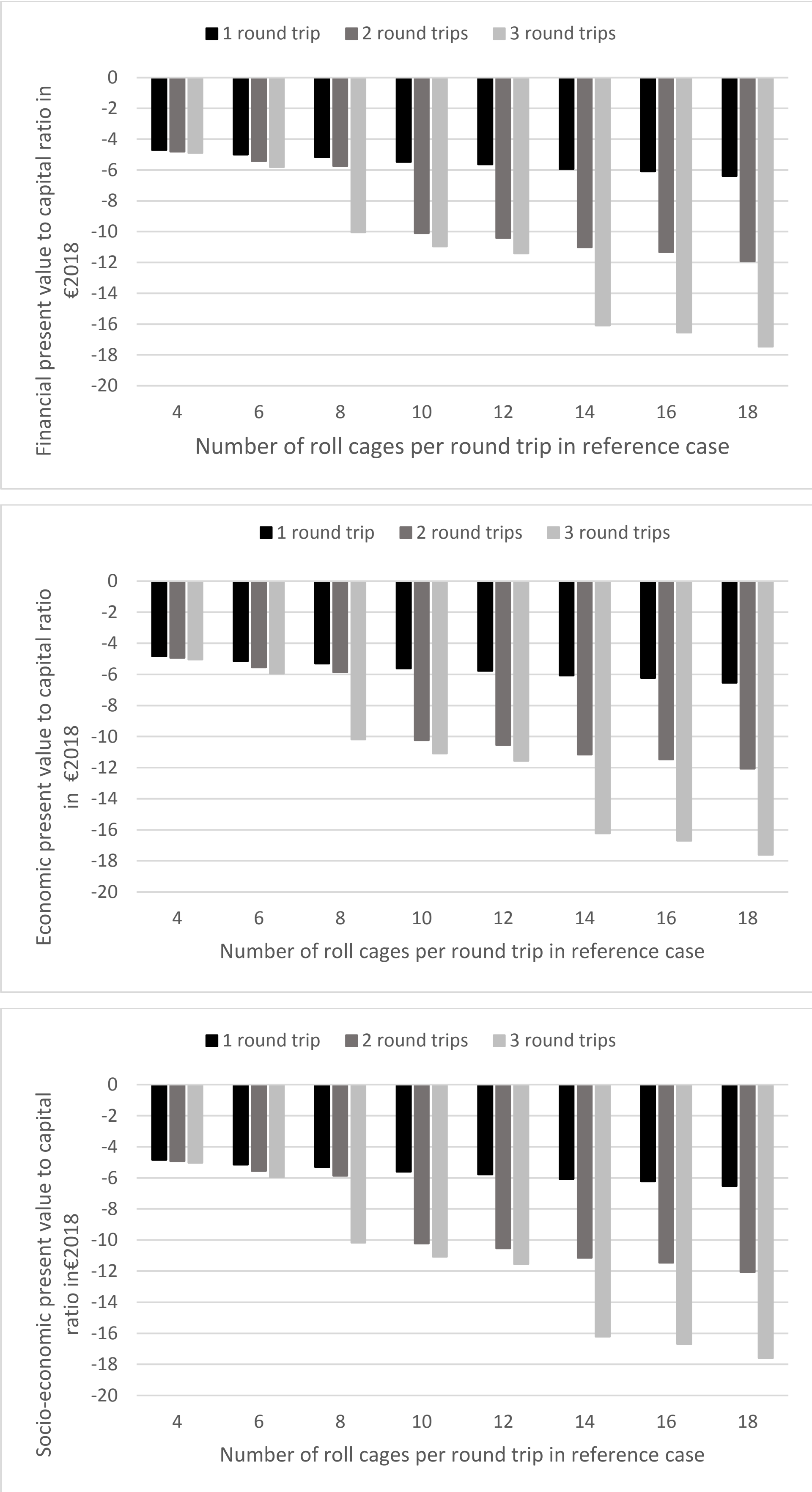
Table 93 – NPV per number of round trips and per number of roll cages for a dedicated freight tram

Number of roll cages in lorry	1 round trip	2 round trips	3 round trips
FINANCIAL NPV in €$_{2018}$			
4	-3,682,704	-3,785,688	-3,888,671
6	-3,938,117	-4,296,513	-4,654,910
8	-4,076,528	-4,573,334	-7,966,470
10	-4,331,941	-7,982,503	-8,729,688
12	-4,470,351	-8,257,310	-9,141,899
14	-4,725,764	-8,766,122	-12,806,480
16	-4,864,174	-9,040,929	-13,217,684
18	-5,119,587	-9,549,741	-13,979,896
ECONOMIC NPV in €$_{2018}$			
4	-3,792,625	-3,896,265	-3,999,905
6	-4,048,366	-4,407,748	-4,767,130
8	-4,187,105	-4,685,226	-8,077,704
10	-4,442,847	-8,093,409	-8,841,416
12	-4,581,586	-8,368,544	-9,254,119
14	-4,837,327	-8,877,685	-12,918,044
16	-4,976,066	-9,152,821	-13,329,576
18	-5,231,808	-9,661,962	-14,092,117
SOCIO-ECONOMIC NPV in €$_{2018}$			
4	-3,790,341	-3,890,880	-3,991,419
6	-4,046,152	-4,402,501	-4,758,851
8	-4,184,934	-4,680,066	-8,070,373
10	-4,440,759	-8,089,234	-8,834,335
12	-4,579,548	-8,364,470	-9,247,190
14	-4,835,388	-8,873,807	-12,912,226
16	-4,974,185	-9,149,058	-13,323,932
18	-5,230,038	-9,658,424	-14,086,809

Source: Own creation

Secondly, Figure 145 shows the related present value to capital ratio per number of round trips and number of roll cages. The underlying data are shown in Table 94.

Figure 145 – Present value to capital ratios for a dedicated freight tram



Source: Own creation

Table 94 – Background data present value to capital ratios for a dedicated freight tram

Number of roll cages in lorry	1 round trip	2 round trips	3 round trips
FINANCIAL PRESENT VALUE TO CAPITAL RATIO (2018)			
4	-4.70	-4.80	-4.90
6	-5.01	-5.41	-5.81
8	-5.17	-5.73	-10.04
10	-5.48	-10.09	-10.95
12	-5.63	-10.41	-11.42
14	-5.94	-11.01	-16.09
16	-6.09	-11.33	-16.56
18	-6.40	-11.93	-17.46
ECONOMIC PRESENT VALUE TO CAPITAL RATIO (2018)			
4	-4.84	-4.94	-5.04
6	-5.15	-5.55	-5.95
8	-5.31	-5.87	-10.18
10	-5.62	-10.23	-11.09
12	-5.77	-10.55	-11.56
14	-6.08	-11.15	-16.23
16	-6.23	-11.47	-16.70
18	-6.54	-12.07	-17.60
SOCIO-ECONOMIC PRESENT VALUE TO CAPITAL RATIO (2018)			
4	-4.83	-5.03	-5.03
6	-5.14	-5.55	-5.94
8	-5.31	-5.86	-10.17
10	-5.61	-10.22	-11.08
12	-5.77	-10.54	-11.55
14	-6.08	-11.15	-16.22
16	-6.23	-11.46	-16.69
18	-6.53	-12.06	-17.60

Source: Own creation

Thirdly, Table 95 presents the underlying data used for Figure 91, being the net private and social benefit in euro per parcel.

Table 95 – Net benefit for a dedicated freight tram

Number of roll cages in lorry	1 round trip	2 round trips	3 round trips
NET PRIVATE BENEFIT (in €$_{2018}$/parcel)			
4	-1.26	-0.65	-0.44
6	-0.90	-0.49	-0.36
8	-0.70	-0.39	-0.46
10	-0.59	-0.55	-0.40
12	-0.51	-0.48	-0.35
14	-0.46	-0.43	-0.42
16	-0.42	-0.39	-0.38
18	-0.39	-0.37	-0.36
NET SOCIAL BENEFIT (in €$_{2018}$/parcel)			
4	-1.24	-0.63	-0.43
6	-0.89	-0.48	-0.34
8	-0.69	-0.38	-0.45
10	-0.59	-0.55	-0.40
12	-0.51	-0.47	-0.35
14	-0.46	-0.43	-0.42
16	-0.41	-0.39	-0.38
18	-0.39	-0.36	-0.36

Source: Own creation

Next to the amount of goods transported, the effect of a change of the discount rate is examined in Figure 92. Table 96 provides the underlying data.

Table 96 – Effect of the change of the discount rate on the project outcome, dedicated freight tram

Financial & social discount rate	2%	4%	8%
FNPV in €$_{2018}$	-5,303,147	-4,076,528	-2,671,541
ENPV in €$_{2018}$	-5,335,600	-4,187,105	-2,876,205
SNPV in €$_{2018}$	-5,333,451	-4,184,934	-2,874,043
Financial present value to capital ratio	-6.72	-5.17	-3.39
Economic present value to capital ratio	-6.76	-5.31	-3.65
Socio-economic present value to capital ratio	-6.76	-5.31	-3.64

Source: Own creation

Other sensitivity analyses are carried out. Table 97 shows the underlying data used in Figure 94.

Table 97 – Sensitivity analyses, dedicated freight tram

Variable increased by 1%	Absolute change variable (in €$_{2018}$/year)	Change ENPV
Rolling stock	5,123	-0.12%
Line infrastructure	2,672	-0.06%
Tram	1,267	-0.69%
Handling & storage	219	-0.12%
Post-haulage	120	-0.07%
Nodal infrastructure	94	0.00%
Pre-haulage	47	-0.03%

Source: Own creation

The NPV is calculated for different scenarios. Table 98 displays the NPVs and NPV changes for scenarios 2-9.

Table 98 – NPVs and NPV changes for scenarios 2-9, dedicated freight tram

Scenario	FNPV (€2018)	% change	ENPV (€2018)	% change	SNPV (€2018)	% change
S2: Congestion on roads	-4,004,935	1.76%	-4,115,513	1.71%	-4,111,874	1.75%
S3: Unaccompanied tram leg	-3,746,631	8.09%	-3,857,208	7.88%	-3,855,037	7.88%
S4: Shortest tram path	-3,352,791	17.75%	-3,463,369	17.28%	-3,460,994	17.30%
S5: Free access tram network	-3,561,064	12.64%	-3,671,641	12.31%	-3,669,470	12.32%
S6: Ancillary revenue	-3,694,703	9.37%	-3,805,280	9.12%	-3,803,109	9.12%
S7: No pre-haulage	-3,876,816	4.90%	-3,986,955	4.78%	-3,985,071	4.78%
S7: No post-haulage	-3,498,576	14.18%	-3,608,277	13.82%	-3,606,106	13.83%
S8: Changing external costs	-4,076,528	0.00%	-4,187,105	0.00%	-4,181,332	0.09%
S9: Peak hour transport	-4,064,028	0.31%	-4,174,606	0.30%	-4,171,585	0.32%

Source: Own creation

Table 99 provides the NPVs and NPV changes when scenarios 2-9 are gradually added in scenario 10a.

Table 99 – NPV and NPV changes when scenarios 2-9 are added, dedicated freight tram

In €2018	**Financial**	**Economic**	**Socio-economic**
NPV S4	-2,260,454	-2,371,032	-2,368,350
% change of the NPV S4	44.55%	43.37%	43.41%
NPV S4+S7	-1,482,791	-1,592,054	-1,589,659
% change of the NPV S4+S7	63.63%	61.98%	62.01%
NPV S4-S5+S7	-1,289,194	-1,398,457	-1,396,061
% change of the NPV S4-S5+S7	68.38%	66.60%	66.64%
NPV S4-S7	-907,369	-1,016,632	-1,014,236
% change of the NPV S4-S7	77.74%	75.72%	75.76%
NPV S3-S7	-783,467	-892,730	-890,334
% change of the NPV S3-S7	80.78%	78.68%	78.73%
NPV S2-S7	-676,078	-785,341	-782,278
% change of the NPV S2-S7	83.42%	81.24%	81.31%
NPV S2-S7+S9	-687,963	-797,226	-794,171
% change of the NPV S2-S7+S9	83.12%	80.96%	81.02%
NPV S2-S8	-676,078	-785,341	-778,637
% change of the NPV S2-S8	83.42%	81.24%	81.39%

Source: Own creation

In the next section, similar data are provided for the reference case in which a van is used instead of a lorry.

Appendix 16.2: Outcome if a van of 3.5 tonnes is used in the reference case

In this section, costs and benefits are displayed in case a van with a gross weight of 3.5 tonnes is used in the reference case and hence, in the road pre-haulage leg of the project case.

Table 100 displays the financial, economic and socio-economic net present value for different numbers of round trips carried out in the reference case by a van. This table serves as the source of Figure 106.

Table 100 – NPV per number of round trips of a van for a dedicated freight tram

	FNPV (in €$_{2018}$)	ENPV (in €$_{2018}$)	SNPV (in €$_{2018}$)
1 round trip	-3,579,116	-3,688,872	-3,688,119
2 round trips	-3,578,512	-3,688,760	-3,686,343
3 round trips	-3,577,907	-3,688,648	-3,684,566
4 round trips	-3,577,302	-3,688,537	-3,682,790
5 round trips	-3,576,697	-3,688,425	-3,681,013
6 round trips	-3,576,092	-3,688,313	-3,679,237
7 round trips	-6,473,830	-6,584,900	-6,575,072

Source: Own creation

Table 101 shows the financial, economic and socio-economic present value to capital ratio per number of round trips executed in the reference case.

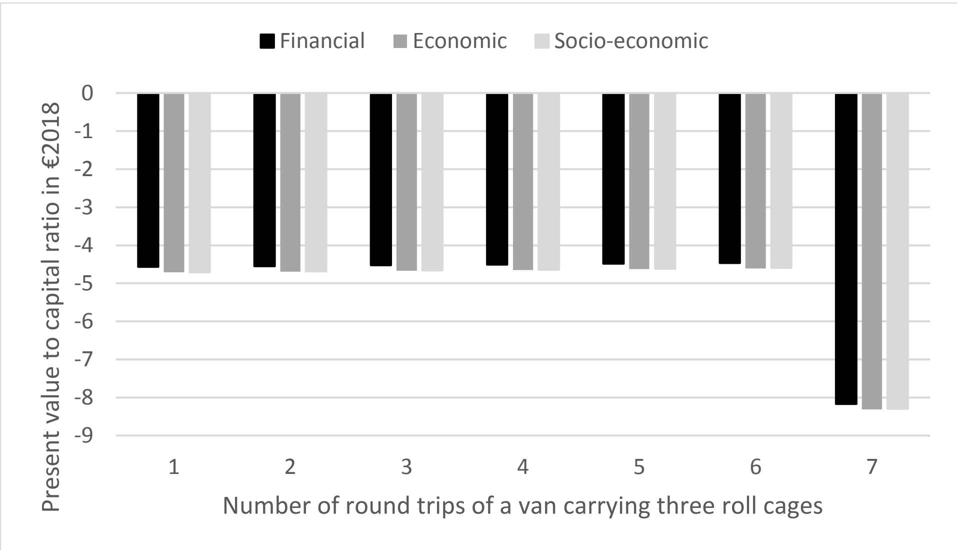
Table 101 – Present value to capital ratio per number of round trips of a van, dedicated freight tram

In 2018	Financial	Economic	Socio-economic
1 round trip	-4.57	-4.71	-4.71
2 round trips	-4.55	-4.69	-4.69
3 round trips	-4.53	-4.67	-4.66
4 round trips	-4.51	-4.65	-4.64
5 round trips	-4.49	-4.63	-4.62
6 round trips	-8.17	-4.61	-4.60
7 round trips	-8.17	-8.31	-8.30

Source: Own creation

The figures shown in Table 101 are graphically presented in Figure 146.

Figure 146 – Present value to capital ratio for a van, dedicated freight tram



Source: Own creation

Table 102 displays the underlying data used in Figure 107 and Figure 108.

Table 102 – Annual costs and benefits per number of round trips of a van, dedicated freight tram

Costs/Benefits in €2018	1 round trip	2 round trips	3 round trips	4 round trips	5 round trips	6 round trips	7 round trips
Operations	**-142,444**	**-158,139**	**-173,834**	**-189,529**	**-205,224**	**-220,919**	**-363,363**
Tram	-126,749	-126,749	-126,749	-126,749	-126,749	-126,749	-253,498
Pre-haulage	-4,229	-8,459	-12,688	-16,917	-21,146	-25,376	-29,605
Post-haulage	-3,404	-6,807	-10,211	-13,615	-17,019	-20,422	-23,826
Handling & storage	-8,062	-16,124	-24,186	-32,248	-40,310	-48,372	-56,434
Operational income	**15,853**	**31,706**	**47,559**	**63,412**	**79,265**	**95,118**	**110,971**
Consumer surplus change	**-3**	**-5**	**-8**	**-11**	**-13**	**-16**	**-19**
External cost savings	**848**	**2,643**	**4,438**	**6,233**	**8,029**	**9,824**	**10,672**
Net benefits per year	**-125,746**	**-123,795**	**-121,845**	**-119,895**	**-117,943**	**-115,993**	**-241,739**

Source: Own creation

Table 103 displays the figures used to set up Figure 109.

Table 103 – Net benefit per number of round trips of a van, dedicated freight tram

In €2018/parcel	Net private benefit	Net social benefit
1 round trip	-1.63	-1.62
2 round trips	-0.82	-0.80
3 round trips	-0.54	-0.53
4 round trips	-0.41	-0.39
5 round trips	-0.33	-0.31
6 round trips	-0.27	-0.26
7 round trips	-0.43	-0.41

Source: Own creation

Table 104 shows the net present values when scenarios 1-9 are added in scenario 10b. The scenarios are ranked according to a decreasing NPV.

Table 104 – NPVs and NPV changes for scenarios 1-9, dedicated freight tram

Scenario	FNPV (€2018)	% change	ENPV (€2018)	% change	SNPV (€2018)	% change
S4: Shortest tram path	-1,761,833	50.76%	-1,872,575	49.23%	-1,867,924	49.30%
S7: No pre- and post-haulage	-2,792,626	21.95%	-2,901,889	21.33%	-2,898,151	21.34%
S5: Free access tram network	-3,062,443	14.41%	-3,173,185	13.97%	-3,169,102	13.99%
S6: Ancillary revenue	-3,196,082	10.67%	-3,306,823	10.35%	-3,302,741	10.36%
S3: Unaccompanied tram leg	-3,248,010	9.22%	-3,358,752	8.94%	-3,354,669	8.95%
S2: Congestion on roads	-3,363,130	6.00%	-3,473,872	5.82%	-3,467,621	5.89%
S1: Road pricing vans	-3,531,816	1.29%	-3,642,557	1.25%	-3,638,475	1.25%
S9: Peak hour transport	-3,540,409	1.05%	-3,651,151	1.02%	-3,645,814	1.05%
S8: Changing external costs	-3,577,907	0.00%	-3,688,648	0.00%	-3,678,932	0.15%

Source: Own creation

Table 105 provides the resulting NPVs and change of the NPV is scenarios 1-9 are added gradually.

Table 105 – NPV and NPV change when scenarios 1-9 are added, dedicated freight tram

In €2018	**Financial**	**Economic**	**Socio-economic**
NPV S4	-1,761,833	-1,872,575	-1,867,924
% change of the NPV S4	50.76%	49.23%	49.30%
NPV S4+S7	-976,553	-1,085,816	-1,081,509
% change of the NPV S4+S7	72.71%	70.56%	70.65%
NPV S4-S5+S7	-782,956	-892,219	-887,912
% change of the NPV S4-S5+S7	78.12%	75.81%	75.90%
NPV S4-S7	-401,131	-510,394	-506,087
% change of the NPV S4-S7	88.79%	86.16%	86.26%
NPV S3-S7	-280,806	-386,491	-382,184
% change of the NPV S3-S7	92.15%	89.52%	89.63%
NPV S2-S7	-186,787	-279,103	-273,941
% change of the NPV S2-S7	94.78%	92.43%	92.57%
NPV S1-S7	-166,713	-254,812	-249,649
% change of NPV S1-S7	95.34%	93.09%	93.22%
NPV S1-S7+S9	-196,387	-290,465	-285,310
% change of the NPV S1-S7+S9	94.51%	92.13%	92.26%
NPV S1-S8	-166,713	-254,812	-243,788
% change of the NPV S1-S8	95.34%	93.09%	93.38%

Source: Own creation

Ultimately, based on the combination of scenarios 1-8 in scenario 10b, more round trips are added. The effect on the project outcome is shown in Table 106.

Table 106 – Project outcome when more round trips are added to scenario 10b, dedicated freight tram

	3 round trips	4 round trips	5 round trips	6 round trips	7 round trips
FNPV in €2018	-166,713	50,306	252,467	454,628	-1,313,463
ENPV in €2018	-254,812	51,446	357,704	663,963	-1,422,726
SNPV in €2018	-243,788	66,202	376,191	686,181	-1,397,231
FNPV to capital	-0.21	0.06	0.32	0.58	-1.69
ENPV to capital	-0.33	0.07	0.46	0.85	-1.83
SNPV to capital	-0.31	0.08	0.48	0.88	-1.79
FRR	-3.15%	0.83%	3.79%	6.40%	n/a
ERR	-2.56%	0.45%	2.90%	5.04%	n/a
SRR	-2.48%	0.59%	3.09%	5.31%	n/a

Source: Own creation

Appendix 17: Sensitivity and scenario analyses for a freight wagon attached to a passenger tram

This appendix provides underlying data and additional figures for the analysis of the use of a freight wagon attached to a passenger tram. The data provided in this appendix are complementary to Chapter 6.

Appendix 17.1: Outcome if a lorry of 12 tonnes is used in the reference case

Table 107 provides the data used to show the evolution of the NPVs shown in Figure 96.

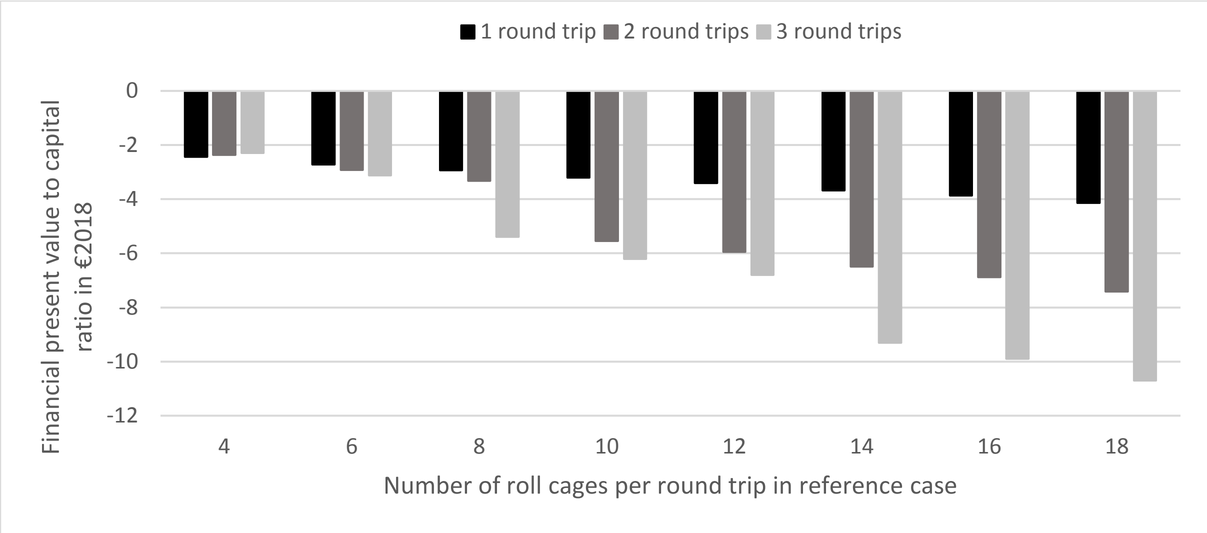
Table 107 – NPV per number of round trips and per number of roll cages, freight wagon

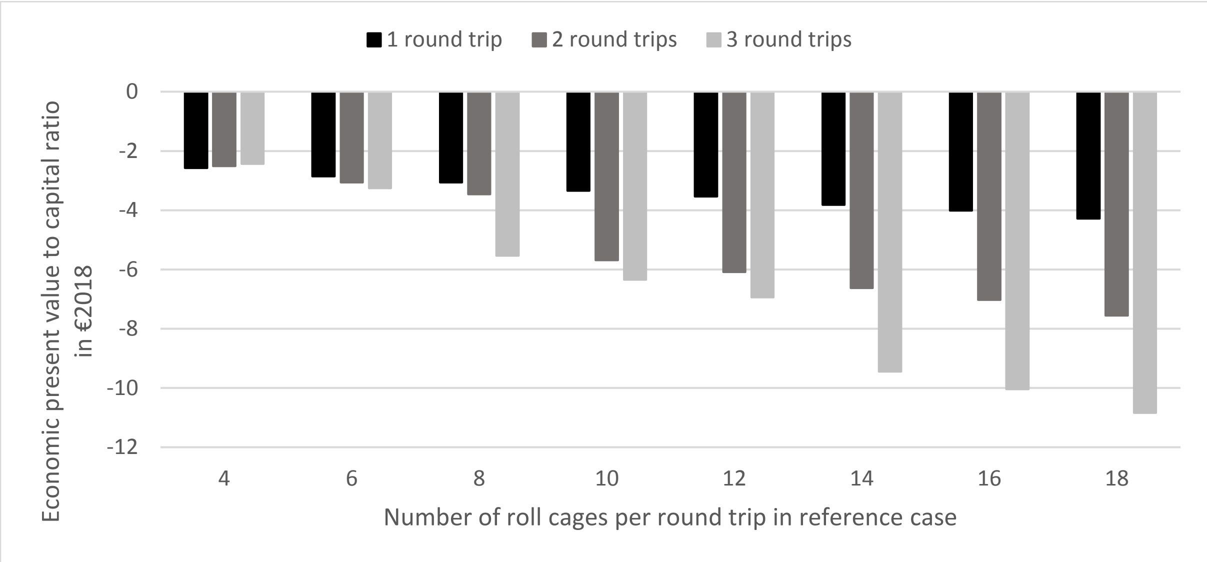
Number of roll cages in lorry	1 round trip	2 round trips	3 round trips
FINANCIAL NPV in €$_{2018}$			
4	-1,257,222	-1,230,111	-1,203,000
6	-1,408,559	-1,532,786	-1,657,012
8	-1,520,951	-1,757,569	-2,827,765
10	-1,672,288	-2,895,836	-3,278,757
12	-1,784,680	-3,118,605	-3,612,911
14	-1,936,017	-3,419,266	-4,902,516
16	-2,048,409	-3,642,036	-5,235,663
18	-2,199,746	-3,942,697	-5,685,648
ECONOMIC NPV in €$_{2018}$			
4	-1,329,479	-1,303,026	-1,276,572
6	-1,481,146	-1,606,358	-1,731,570
8	-1,593,866	-1,831,798	-2,901,337
10	-1,745,532	-2,969,079	-3,352,822
12	-1,858,252	-3,192,177	-3,687,469
14	-2,009,918	-3,493,167	-4,976,416
16	-2,122,638	-3,716,265	-5,309,892
18	-2,274,304	-4,017,255	-5,760,206
SOCIO-ECONOMIC NPV in €$_{2018}$			
4	-1,261,011	-1,158,412	-1,055,814
6	-1,412,716	-1,461,821	-1,510,927
8	-1,525,460	-1,687,310	-2,688,443
10	-1,677,179	-2,832,373	-3,140,086
12	-1,789,930	-3,055,533	-3,474,827
14	-1,941,663	-3,356,658	-4,771,652
16	-2,054,422	-3,579,833	-5,105,244
18	-2,206,169	-3,880,986	-5,555,802

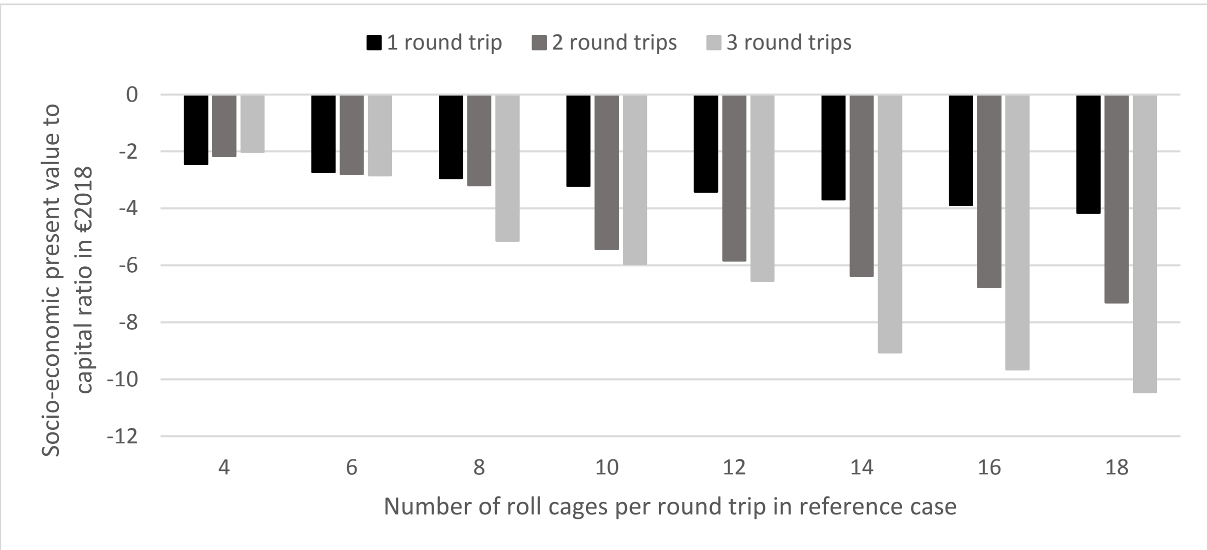
Source: Own creation

Figure 147 displays the related present value to capital ratio from a financial, economic and socio-economic perspective. The underlying data used for Figure 147 are presented in Table 108.

Figure 147 –Present value to capital ratios for a freight wagon







Source: Own creation

Table 108 – Background data present value to capital ratios for a freight wagon

Number of roll cages in lorry	1 round trip	2 round trips	3 round trips
FINANCIAL PRESENT VALUE TO CAPITAL RATIO (2018)			
4	-2.44	-2.37	-2.29
6	-2.72	-2.92	-3.12
8	-2.93	-3.32	-5.39
10	-3.20	-5.55	-6.21
12	-3.40	-5.95	-6.80
14	-3.68	-6.49	-9.31
16	-3.87	-6.88	-9.90
18	-4.14	-7.42	-10.70
ECONOMIC PRESENT VALUE TO CAPITAL RATIO (2018)			
4	-2.58	-2.51	-2.43
6	-2.86	-3.06	-3.26
8	-3.07	-3.46	-5.53
10	-3.34	-5.69	-6.35
12	-3.54	-6.09	-6.94
14	-3.82	-6.63	-9.45
16	-4.01	-7.02	-10.04
18	-4.28	-7.56	-10.84
SOCIO-ECONOMIC PRESENT VALUE TO CAPITAL RATIO (2018)			
4	-2.45	-2.16	-2.01
6	-2.73	-2.79	-2.84
8	-2.94	-3.19	-5.13
10	-3.21	-5.43	-5.95
12	-3.41	-5.83	-6.54
14	-3.69	-6.37	-9.06
16	-3.88	-6.77	-9.65
18	-4.15	-7.30	-10.46

Source: Own creation

Table 109 presents the net private and social benefit in euro per parcel.

Table 109 – Net benefit per number of round trips and per number of roll cages for a freight wagon

Number of roll cages in lorry	1 round trip	2 round trips	3 round trips
NET PRIVATE BENEFIT (in €$_{2018}$/parcel)			
4	-0.42	-0.21	-0.13
6	-0.32	-0.17	-0.13
8	-0.26	-0.15	-0.16
10	-0.23	-0.20	-0.15
12	-0.20	-0.18	-0.14
14	-0.19	-0.19	-0.16
16	-0.17	-0.16	-0.15
18	-0.17	-0.15	-0.15
NET SOCIAL BENEFIT (in €$_{2018}$/parcel)			
4	-0.39	-0.17	-0.10
6	-0.23	-0.15	-0.10
8	-0.24	-0.13	-0.15
10	-0.22	-0.19	-0.14
12	-0.19	-0.17	-0.13
14	-0.18	-0.16	-0.15
16	-0.17	-0.15	-0.14
18	-0.16	-0.14	-0.14

Source: Own creation

Table 110 displays the results of altering the financial and social discount rate. These data are used in Figure 98.

Table 110 – Effect of the change of the discount rate on the project outcome, freight wagon

Financial & social discount rate	2%	4%	8%
FNPV in €$_{2018}$	-1,935,513	-1,520,951	-1,044,566
ENPV in €$_{2018}$	-1,956,915	-1,593,866	-1,179,495
SNPV in €$_{2018}$	-1,865,390	-1,525,460	-1,137,476
Financial present value to capital ratio	-3.72	-2.93	-2.01
Economic present value to capital ratio	-3.77	-3.07	-2.27
Socio-economic present value to capital ratio	-3.59	-2.94	-2.19

Source: Own creation

Table 111 provides the underlying data used in Figure 100.

Table 111 – Sensitivity analyses, freight wagon

Variable increased by 1%	Absolute change variable (in €$_{2018}$/year)	Change ENPV
Rolling stock	5,103	-0.32%
Tram	369	-0.53%
Handling & storage	180	-0.26%
Post-haulage	94	-0.01%
Nodal infrastructure	47	-0.07%
Pre-haulage	46	-0.07%

Source: Own creation

Table 112 provides the NPVs and NPV changes when scenarios 2-9 are gradually added in scenario 10a for a freight wagon attached to a passenger tram.

Table 112 – NPV and NPV changes when scenarios 2-9 are added, freight wagon

In €2018	Financial	Economic	Socio-economic
NPV S4	-992,903	-1,065,818	-992,619
% change of the NPV S4	34.72%	33.13%	34.93%
NPV S4+S7	-475,429	-547,029	-479,676
% change of the NPV S4+S7	68.74%	65.68%	68.56%
NPV S4+S6-S7	-107,996	-165,204	-97,851
% change of the NPV S4+S6-S7	92.90%	89.64%	93.59%
NPV S3-S4+S6-S7	-16,740	-41,301	26,051
% change of the NPV S3-S4+S6-S7	98.90%	97.41%	101.71%
NPV S2-S4+S6-S7	6,894	-5,505	75,349
% change of the NPV S2-S4+S6-S7	100.45%	99.65%	104.94%
NPV S2-S4+S6-S7+S9	-951	-17,390	63,571
% change of the NPV S2-S4+S6-S7+S9	99.94%	98.91%	104.17%
NPV S2-S4+S6-S8	6,894	-5,505	160,632
% change of the NPV S2-S4+S6-S8	100.45%	99.65%	110.53%

Source: Own creation

Table 113 provides the NPVs, present value to capital ratios and IRRs when more round trips are added in scenario 10a. These data are used in Figure 137.

Table 113 – Project outcome when more round trips are added to scenario 10a, freight wagon

	1 round trip	2 round trips	3 round trips	4 round trips	5 round trips
FNPV in €2018	6,894	215,917	215,284	424,307	423,674
ENPV in €2018	-5,505	311,148	310,189	626,842	625,883
SNPV in €2018	159,393	642,386	806,326	1,289,320	1,453,259
FNPV to capital	0.01	0.42	0.42	0.83	0.83
ENPV to capital	-0.01	0.61	0.61	1.23	1.23
SNPV to capital	0.31	1.26	1.58	2.53	2.85
FRR	0.18%	4.82%	4.81%	8.73%	8.72%
ERR	-0.08%	3.75%	3.74%	6.94%	6.93%
SRR	2.03%	7.09%	8.63%	12.91%	14.31%

Source: Own creation

Appendix 17.2 Outcome if a van of 3.5 tonnes is used in the reference case

In Scenario 1, it is investigated how the viability of the tram-based project alters if the reference case is executed by vans instead of lorries. Table 114 shows the resulting NPVs for a different number of round trips.

Table 114 – NPV per number of round trips of a van, freight wagon

	FNPV (in €2018)	ENPV (in €2018)	SNPV (in €2018)
1 round trip	-1,205,672	-1,277,765	-1,244,273
2 round trips	-1,127,010	-1,199,596	-1,124,936
3 round trips	-1,048,349	-1,121,428	-1,005,599
4 round trips	-969,687	-1,043,259	-886,262
5 round trips	-891,026	-965,091	-766,925
6 round trips	-812,365	-886,923	-647,588
7 round trips	-1,569,295	-1,642,703	-1,369,877

Source: Own creation

Table 115 shows the financial, economic and socio-economic present value to capital ratio per number of round trips executed in the reference case.

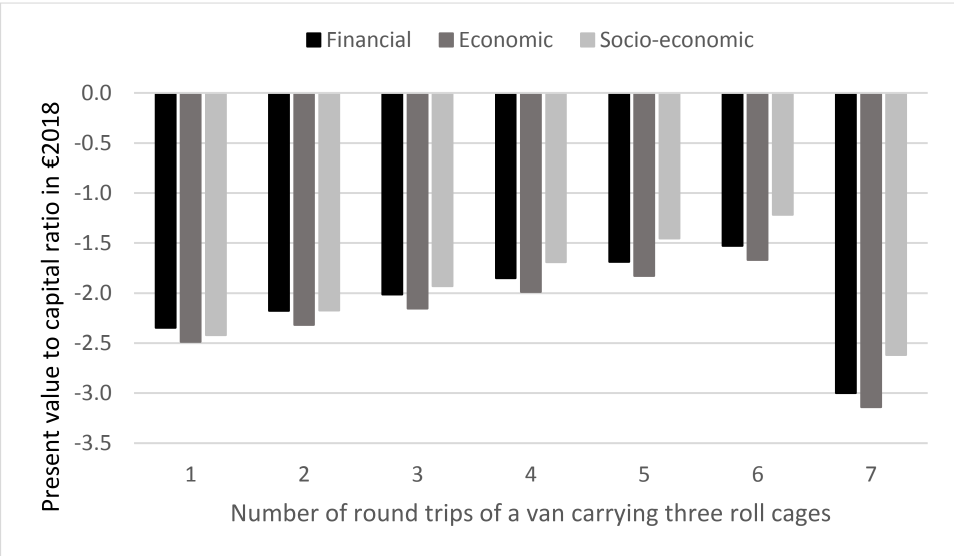
Table 115 – Present value to capital ratio per number of round trips of a van, freight wagon

In 2018	Financial	Economic	Socio-economic
1 round trip	-2.35	-2.49	-2.42
2 round trips	-2.18	-2.32	-2.17
3 round trips	-2.01	-2.15	-1.93
4 round trips	-1.85	-1.99	-1.69
5 round trips	-1.69	-1.83	-1.45
6 round trips	-1.53	-1.67	-1.22
7 round trips	-3.00	-3.14	-2.62

Source: Own creation

The figures shown in Table 115 are graphically presented in Figure 148.

Figure 148 – Present value to capital ratio for a van carrying three roll cages, freight wagon



Source: Own creation

Table 116 displays the underlying data used in Figure 115.

Table 116 – Annual costs and benefits per number of round trips of a van, freight wagon

Costs/Benefits in €2018	1 round trip	2 round trips	3 round trips	4 round trips	5 round trips	6 round trips	7 round trips
Operations	**-49,147**	**-61,441**	**-73,734**	**-86,028**	**-98,321**	**-110,615**	**-159,761**
Tram	-36,854	-36,854	-36,854	-36,854	-36,854	-36,854	-73,708
Pre-haulage	-4,229	-8,459	-12,688	-16,917	-21,146	-25,376	-29,605
Post-haulage	-1,298	-2,596	-3,894	-5,192	-6,490	-7,788	-9,085
Handling & storage	-6,766	-13,532	-20,298	-27,065	-33,831	-40,597	-47,363
Operational income	**15,853**	**31,706**	**47,559**	**63,412**	**79,265**	**95,118**	**110,971**
Consumer surplus change	**-1.18**	**-2.37**	**-3.55**	**-4.74**	**-5.92**	**-7.10**	**-8.29**
External cost savings	**1,461**	**3,256**	**5,051**	**6,847**	**8,642**	**10,437**	**11,898**
Net benefits per year	**-31,834**	**-26,481**	**-21,128**	**-15,774**	**-10,420**	**-5,067**	**-36,900**

Source: Own creation

Table 117 displays the figures used to set up Figure 116.

Table 117 – Net benefit per number of round trips of a van, freight wagon

In €2018/parcel	Net private benefit	Net social benefit
1 round trip	-0.54	-0.52
2 round trips	-0.25	-0.23
3 round trips	-0.16	-0.13
4 round trips	-0.11	-0.08
5 round trips	-0.08	-0.06
6 round trips	-0.06	-0.04
7 round trips	-0.10	-0.08

Source: Own creation

Table 118 shows the net present values when scenarios 1-9 are added in scenario 10b. The scenarios are ranked according to a decreasing NPV.

Table 118 – NPVs and NPV changes for scenarios 1-9, freight wagon

Scenario	FNPV (€2018)	% change	ENPV (€2018)	% change	SNPV (€2018)	% change
S4: Shortest tram path	-520,301	50.37%	-593,380	47.09%	-472,758	52.99%
S7: No pre- and post-haulage	-497,238	52.57%	-568,838	49.28%	-526,302	47.66%
S6: Ancillary revenue	-666,524	36.42%	-739,603	34.05%	-623,774	37.97%
S3: Unaccompanied tram leg	-718,452	31.47%	-791,531	29.42%	-675,702	32.81%
S2: Congestion on roads	-833,572	20.49%	-906,651	19.15%	-741,289	26.28%
S8: Changing external costs	-1,048,349	0.00%	-1,121,428	0.00%	-878,174	12.67%
S9: Peak hour transport	-1,010,851	3.58%	-1,083,930	3.34%	-940,027	6.52%
S1: Road pricing vans	-1,002,258	4.40%	-1,075,337	4.11%	-959,508	4.58%
S5: Free access tram network	-1,048,349	0.00%	-1,121,428	0.00%	-1,005,599	0.00%

Source: Own creation

Table 119 provides the resulting NPVs and change of the NPV is scenarios 1-9 are added gradually.

Table 119 – NPV and NPV change when scenarios 1-9 are added, freight wagon

In €2018	**Financial**	**Economic**	**Socio-economic**
NPV S4	-520,301	-593,380	-472,758
% change of the NPV S7	50.37%	47.09%	52.99%
NPV S4+S7	-16,397	-40,791	72,640
% change of the NPV S4+S7	98.44%	96.36%	107.22%
NPV S4+S6-S7	235,645	341,035	454,465
% change of the NPV S4+S6-S7	122.48%	130.41%	145.19%
NPV S3-S4+S6-S7	317,433	464,937	578,367
% change of the NPV S3-S4+S6-S7	130.28%	141.46%	157.51%
NPV S2-S4+S6-S7	388,320	572,325	705,368
% change of the NPV S2-S4+S6-S7	137.04%	151.04%	170.14%
NPV S2-S4+S6-S8	388,320	572,325	842,817
% change of the NPV S2-S4+S6-S8	137.04%	151.04%	183.81%
NPV S2-S4+S6-S9	364,786	536,672	807,510
% change of the NPV S2-S4+S6-S9	134.80%	147.86%	180.30%
NPV S1-S4+S6-S8	404,355	596,616	867,108
% change of the NPV S1-S4+S6-S8	138.57%	153.20%	186.23%

Source: Own creation

Ultimately, based on the combination of scenarios 1-8 in scenario 10b, more round trips are added. The effect on the project outcome is shown in Table 120.

Table 120 – Project outcome when more round trips are added to scenario 10b, freight wagon

	3 round trips	4 round trips	5 round trips	6 round trips	7 round trips
FNPV in €2018	404,355	606,516	808,677	1,010,838	1,003,343
ENPV in €2018	596,616	902,874	1,209,133	1,515,391	1,504,037
SNPV in €2018	734,289	1,086,919	1,439,549	1,792,179	1,825,755
FNPV to capital	0.79	1.19	1.59	1.98	1.97
ENPV to capital	1.17	1.77	2.37	2.97	2.95
SNPV to capital	1.44	2.13	2.82	3.51	3.58
FRR	8.37%	11.91%	15.31%	18.66%	18.54%
ERR	6.65%	9.51%	12.21%	14.84%	14.74%
SRR	7.96%	11.15%	14.20%	17.17%	17.46%

Source: Own creation

Appendix 18: Sensitivity and scenario analyses for freight alongside passengers

This appendix provides the background data used in Chapter 6 for the scenario and sensitivity analyses with respect to the transport of freight alongside passengers.

Table 121 presents the underlying data about the net private and social benefit when more round trips are added, which are used in Figure 102.

Table 121 – Net benefit per number of round trips, freight alongside passengers

In €$_{2018}$/parcel	Net private benefit	Net social benefit
1 round trip	0.76	1.84
2 round trips	0.86	1.94
3 round trips	0.89	1.97
4 round trips	0.91	1.99
5 round trips	0.92	2.00
6 round trips	0.92	2.00
7 round trips	0.93	2.01
8 round trips	0.93	2.01
9 round trips	0.93	2.01
10 round trips	0.94	2.01

Source: Own creation

Table 122 displays the annual operational costs for the different legs of the urban rail freight supply chain when parcels are transported alongside passengers. These data are used in Figure 104.

Table 122 – Annual operational costs per number of round trips, freight alongside passengers

In €$_{2018}$	Tram	Pre-haulage	Post-haulage	Handling & storage	Total
1 round trip	9,060	4,229	1,298	0	14,587
2 round trips	17,796	8,459	2,596	0	28,851
3 round trips	26,532	12,688	3,894	0	43,114
4 round trips	35,268	16,917	5,192	0	57,377
5 round trips	44,004	21,146	6,490	0	71,640
6 round trips	52,740	25,376	7,788	0	85,904
7 round trips	61,476	29,605	9,085	0	100,166
8 round trips	70,212	33,834	10,383	0	114,429
9 round trips	78,948	38,064	11,681	0	128,693
10 round trips	87,684	42,293	12,979	0	142,956

Source: Own creation

In Figure 105, sensitivity analyses are performed. Table 123 provides the background data for this figure.

Table 123 – Net benefit and net benefit change, freight alongside passengers

Variable increased by 1%	Net private benefit (€2018/parcel)	% change net private benefit	Net social benefit (€2018/parcel)	% change net social benefit
Operational income	0.86	12.52%	1.93	5.18%
Time needed in reference case	0.84	9.96%	1.92	4.12%
Labour cost	0.76	-0.04%	1.84	-0.02%
Post-haulage	0.75	-1.03%	1.83	-0.42%
Pre-haulage	0.74	-3.34%	1.81	-1.38%
Tram	0.71	-7.16%	1.78	-2.96%
Operational costs	0.67	-11.52%	1.75	-4.77%

Source: Own creation