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The importance of external costs for assessing the potential of trams and trains for urban freight distribution

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Abstract

As a solution for increasing urban freight distribution issues, such as rising vehicle movements, more environment-friendly transport modes including rail could be an option. So far, investigation within this domain has been confined primarily to applying (social) cost-benefit analyses to specific cases. These existing (social) cost-benefit analyses show the importance of external costs in the profitability calculations of urban rail freight initiatives. Therefore, accurate and appropriate external cost data are crucial for the robustness of a social cost-benefit framework. This paper identifies firstly the external cost elements related to the use of trams and trains for urban freight distribution. Secondly, a range of common external cost values is provided for Belgian and Flemish urban areas. A minimum and maximum value is determined for each external cost, when available data allowed this. In further research, these values will be used as input for a generic social cost-benefit framework to assess the potential of trains and trams for urban freight distribution.

Keywords: Urban freight distribution; rail; external costs

1. Introduction

Urban freight distribution is influenced by several trends, including increasing freight transport, growing population as well as urbanisation and an increasing sustainability awareness (Behrends, 2012; Meersman et al., 2015). This often leads to increasing urban freight distribution issues, such as more vehicle movements. As a solution, more environment-friendly transport modes such as rail transport could be an option (Arvidsson & Browne, 2013; Behrends, 2012; European Commission, 2011; Ruesch, 2001). So far, investigation within this domain has been confined primarily to applying social cost-benefit analyses (SCBA) to specific cases. These analyses do not measure the same variables and cannot be transferred as such from one case to another (Alessandrini, Delle Site, Filippi, & Valerio Salucci, 2012; De Langhe, 2014; Delaître & De Barbeyrac, 2012; Filippi, 2014; Gonzalez-Feliu, 2014, 2016; Köhler, 2000; Nuzzolo, Crisalli, & Comi, 2007; Regué & Bristow, 2013). Therefore, this research comprises the development of a generic social cost-benefit framework for assessing the feasibility of rail for the transport of goods towards, from and within urban areas. When referring to rail transport in this paper, the use of trams or trains is meant.

An investigation of the external costs plays an important role in the development of an SCB-framework (Lammgård, 2012; Mostert, Caris, & Limbourg, 2017). The rationale is twofold. Firstly, 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) developed a multimodal urban distribution centre scheme for Rome in which rail shuttles are used for the transport between the city centre and the hinterland. For the transport in the city centre, either conventional or hybrid vehicles are used. The same authors find that the benefits 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) developed a freight tram scheme for Barcelona. 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, accounting for 6.2% of the total benefits. When making abstraction of the benefits related to value added and stockholding activities and reverse logistics, externalities account for 33% of total benefits, while freight tram operations savings explain 67% of the benefits.

Secondly, 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. The European handbook on external costs of transport (Korzhenevych et al., 2014) offers a general overview of

different externalities and related values. However, this handbook has three main shortcomings with respect to urban rail freight transport. First of all, it does not focus on the comparison of road and rail urban freight transport as such. Moreover, it often has to be combined with other sources that offer more appropriate and detailed information for this specific research topic. The handbook contains average externalities values, while in some cases the average externality values might not be appropriate for the specific case. Ultimately, no comparison of externalities and related values for specific small regions is made.

The objective of this paper is twofold. Firstly, the external costs that have to be included in an SCBA of rail transport for urban freight distribution are identified. Secondly, common values of the external costs are determined, which will be used to quantify the external costs in the generic social cost-benefit framework developed in further research. The research strategy of this paper consists of an in-depth analysis of existing external cost literature. The scope of the analysis is Europe for the typology of external costs and Belgium for the determination of external cost values. External costs differ depending on the context in which they appear. Since the cost-benefit framework will be applied to Belgium and an in-depth analysis of rail-based urban freight distribution external costs in Belgium has not yet been done, external cost figures for Belgium are the focus of this paper. The remainder of this paper is structured as follows. Section 2 gives an overview of the literature review. Section 3 explains the research strategy. Section 4 offers the results and discussion, while Section 5 provides the conclusions and research implications.

2. Literature review

External costs are a main topic 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 (1985, 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*”.

Table 1 gives a non-exhaustive overview of academic papers that use external cost figures in their research and/or discuss the use of rail transport in urban freight distribution. The authors are listed in chronological order and evaluated for the transport mode included, the urban versus interurban scope and the external costs examined.

The first observation of Table 1 concerns the transport mode used. The modes considered in this research are trucks, trams and trains. The incorporation of trucks is important as a benchmark. External costs of the rail transport can be compared in the SCBA to those of the road transport. Only a few papers discuss the external costs related to the use of rail freight transport. Mayeres et al. (1996), den Boer et al. (2008), Regué & Bristow (2013), Gorçun (2014), Kim & van Wee (2014) and Zych (2014) discuss the external effects of trams and road transport, although Mayeres et al. (1996) only consider passenger transport and Zych (2014) only makes a qualitative analysis. Beuthe et al. (2002), Nijland & van Wee (2005), Andersson & Ögren (2007), Janic (2007), den Boer et al. (2008), De Nocker et al. (2010), Alessandrini et al. (2012) and Korzhenevych et al. (2014) examine the external effects of trains and road transport.

Secondly, it can be observed that not all papers determine their geographical scope. An urban scope means either that the external costs are measured in a city centre, or that the terminology “urban” is used in the original paper. Interurban means that the figures concern transport between cities, or that the terminology “interurban”, or “rural” is used in the original 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.

The third observation is related to the external costs examined in the papers. Some papers deal with multiple external cost categories, others focus on one category. Most of the 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 other external costs. Not any of the papers dealing with the external costs of road transport and trams provides an analysis of all external cost categories.

Table 1. Literature review external costs road versus rail transport

Author (s) (year)	Mode			Scope		External costs examined						
	Truck	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				
De Langhe et al. (2012)	X				X	X	X				X	
European Environment Agency (2013)							X					
Regué & Bristow (2013)	X	X		X		X	X	X	X	X	X	
Korzhenevych et al. (2014)	X		X	X	X	X	X	X	X	X	X	X
Gorçun (2014)	X	X		X				X				
Kim & van Wee (2014)	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	

Source: Own composition

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. More specifically, these authors state that the external costs caused by a truck 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 Dablanç (2009), who relates freight activities to the population.

Table 2 shows an application of these relationships between number of loading/unloading operations, number of truck trips and number of freight tons on the one hand and the population on the other hand for the two largest cities of Belgium, being Brussels and Antwerp. Both cities are listed high in the TomTom Traffic Index (TomTom, 2015), meaning that they suffer from congestion. This table shows that urban areas with higher population densities, experience more loading and unloading operations,

more truck trips and generate more tons of freight. As a result, external costs due to freight activities differ in these two urban areas.

Table 2. Relationship population – freight activities

City	Number of inhabitants (01/01/15)	Number of loading/ unloading operations (per year, in 1,000)	Number of truck trips (per year, in 1,000)		Number of freight tons (per year, in 1,000)	
			Minimum	Maximum	Minimum	Maximum
Antwerp	513,570	18,745	56,236	74,981	15,407	20,543
Brussels	1,175,173	42,894	128,681	172,000	35,255	47,006

Source: Own composition based on Dablanç (2009) and FOD Economie (2015)

3. Research strategy

The three-step research strategy applied in this paper is shown in Figure 1. Firstly, relevant external cost categories are selected from the existing literature. Secondly, urban (rail) freight external costs are identified. Thirdly, external cost values are collected for each of these external cost categories. As such, a database was built, including all relevant monetary values and their characteristics. In the database, all cost values are discounted to the same base year. Based on the external cost values available in the database, the minimum and the maximum value for each external cost category is defined. These three steps are now discussed more in detail in the next sections.

Figure 1. Research strategy

3.1 Step 1: Selection of relevant external cost categories

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. As a result, they are only of limited relevance for the calculation of the marginal external costs of using rail transport.

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. Therefore, the focus of this analysis is on the environmental costs of air pollution, climate change and noise. Other categories, such as the loss of nature, the loss of space or odour nuisance are mentioned by for instance Delhayé et al. (2012), but are by the same authors not included in the analysis of external costs for transport projects. When new transport infrastructure is considered, landscape contamination has to be included as an additional factor (den Boer et al., 2008). This is not the case in this research, since new infrastructure is beyond the scope of this paper.

The European Commission uses the European handbook on external costs of transport (Korzheneych et al., 2014), of which previous versions were developed by Maibach et al. (2008) and van Essen et al. (2011). The most recent version of the handbook proposes seven external costs categories: accidents, air pollution, congestion, climate change, marginal infrastructure costs, noise and up- and downstream processes. The remainder of this paper is structured according to this classification of seven categories, since it is the most complete classification, covering all the classification categories by other authors.

3.2 Step 2: Identification of urban (rail) freight external costs

The second step in the analysis is to identify which urban (rail) freight external costs are relevant (see Figure 2).

Figure 2. Main urban rail freight external costs factors

Source: Own composition

3.2.1 Accidents

Blauwens et al. (2016) define the marginal road 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 road vehicle makes traffic more dangerous to other road users. Other factors, such as traffic regulations, or promoting road 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). Mainly the accidents between a tram or train and a road vehicle, cyclist, pedestrian have to be considered in an urban rail freight context. Forkenbrock (2001) elaborates on the marginal rail accident costs. These costs depend on i.a. the topography, the tracks and weather conditions and specific train and operator conditions.

3.2.2 Air pollution

Air pollution caused by transport includes emissions of nitrogen oxides (NO_x), lead (Pb), particulate matter (PM₁₀), sulfur dioxide (SO₂) and volatile organic compounds (VOC) (Mayeres et al., 1996). A distinction has to be made between diesel-driven and electricity-driven rail vehicles. Diesel-driven rail vehicles account for direct air pollution that consists of exhaust and non-exhaust emissions. The exhaust emissions of the diesel rail vehicles are evaluated in the same way as the road exhaust emissions (Korzhenevych et al., 2014). Exhaust emissions originate from the burning of fuel, while non-exhaust emissions result from the emissions from wear and tear of tires and brakes (Rebel, 2013). Electricity-driven rail vehicles, such as electric trains and trams, do not cause local air pollution. Important to note here is that up-and downstream emissions due to electricity generation have to be taken into account. However, these emissions do not appear in the urban area itself, but at the location of electricity generation. In case this happens in rural areas, the population is less dense and thus, the actual exposure to the air pollution is lower.

3.2.3 Climate change

Climate change is brought about by the emission of greenhouse gases, such as carbon monoxide (CO) and carbon dioxide (CO₂). De Nocker et al. (2010) and Delhayé et al. (2012) add the emissions of methane (CH₄) and nitrous oxide (N₂O) to this category of emissions that evoke climate change and De Nocker et al. (2010) also mention sulfur hexafluoride (SF₆) emissions. The amount of CO₂ emitted is related to the fuel consumption of the vehicle doing the transport and the type of fuel used (ICF Consulting, 2006). The CO₂ emissions of rail transport are related to the fuel consumption of the freight trains. As a result, only diesel freight trains cause direct climate change emissions. The potential indirect emissions caused by electric freight trains are considered under the category of up- and downstream emissions (Korzhenevych et al., 2014).

3.2.4 Congestion

Congestion is present when “*an additional vehicle [...] reduces the speed of the other vehicles*” (Mayeres et al., 1996). 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). Specifically for trams, congestion costs related to the road transport may exist. 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 will 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 city 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).

3.2.5 Infrastructure damage

Marginal infrastructure costs are defined by Blauwens et al. (2016) 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 [infrastructure] maintenance and repair expenditures that are induced by higher traffic levels*”. With respect to rail transport, potential rail damage is included in the rail access charges (Blauwens et al., 2016). However, damage to the road infrastructure caused by the trams or trains should be taken into account.

3.2.6 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 is measured during a certain period of time and at a certain time of the day (Le Maître, 2015). With respect to noise emissions due to rail transport, especially the braking and starting of the rail vehicles, as well as the act of driving on the tracks itself have to be mentioned. The noise level of rail transport depends on the traffic volume, the distance to the noise emission source and other factors such as barriers, traffic composition and ground characteristics (Andersson & Ögren, 2007; Le Maître, 2015). Depending on the time of the day, i.e. daytime versus night time, or peak versus off-peak time, 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.

3.2.7 Up- and downstream processes

Up- and downstream processes are activities that occur outside the transport market. Delhayé et al. (2012) and Rebel (2013) describe up- and downstream emissions as indirect emissions resulting from the production of fuel 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. The external up- and downstream costs are especially important to mention when electric trains or trams are used. The way of electricity generation is crucial to reliably estimate the up- and downstream emissions costs. In 2009 in Belgium, 50.9% of the electricity production originated from nuclear power, 32.6% from natural and derived gas, 8.5% from renewables, 5.6% from coal and lignite, 1.8% from other fuels and 0.6%

from oil (European Environment Agency, 2012).

3.2.8 Synopsis

In order to get a detailed insight in the external costs that are of main importance for the evaluation of rail transport for urban freight distribution, existing urban rail case studies are analysed with respect to the external costs they measure. Table 3 displays the existing case studies for which external cost data 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, CO₂, NO_x, PM, SO₂ and VOCs. As a comparison, Meersman et al. (2015) mention in descending order NO_x, CO, NMVOS and PM as the main emissions resulting from road transport.

Table 3. External costs calculated in urban rail freight transport

Author(s) (year)	Mode	Case study	External costs
Alessandrini et al. (2012)	Train	Rome	CO, CO ₂ , HC, NO _x , PM, electricity consumption
Regué & Bristow (2013)	Tram	Barcelona	Accidents, congestion, infrastructure damage, noise, CO ₂ , NO _x , PM ₁₀ , SO ₂ , VOCs
Gorçun (2014)	Tram	Istanbul	Energy consumption, environmental pollution

Source: Own composition

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 effect 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. The European Environment Agency (2013) argues that NO_x emissions cover a larger geographical scope than PM_{2.5} emissions. The latter are local emissions, which affect the nearby population. However, in densely populated urban areas, PM_{2.5} emissions may result in higher external costs than NO_x 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 PM_{2.5} external costs above national levels. For Belgium, the listed urban areas are Antwerp, Brussels and Liege. In the city of Brussels, the life expectancy of people of 30 years and older could be increased by seven months per person by reducing the air pollution to the level of 10 µg/m³ of PM₁₀ (Aphekom, 2011).

3.3 Step 3: Selection of minimum and maximum values and discounting

The third step in this analysis is related to the determination of a min-max range of external cost values that can be applied to Belgium. Firstly, external cost figures of freight transport by respectively light goods vehicles (LGVs) of less than 12 tons and trams and trains are collected from the literature review conducted in step 1 and step 2. Figures concerning Belgium and Flanders are selected. 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. A distinction is made between monetary (e.g. euro/kg) and non-monetary values (e.g. g/km). Secondly, all monetary values are converted to euro values. Since only values for Belgium are selected, the only non-euro currency present is the ECU. The ECU is the ancestor of the euro¹. Thirdly, all monetary values are discounted to 2014 values. This is done based on the purchasing power index proposed by Rebel (2013), which is expressed in Formula (1):

$$PPI_{st} = \frac{GDP_t}{GDP_s} * \frac{POP_s}{POP_t} \quad (1)$$

in which

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

¹ On the 1st of January 1999, the ECU became the Euro. The exchange rate is 1 ECU = 1 EUR (ECB, 2015).

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 (2015a, 2015b). Concerning the congestion costs, an additional adaptation is made. An elasticity value of 75% is taken into account to correct for the value of time that is not related to the GDP (Gérard et al., 2015; Rebel, 2013). 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.

4. Results and discussion

Based on the existing literature, the minimum and maximum values for each external cost category, are presented in Table 4 for light goods vehicles (LGVs), (freight) trains and passenger trams. The term 'light goods vehicles' refers to trucks or vans of less than 12 tons. Figures for freight trains are used where possible, but sometimes had to be complemented by figures of passenger trains. When the term 'rail' is mentioned in Table 4, this means that both freight and passenger data are used to calculate the figure. Passenger tram external cost figures are used as an approximation for freight tram figures here, since no freight tram external cost figures are available for Belgium. For the LGVs, only urban external cost figures are considered. Trams only operate in an urban context in Belgium, while train figures are applicable to Belgium.

The values are expressed in euro₂₀₁₄ 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, it is the vehicles that are compared to each other. Therefore, the choice of using vehicle-kilometre and not ton-kilometre is made. 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. In the study of Mayeres et al. (1996), a peak tram is considered to have 40 passengers on board. Assuming an average weight of 80 kg per passenger, the capacity of one freight tram is 3.2 ton. This equals more or less an LGV of 3.5 ton which does not operate at full capacity. As of 2014, new trams have a theoretical capacity of around 16 tons in Flanders. In this case, one tram substitutes more than one LGV, leading to lower external costs of transporting a certain amount of goods by tram than by road.

Table 4 shows a range of external cost values between which the external cost in a certain context is situated. The minimum and maximum values cannot be compared to each other as such, since they result from different assumptions. These assumptions are partly shown in the description of the cost in Table 4. 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. Delhay et al. (2012) 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) and Gérard et al. (2015) consider goods vehicles below 12t as light goods vehicles, while Korzhenevych et al. (2014) define light goods vehicles as vehicles below 3.5t. Due to these different definitions, comparisons between figures of different authors become more difficult.

Secondly, figures coming from one source are not necessarily identical anymore after being converted by different authors to the same base year. Gérard et al. (2015) updated the figures of Rebel (2013) for their research. However, when converting the figures from both sources to values of 2014, slightly different values are obtained. This means that differences between the minimum and maximum values can partially be explained by different converting methods used by different authors.

The results of the analysis are now discussed more in depth for the different external cost categories.

Table 4. Minimum and maximum values of external costs of LGV, train and tram in €/vkm (price level of 2014)

External cost	Mode	Minimum value			Maximum value		
		Source	Description	Value (in €/vkm)	Source	Description	Value (in €/vkm)
Accidents	LGV	Mayeres et al. (1996)	Peak, light injury, Brussels	0.00294	Mayeres et al. (1996)	Off-peak, all injuries, Brussels	0.51605
	Train	Delhay et al. (2012)	Rail, injuries	0.02013	Rebel (2013)	Average freight train, Belgium	0.37473
	Tram	Mayeres et al. (1996)	Off-peak, light injury, Brussels	0.11170	Rebel (2013)	Average, Belgium	0.79394
Air pollution	LGV	Korzhenevych et al. (2014)	Light commercial petrol vehicle (<3.5t), euro 5/6, Belgian urban areas	0.00537	Blauwens et al. (2012)	Heavy goods vehicle, Belgian urban areas	0.32178
	Train	Delhay et al. (2012)	Diesel freight train, including CO ₂ , Flanders	0.47801	Rebel (2013)	Average freight train, Belgium	0.93175
	Tram	Mayeres et al. (1996)	Off-peak, Brussels	1.05755	Mayeres et al. (1996)	Peak, Brussels	1.05755
Climate change	LGV	Gérard et al. (2015)	Light goods vehicles (<12t), Flemish urban roads	0.01075	Delhay et al. (2012)	Road, CO ₂ , Belgian urban areas	0.02000
	Train			n.a.	Rebel (2013)	Average freight train, Belgium	0.37937
	Tram			n.a.			n.a.
Congestion	LGV	Mayeres et al. (1996)	Off-peak truck, Brussels	0.00927	Korzhenevych et al. (2014)	Articulated truck, over-capacity traffic, Belgian metropolitan area, other roads	8.85430
	Train	Rebel (2013)	Rail, Belgium	0.00000	Korzhenevych et al. (2014)	Rail freight, Belgium	0.00052
	Tram	Mayeres et al. (1996)	Off-peak, Brussels	0.01696	Mayeres et al. (1996)	Off-peak, Brussels	0.07026
Infrastructure	LGV	Beuthe et al. (2002)	Unloaded light truck (<10t), Belgium	0.00005	Delhay et al. (2012)	Truck, renewal (high), Belgium	1.53776
	Train	Delhay et al. (2009)	Renewal and maintenance (low), Flanders	0.00081	Delhay et al. (2009)	Operational costs (high), Flanders	0.04082
	Tram			n.a.			n.a.
Noise	LGV	Mayeres et al. (1996)	Peak truck, Brussels	0.01708	Korzhenevych et al. (2014)	Light goods vehicles, night, thin traffic, Belgian urban area	0.45872
	Train	Delhay et al. (2012)	Rail, Flanders	0.03671	Korzhenevych et al. (2014)	Freight train, night, Belgian urban area	2.53306
	Tram	Mayeres et al. (1996)	Peak, Brussels	0.01696	Mayeres et al. (1996)	Off-peak, Brussels	0.07026
Up- and downstream processes	LGV			n.a.			n.a.
	Train			n.a.			n.a.
	Tram			n.a.			n.a.
Column total	LGV			0.04545			11.70862
	Train			0.53566			4.26025
	Tram			1.20317			1.99201

Source: Own composition

4.1 Accidents

With respect to the external accident costs, the range of LGVs varies between 0.00294 €/vkm and 0.51605 €/vkm. The minimum value of a train, 0.02013 €/vkm, is higher than the minimum value of an LGV, while the maximum value of a train, 0.37473 €/vkm, is lower than the one of LGVs (0.51605 €/vkm). The minimum and maximum values of transport by tram, respectively 0.11170 €/vkm and 0.79394 €/vkm are both higher than the ones of LGVs.

A remark has to be made regarding these figures. As a subdivision of the accident costs, Mayeres et al. (1996, p. 124) distinguish among motorised and non-motorised accident costs. These authors define the motorised accident cost as the cost of an “*accident with victims who are occupants of a motorised vehicle*” and the non-motorised accident cost as the cost of “*non-motorised road users of being victims in an accident with a motorised vehicle*”. When only examining the motorised costs, it appears that the costs of an LGV are higher than the ones of a tram. When investigating only the non-motorised costs, the ones of a tram are higher than the ones of an LGV. An additional remark here is that the external accident costs of a freight tram can be considered to be lower than the ones of a passenger tram, displayed in Table 4, since no passengers are potentially involved in an accident of a freight tram.

4.2 Air pollution and climate change

Concerning the external air pollution costs, the costs of an LGV are lower than the ones of a train or tram. The costs of an LGV are mainly the result of high NO_x emissions, accounting for 63% and 68% of total external air pollution costs of LGVs, respectively during peak and off-peak hours. Some additional remarks have to be made.

Firstly, the external air pollution costs of a tram displayed in Table 4 include the external climate change costs. This is also partly the case for a train and for an LGV, where the air pollution cost comprises the costs of CO₂ in the work of Delhay et al. (2012). This finding is in line with the existing literature, where air pollution and climate change are often taken together under the terminology of environmental pollution (Blauwens et al., 2016).

Secondly, the high cost of 1.05755 €/vkm for a tram consists for 85% of the costs of SO_x emissions. The SO_x emissions are so high, because they are referring 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 SO₂ per kWh. However, more recent studies, such as Ito (2011, p. 12), give emissions of 0.45g SO₂ 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 2014 much lower than the ones displayed in Table 4. A quick calculation of the external cost using an emission factor of 0.06 g/kWh, ceteris paribus, provides a total external air pollution cost of 0.22361 €/vkm. This cost is remarkably lower than the one of 1.05755 €/vkm.

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 2014. Although all the figures in Table 4 are discounted to euro₂₀₁₄ 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), technological changes lead to lower vehicle emissions.

4.3 Congestion

Concerning the external congestion costs, 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.

Especially the very low minimum value of a train (0.00000 €/vkm) and the very high maximum value of an LGV (8.85430 €/vkm) catch the attention. 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 to be zero. The high value of the external LGV cost comes from the assumption by Korzhenevych et al. (2014) that traffic is at over-capacity. This means that the volume-to-capacity ratio is larger than 1.

The external congestion costs of a tram are higher than the ones of a train. The reasoning behind this is the following. The tram figures come from the Brussels context, in which the trams do not have separated tramways and thus, share the road network with the road traffic. Therefore, congestion costs in Table 4 are higher for trams than for trains. A last remark here is that the congestion costs are estimated based on the traffic level in the base year of the different studies. In 2014, traffic levels are

different and thus, the external congestion cost will be different.

4.4 Infrastructure

The external infrastructure costs caused by LGVs are in general higher than the ones caused by trains. The minimum value of the external LGV cost is very small (0.00005 €/vkm), but this figure is only valid for unloaded LGVs <10t. Delhay et al. (2012) assign an external cost to a train between 0.00081 €/vkm and 0.04082 €/vkm. However, these authors admit that other sources argue that the external infrastructure cost of a train is zero, because this cost is paid for by the rail operators and thus, is not external. Since these sources could not be checked, the minimum value in Table 4 is left 0.00081 €/vkm, approaching the cost of 0 €/vkm. The external infrastructure costs of a tram are not available for Belgium. However, it could be argued that they will be comparable to the ones of a train.

4.5 Noise

The minimum external noise costs are associated with a peak tram in Brussels (0.01696 €/vkm), while the maximum external noise costs relate to a freight train operating at night in Belgian urban areas (2.53306 €/vkm). The minimum value of the external LGV costs is rather low. The reasoning behind this low figure is that trucks driving in an urban area during peak hour, drive at a low speed. Hence, their noise level is limited (Mayeres et al., 1996).

4.6 Up- and downstream processes

For none of the three modes considered figures were available regarding the up- and downstream processes. The costs related to these processes are often already incorporated in for example the air pollution costs of a tram (Mayeres et al., 1996).

4.7 Total external cost

At the bottom of Table 4, a column total is given for each mode. As such, the column total is not very robust, since it is made up based on different sources, using a different methodology, and different context descriptions. Widely applied evaluation methods in this domain include for example the avoidance cost, hedonic pricing and the willingness-to-pay (Blauwens et al., 2016). Hence, double counting might be present in this figure and peak situations are sometimes added up to off-peak situations, which is not useful. Therefore, the column total is rather a theoretical measure than one that is present in reality.

When examining the minimum values, it is clear that a tram bears the highest external cost, followed by a train and an LGV. An explanation for this result is the use of passenger external accident costs of a tram and the overestimated external air pollution costs of a tram.

The maximum value of the column total shows that the use of an LGV causes the most external costs (11.38684 €/vkm) followed by the use of a train (4.26025 €/vkm) and a tram (1.99201 €/vkm). The maximum value available in the literature and converted to a price level of 2014 provides a larger external cost of a tram (5.18234 €/vkm) than of an LGV (3.89220 €/vkm) (Mayeres et al., 1996). Here too, the overestimation of the external air pollution costs of a tram plays a role. However, the largest difference here is the inclusion of the high LGV congestion costs estimated by Korzhenevych et al. (2014) in the column total of the LGV, while these are not included in the estimation of Mayeres et al. (1996).

As Table 4 shows, calculating the external costs is a challenging task for several reasons. Firstly, figures from existing sources cannot always be used, because they become outdated even when discounted to the year of the current study. Technological and traffic changes are the main reasons behind this. Secondly, it is impossible to give 'the' external cost figures. The context in which the transport occurs, i.e. the vehicle type, the time of the day, the area, the load, etc., determines largely the external cost value.

In brief, the results in Table 4 are useful for two reasons. Firstly, this table offers a framework in which

the external cost measurement in a certain context can be placed. Updated external cost figures for Belgium can be fitted in the framework and hence, benchmarked. The framework offers a control measure to know whether ad hoc external cost measurements are realistic. When using a value of Table 4 in for instance an SCBA, one knows based on this framework in which direction performing a sensitivity analysis is valuable. Secondly, Table 4 shows that the results of an SCBA always have to be carefully interpreted, since the choice for using the minimum value versus the maximum value of the external costs can influence the result of the SCBA tremendously. Therefore, it is recommended to still apply some sensitivity analysis (Rietveld, 2013). The main limitation of Table 4 is the fact that figures proposed by different authors are obtained based on different definitions and methodologies. Thus, they can only be combined under certain conditions.

5. Conclusions and research implications

Accurate and appropriate external cost data are crucial for the robustness of a social cost-benefit framework for assessing the role of rail for urban freight distribution. The objective of this paper is twofold: to identify the relevant external cost categories for urban rail freight, and to offer a range of values for Belgian and Flemish urban areas.

With respect to the relevant external cost categories, a typology of urban rail freight external costs is made. The external costs measured in the investigation of the use of trams and trains for urban freight distribution consider especially air pollution and climate change, and to some lesser extent accidents, congestion, infrastructure damage and noise. It has to be added here that other effects, such as reduced liveability and landscape intrusion can also be present, although difficult to quantify.

Concerning the external cost values, an analysis of commonly used values is made for Belgian and Flemish urban areas. The accident costs are the highest for a tram. The main explanation here is that costs are estimated for a passenger tram instead of a freight tram. The accident cost of a freight tram will be lower. The high air pollution and climate change costs of a tram mainly come from the high estimated SO_x emissions of the electricity generation. Recently, these SO_x emissions have decreased significantly, leading to lower air pollution and climate change costs of trams. With respect to congestion costs, trains and trams experience lower costs than LGVs, because almost no congestion on the rail network is present. Concerning the infrastructure costs, trains and trams do not cause high external costs, leaving LGVs with the highest costs regarding this externality. With respect to noise, freight trains, often operating at night, cause the highest noise costs. Figures for up- and downstream processes were not available for this research. The total external cost figures reveal with respect to the minimum value the highest external cost for a tram, followed by a train and an LGV. Concerning the maximum value, LGVs appear to cause the highest external costs, followed by trams and trains. It is crucial to keep in mind the assumptions and context in which these external cost figures are estimated. The values are valuable as a framework through which the external costs in a specific case can be validated. The main weakness of this study is the fact that the minimum and maximum values result from figures calculated based on different definitions and different methodologies. Therefore, one has to be careful when combining them in another research. A more comprehensive research would include different external cost evaluation methods and calculate up-to-date case-specific external cost values where necessary.

The findings of this study have a number of important implications for future practice and policy. The relevant external cost categories and figures reveal the aspects of urban rail freight causing the highest cost to society. Firstly, private actors, such as train and tram manufacturers and energy producers, can use this information to work on technical measures to lower this cost. Train and tram vehicles can be further developed in order to cause less external costs, such as noise and air pollution (diesel vehicles). Energy used for electric trams and trains can be generated by more environment-friendly techniques, such as wind energy, in the future. Secondly, policy makers can respond to the external cost information by promoting and potentially favouring the use of transport modes causing the lowest cost to society. The sometimes extreme differences between the minimum and maximum external cost values should also be a caveat for policymakers. Developers of an SCBA for instance can easily prove what they want to prove by using the external cost value that provides the best outcome of the SCBA.

The results obtained in this paper will be used in further research in which a social cost-benefit framework will be developed to estimate the potential of trams and trains for urban freight distribution.

A quantitative and generic tool is developed. In the tool, different choice criteria are present. The user can for instance indicate the geographical area, time of the day and vehicle type used, i.e. the European emission standard, fuel type and weight category. In this way, external costs can be calculated related to their specific context. Later, the scope of the model will be extended towards a generic model. Case-specific external cost figures will be developed where needed based on the appropriate evaluation method.

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