Calculating the cost of congestion to society : a case study application to Flanders

Reference:
Struyf Els, Sys Christa, Van de Voorde Eddy, Vanelslander Thierry.- Calculating the cost of congestion to society : a case study application to Flanders
Research in transportation business & management - ISSN 2210-5409 - 44(2022), 100573
Full text (Publisher's DOI): https://doi.org/10.1016/J.RTBM.2020.100573
To cite this reference: https://hdl.handle.net/10067/1717120151162165141

Calculating the cost of congestion to society: a case study application to Flanders

Abstract

Road congestion is an issue that has received growing attention in all big economic activity centers around the world. Congestion seems to be inextricably linked to economic growth, and is therefore considered a sign of strong economic performance. However, at the same time, it reflects a problem of lack of matching between demand for and supply of transport capacity, risking to suffocate the economic system. A problem is that the external congestion costs are not included in the price of transport, mainly because it is hard to accurately calculate them, due to the absence of an approach to do so. This paper creates a globally accepted approach for calculating the impact of congestion on costs, both operational and societal. It does so by first of all learning from defining the relevant concepts, based on literature and an expert meeting that was hosted. It shows the components of congestion costs, which comprise both private and societal elements, direct and indirect, and it also identifies that transport can be split up in truck, van, work-related and private trips, each of which has its relevant cost characteristics. Furthermore, an own instrument for congestion cost calculation is elaborated and applied to and validated on a specific Flemish congestion situation. The instrument provides uniform insight into the magnitude and impact of congestion in a specific area or on a specific road. The resulting monetary values can first of all be used in negotiations by trucking companies with customers, for agreeing on transparent calculation of congestion surcharges. The results can also be used for determining a company location where congestion impacts are lower. Finally, resulting monetary values can be used by producers to see how competitive are the alternative modes rail and barge in terms of total generalized costs, not based on theoretical figures, but on calculations taking into account real cost and time impacts. Policymakers can use the results first of all to identify areas where the impact of congestion is high, and which should get priority in setting up solutions. Second, they can use the instrument and its results to test the effect of congestion mitigation measures (e.g. road pricing).

Keywords: road congestion, external congestion cost, congestion cost calculation, distance coefficient, time coefficient

1. Introduction

Road congestion is an issue that has received growing attention in all big economic activity centers around the world. Congestion seems to be inextricably linked to economic growth, and is therefore considered a sign of strong economic performance. However, at the same time, it reflects a problem of lack of matching between demand for and supply of transport capacity, risking to suffocate the economic system. If demand is not well managed, mainly through correct pricing, it may heavily exceed available capacity (Blauwens et al., 2016). Equally, if supply (investment or maintenance) is lacking, it may not allow to cope with 'normal' demand.

No wonder that road congestion occurs so frequently. In Europe for instance, just over half the freight transport kms are driven on roads; for passenger transport, the concentration on roads is even higher, with a mode share of just over 70% (European Commission, 2019). That translates into increasing traffic volumes. On the outer Antwerp Ringway for instance, on the section between Borgerhout and Antwerpen-Oost, the most occupied one in 2019, an average of 139,052 vehicles passed on working days, as compared to 121,379 in 2010 (Vlaams Verkeerscentrum, 2020). Congestion levels rise exponentially: in Flanders in 2019, a daily average of 560.49 km-hrs[1] of congestion occurred, compared to 279.80 km-hrs in 2011 (Vlaams Verkeerscentrum, 2020b).

Both for freight and passenger transport, road remains the most attractive mode of transport, despite it usually being more expensive than other modes, especially due to the time cost. Based on the chain cost model developed in van Hassel et al. (2020), it can be shown that transport from Antwerp to Basel for instance costs €907.78 by road, as compared to €743.40 by rail and €615.61 by inland barge. Its attractiveness comes mainly from flexibility, frequency, reliability, risk of loss and damage, etc. The values of the latter also depend on the value of the goods in the case of freight transport.

The growth of the level of congestion impacts heavily on the time consumption, and therefore on the time cost, but also on reliability[2]. Sessa and Enei (2010) predict that between 2008 and 2030, average road speeds in Europe will decrease by 29% during peak hours, and by 16% during off-peak moments. This is in line with what is observed also in the actual congestion figures of a decade later.

A problem is that the external congestion costs are not included in the price of transport, mainly because it is hard to accurately calculate them, due to the absence of an approach to do so. Moreover, because of the lack of a universally accepted calculation approach, it is very hard for road transport operators to pass on the congestion costs that they experience in the price they charge to shippers: truck operators, due to their smaller size, typically are in a weaker negotiation position.

Hence, this paper creates a globally accepted approach for calculating the impact of congestion on costs, both operational and societal (Nash and Matthews, 2005). It does so by first of all defining the relevant concepts in section 2, based on literature and an expert meeting that was hosted[3]. In section

---

[1] km-hr is the unit of traffic severity: the distance over which a congestion event extends, multiplied by the time it is there.

[2] This impact is not equal over the various transport modes, as the degree of internalisation is not the same across modes. Rail and air traffic systems - and partly parts - are scheduled systems. The latter's system managers are well aware of the impact of additional traffic on all others in the system. That means, the external costs of transport in individual road transport differ from those in trucking and even more in other transport.

[3] The trigger to this research, was an expert meeting hosted by the authors on 16 June 2014 in Antwerp, to get on the view on the practice of making congestion cost calculations. The meeting brought together academics, research institutes, policymakers, industry and police.

3, an own approach for congestion cost calculation is elaborated. Section 4 introduces the Flemish case study. Section 5 illustrates the calculation of the parameter values for Flanders. Section 6 applies the external congestion cost calculation framework to a specific Flemish congestion situation. . Section 7 finally draws conclusions and derives recommendations so as for policymakers but also sector associations and individual operators to be aware about the contribution to congestion.

2. Congestion concepts

This section shows the structured results of a review of the literature in the period 1969 till 2020 that somehow deals with road congestion. Overall, there appears to be scarce scientific literature on congestion calculation. Existing literature mainly focuses on road charging, or is limited to congestion cost calculation in an urban logistics context, or focuses on trucks only and does not take into account the rapidly increasing number of vans, or omits the logistics elements and only deal with pure transport. Equally, study areas may be strongly different, geographically or dealing with main roads or secondary roads only, so that findings cannot be generalized. The majority of studies turns out to concern Europe and the United States. Moreover, since the new millennium, an increase in the number of studies can be observed.

Therefore, this section consecutively deals with a definition of the concept ‘congestion’, the types of congestion, its consequences, as well as the costs it generates.

2.1 Definition and types of congestion

Congestion has many possible definitions. In general, it can be described as a concept that can manifest itself in many aspects and sectors. Schallaböck and Petersen (1999) apply this definition: “*Congestion means a reduction in service quality in infrastructure due to excessive demand or to other reasons. The users suffer from speed reduction, i.e. time penalties*”.

Specifically for transport, two complementary definitions apply:

- “*Congestion is a situation in which transport participants cannot move in a usual or desirable manner. Vehicles of all kinds and pedestrians can experience congestion. It is a general phenomenon when the capacity of an infrastructure is exceeded. This capacity is defined by the number of traffic participants passing per time unit*”. (Schallaböck and Petersen, 1999)
- “*Congestion may be defined as a state of traffic flow on a transportation facility characterised by high densities and low speeds, relative to some chosen reference state*”. (Bovy and Salomon, 1999)

For roads in particular, there are Bovy and Salomon (1999), who define congestion as “*a temporary situation in which the demand for road space exceeds the capacity, on a given section of the network.*”

Finally, there are definitions that specify the economic consequences of a congestion situation, like Lindsey and Verhoef (2000): “*Broadly speaking, traffic congestion occurs when the cost of travel is increased by the presence of other vehicles, either because speeds fall or because greater attention is required to drive safely”*

From the above definitions, this section distills an own definition that will be used further throughout this paper: “*Congestion is a traffic phenomenon whereby the driver is confronted with a limited traffic flow since the capacity of the infrastructure (temporarily) cannot handle the demand. This results in a* *high density and low(-er) speeds, with consequently increasing time and distance costs of traveling, and decreasing road transport reliability.*"

The above concept of congestion manifests itself in different types. A first distinction can be made between structural and one-shot congestion, whereby the latter is caused by a temporary event, such as an accident or road works. Second, a distinction is possible between peak and off-peak congestion. A final distinction is made between highway and urban congestion.

An interesting qualification is made by Goodwin (2004), who refers to the fact that often the quantification of the economic cost of road traffic congestion "*has suffered from a convenient simplification that is almost universal in transport forecasting, but seriously reduces its usefulness. It deals with the average speeds that apply to average more and less congested conditions.*" This has implications for the speeds to be used also in this paper.

2.2 Consequences of congestion

This section discerns among three types of consequences: out-of-pocket, time and competition ones.

The basic consequence is a reduction of the average speed. This can be analysed for three different types of roads, given their speeds under free capacity[4] (Christidis and Ibanez-Rivas, 2012):

- Roads with a speed below 50 kms/hr, which are supposed to be within the built area
- Roads with a speed between 80 and 100 kms/hr
- Roads with a speed above 100 kms/hr, corresponding to highways or main roads.

Most congestion problems around the world occur in urban areas. Exceptions are the European countries The Netherlands, Belgium, Luxemburg, the United Kingdom and Germany (Christidis & Ibanez-Rivas, 2012), where congestion is much more widespread.

Speed impacts will first of all be found in changing fuel costs: lower fuel costs due to lower speed, but compensated partly or fully for the longer time that the engine runs and consumes fuel. Furthermore, the impact emerges as an increasing wage cost.

The second consequence is actual lost hours, which obviously generate important opportunity costs to society. For Flanders, the annual number of hours lost has increased from 42,651 h. in 2010 to 82,832 h. in 2019.

The combination of out-of-pocket and time costs will also lead to competition effects, as a third consequence: higher out-of-pocket costs due to for instance more fuel consumption, combined with time loss decreases a country's competitive position.

2.3 Cost components of congestion

Literature shows that models quantifying congestion cost components are scarce, featuring different goals and different assumptions.

Time losses can be quantified using the speed-flow relations of Van Woensel and Cruz (2008), whereby road segments are treated as service stations, whereby a queuing model can help in calculating the average waiting time, given the throughput and capacity of the service stations.

Transport costs are not only composed of time but also distance costs (Blauwens et al., 2016; Santos, 2014). Furthermore, both studies also mention external costs, comprising congestion, infrastructure, environmental and accident costs. In this respect, it is interesting also to refer to Piccioni (2011), who

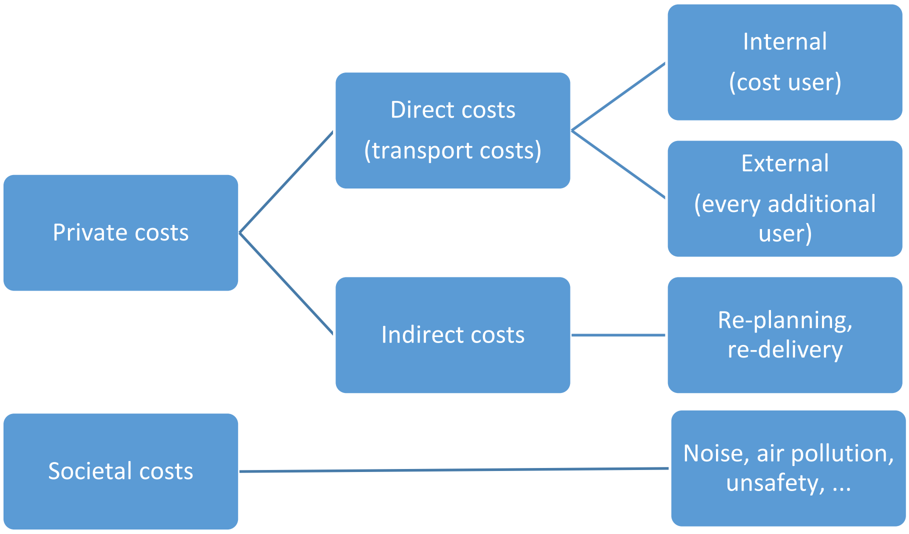
---

[4] The speeds can diverge slightly, according to the specific country regulations.

links transport conditions to economic activities, thereby linking road capacity to maintenance costs as well as an additional cost compensating for the above-mentioned negative road externalities.

Blauwens et al. (2016) furthermore discern among following cost categories (figure 1). Direct costs comprise the above-mentioned time and distance costs. These can be both internal and external. Internal congestion costs are those borne directly by the one causing the delays in transportation. External congestion costs are those borne by another actor than the one causing the congestion. Indirect costs are costs imposed to others than those involved in the congestion situation. These can be for instance the re-planning and re-delivery costs (Golob en Regan, 2001), or the opportunity costs due to missed meetings and contracts. Societal costs finally can be categorized as either regional or global. Regional emission impacts for instance are particulate matter, while global impacts come from greenhouse gas emissions. In the latter category, CO_2 emissions are a prominent element, with their emission level increasing as speed reduces (Schallaböck en Petersen, 1999).

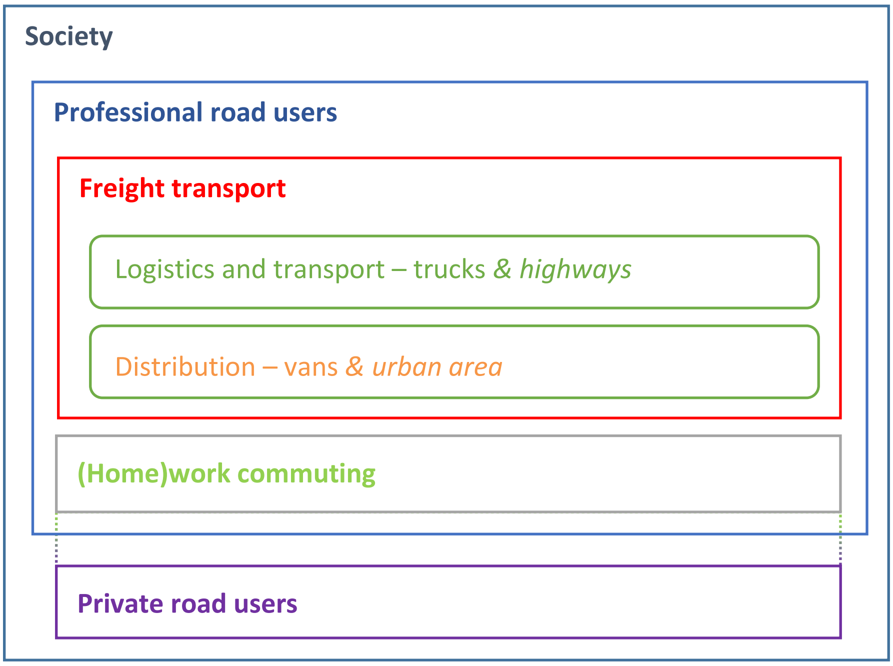
Figure 1: Transport cost components



Source: own composition based on Blauwens et al. (2016)

Kristofferson (2013) distinguishes among the various categories of road users, which take into account different costs. Road capacity is used by freight and passengers simultaneously. Freight transport by road encompasses both logistics transport (by lorries on main and secondary roads) and distribution (more and more by vans, on secondary roads). Passenger transport by road involves professional (homework commuting) as well as non-professional users (spare time, shopping, holidays, etc.). In passenger transport, the distinction between professional and non-professional usage can be very hard to make: a person combining the home-work commuting trip with a shopping stop for instance. Figure 2 summarizes the categorization of road users.

Figure 2: Different types of road users



Source: own composition based on Kristofferson (2013)

The time cost for a professional driver for instance is the wage that the company has to pay to the driver, while that for a private transporter is the opportunity cost of the time lost in congestion, i.e. the willingness to pay for fluent traffic. Armelius (2005) and Olszewski and Xie (2005) discern various types of congestion according to the time moments: morning and evening peaks for instance.

The combination of the above insights will be used to develop an own congestion cost calculation model in section 3.

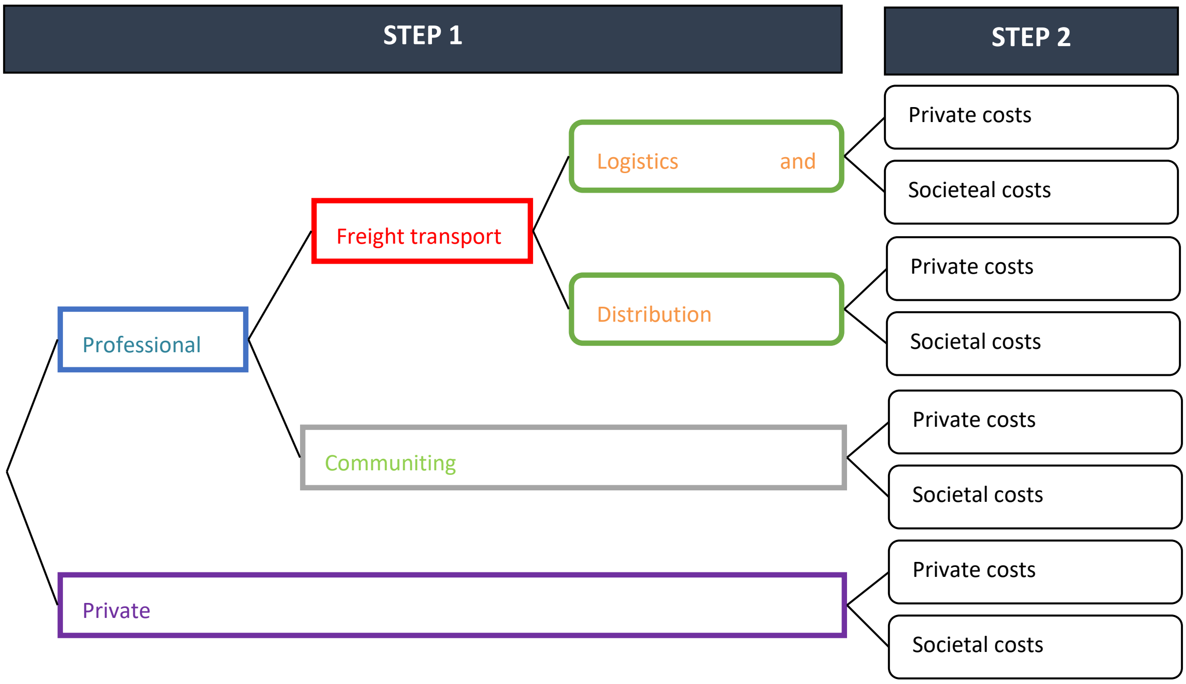
3. Developing a generic congestion cost model

This section develops a conceptual model for calculating the cost impact of congestion. Congestion can occur both at main and secondary roads. This can happen both inside and outside urban areas. Christidis & Ibanez-Rivas (2012) mention that urban congestion typically is substantial, given the large amount of traffic attracted, and the various types of roads surrounding and crossing cities. Since it is hard to distinguish among the exact causes and consequences, and hence to delineate a specific congestion situation, even when one-shot, it is opted to develop a generic congestion cost model.

The developed model will hence be modular, so that it can be used for all application types (freight, commuting, transit and leisure) and for all actors (transport companies, logistics operators, private users, etc.). The unit of calculation is always one specific congestion occurrence, whereby specific scenarios are taken into account: weekdays / weekend, peak / off-peak, main / secondary road.

The model is elaborated in two steps (figure 3). Step 1 determines the weights attached to each component included in a congestion situation. Step 2 identifies the costs that each vehicle category causes.

Figure 3: Model development steps and components



Source: own composition

3.1 Step 1: Determining weights

It is first of all important which type of users are present in the congestion situation, as the type of user determines the costs they will be confronted with. Following sub-questions need to be answered:

- How many cars are implied in the congestion situation?
- What vehicle type are the involved cars?
- How many persons does the average car count?

Answering these questions leads to Equation 1.

$$Congestion\ cost = Q[(\alpha_1\ K_{LT} + \alpha_2\ K_D) + \ \beta\ K_W\ +\ \gamma\ K_P] \qquad \text{(Eq. 1)}$$

Where:

- Q = number of involved cars
- α_1 = logistics and transport share
- α_2 = distribution share
- β = commuting share
- γ = private transport share
- K_{LT} = logistics and transport cost
- K_D = distribution cost
- K_W = commuting cost
- K_P = private transport cost

Q is determined by linking the congestion length of a vehicle. A distinction is made among trucks, vans and passenger cars. The share of each of those vehicle types then also needs to be determined.

3.2 Step 2: Calculating cost components

This section elaborates the way of calculating the various cost components from section 2.3. Grouping those for each of the respective vehicle types from section 3.1 will lead to an updated Equation 1.

For the direct costs, one starts from Equation 2 (Blauwens et al., 2016):

Transport cost = u'U+(d1 D1+d2 D2)+Z (Eq. 2)

Where:

- *u* = time cost coefficient
- *U* = total amount of time
- *d1* = standard distance cost coefficient
- *D1* = standard distance
- *d2* = distance coefficient with kilometre charge
- *D2* = distance with kilometre charge
- *Z* = miscellaneous costs

This paper only focuses on the additional costs caused by a congestion event, not the total costs of the transport operation. These extra cost elements are the ones from section 2.1. The corresponding amounts differ according to the vehicle type and the number of persons involved.

For the wage under the direct costs, the additional cost equals the number of additional driving hours, multiplied by the wage cost per hour for professional transport, or the value of time for private transport[5]. For the fuel, the additional cost depends on the covered distance, the fuel consumption and the price of the fuel. The fuel consumption thereby depends on the speed[6].

The external direct congestion costs are to be calculated in a similar way, but for all other cars impacted on (see also Cerwenka and Meyer-Rühle, 2008).

Adding up the internal and external direct congestion costs leads to Equation 3:

$$Extra\ direct\ transport\ costs = u\ \Delta U + \Delta d_1 D_1 \qquad \text{(Eq. 3)}$$

The indirect costs (*I*) are the hardest to calculate, as they depend very much on the specific situation, and are not necessarily linked to the value of the goods or the type of passenger.

Under societal costs (*M*), the emissions depend on the consumption of the vehicle and the type of fuel. The consumption in turn is determined by the type of vehicle, its engine size, its age and the speed) (Maerivoet & Yperman, 2008). For noise, determinants are the type of vehicle, the speed and the road surface quality.

The sum of the above-mentioned components, added up over all vehicle types, then leads to Equation 4, which is the detailed update of Equation 1.

---

[5] This is an approximation of the real economic time loss. To get more accurate figures, it would be good if stated or revealed preference studies would be set up, trying to to identify the value people attach to different activities (Gunn and Sillaparcharn, 2007; Wardman, 1998). These values can change according to the situation for the same person, and even over time with income, etc. Such exercise however exceeds the scope of this paper.

[6] Fuel consumption will also depend on other specific conditions, for instance the amount of 'stop and go' in slowed traffic, eventual cold start, etc. More detail on such other influencing conditions is provided in Notter et al. (2019) and Ntziachristos (2009). Using these distinctions and specific values would however make the analysis in this paper overly complex.

$$Total\ congestion\ cost = Q[(\alpha_1(u\Delta U + \Delta d_1 D_1 + I + M)_{LT} + \alpha_2(u\Delta U + \Delta d_1 D_1 + I + M)_D) + \beta(u\Delta U + \Delta d_1 D_1 + I + M)_W + \gamma(u\Delta U + \Delta d_1 D_1 + I + M)_P]$$

In what follows, the paper will apply and validate the developed model with an application for Flanders. To do so, first, section 4 will introduce the Flemish congestion situation.

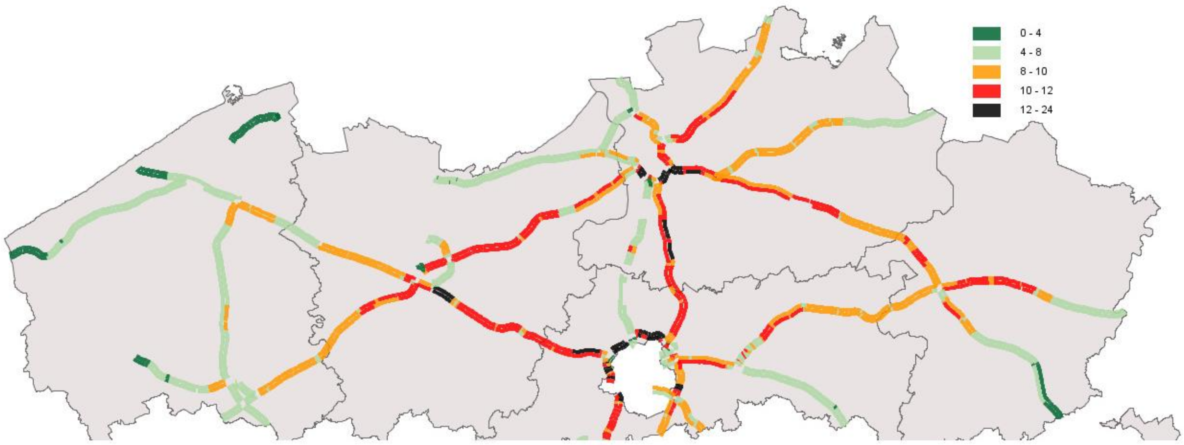
4. The case of Flanders: congestion situation and identification

This section shows how to determine the level of congestion for Flanders on highways, secondary roads and urban areas.

For the highways, various indicators are available: congestion severity, saturation degree[7] and lost vehicle hours. To measure congestion, Flemish highways feature inductive loop detectors on 90% of the network.

A road in Flanders is considered to be saturated as soon as its saturation degree is more than 10 hours. Of the Flemish main roads on working days, 22% was saturated in 2018. Most saturated road segments in Flanders are situated around Brussels, Antwerp and Ghent (Figure 4).

Figure 4: Saturation degree 2018 for the Flemish main roads on working days (excl. school holidays) (hours/day)

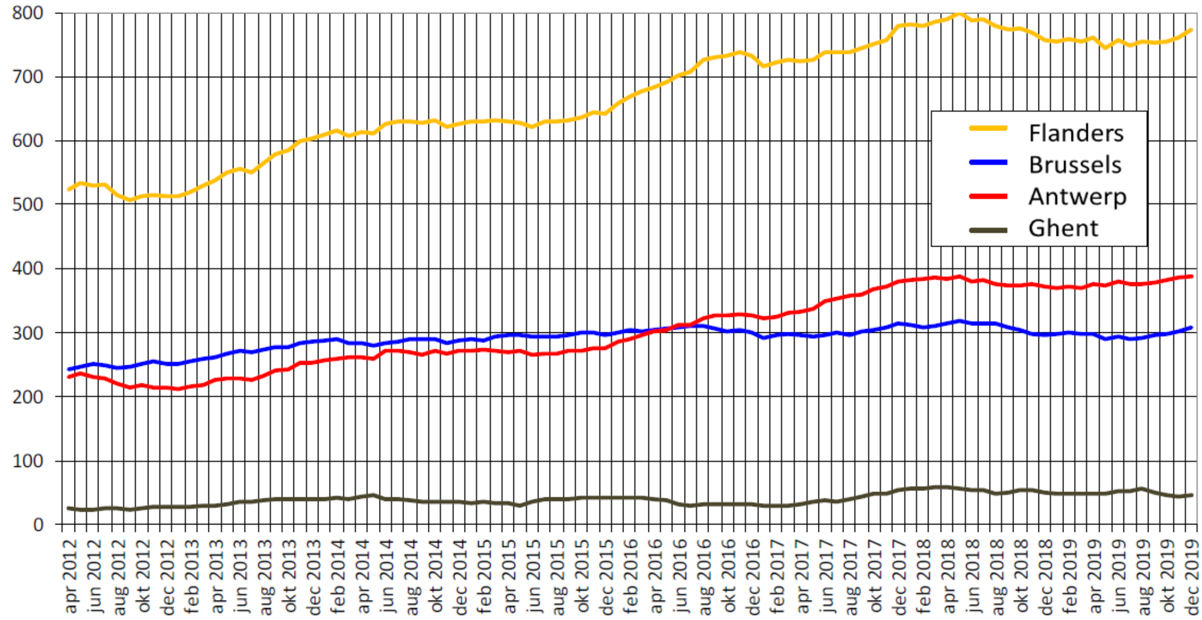


Source: Vlaams Verkeerscentrum (2020)

The average congestion severity in Flanders strongly increased in the past decade, by more than 200 km-hrs per average working day between 2012 and 2018 (Figure 5). The evening peak appears to suffer from higher congestion severity than the morning peak (Vlaams Verkeerscentrum, 2019).

Figure 5: Congestion severity evolution in Flanders on working days[8]

[7] The saturation degree = the traffic volume per hour / (number of lanes x hourly capacity per lane)
[8] Moving average of the preceding 12 months



Source: Vlaams Verkeerscentrum (2020)

The number of lost hours as a share of the total performed vehicle-kms on a daily basis, in Flanders in 2018 amounted to 16%. Around Brussels, it even amounted to 25% (Vlaams Verkeerscentrum, 2020).

For secondary roads, the inductive loop detector coverage is only 20% of the network. Private operators like BeMobile and TomTom do collect data that could be used there, but these are not publicly available. An approximation for the number of lost hours could be made with the formula by Maerivoet & Yperman (2008) (Equation 4).

$$LVH = (q.V)/3600 \qquad \text{(Eq. 4)}$$

Where

LVH = lost vehicle hours

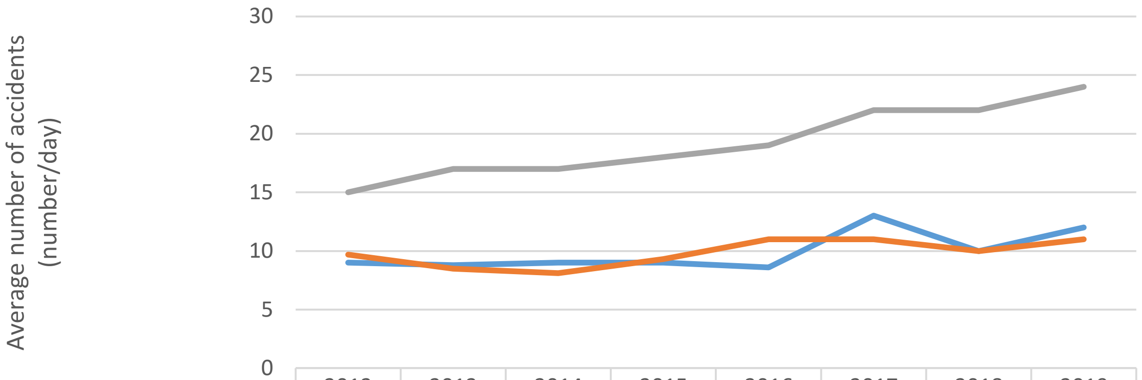
q = traffic performance

V = unit lost hours

In urban areas, typically there is a high concentration of economic activity, and local traffic mingles with transit traffic, which all contributes to congestion. Private operators Inrix and TomTom collect data on urban traffic: TomTom does so for cities with more than 800,000 inhabitants or European capitals also with less than 800,000, while Inrix focuses on the most congested cities. TomTom reports for Brussels a congestion level of 38% for 2019, up by 1% compared to 2018. That figure indicates that the average trip lasts 38% longer than under non-congested conditions. On highways, the reported congestion level was 40%, while on secondary roads; it amounted to 38% (TomTom, 2020). Similar figures for Flanders are available for Antwerp, Ghent and Bruges. Inrix reports 195 lost hours per person per year for Brussels for 2017, up by 1% as compared to 2016 (Inrix, 2020). A similar figure is available for Antwerp.

Next to the above figures, which include both structural and ad-hoc congestion, it is interesting to specifically focus also on ad-hoc congestion. It can be observed that the number of ad-hoc congestion events has significantly increased over the past decade (Figure 6). Relevant with respect to the number of lost hours is the handling time of ad-hoc congestion events, which in 2018 was 46 minutes on average, being rather stable over the years (Figure 7).

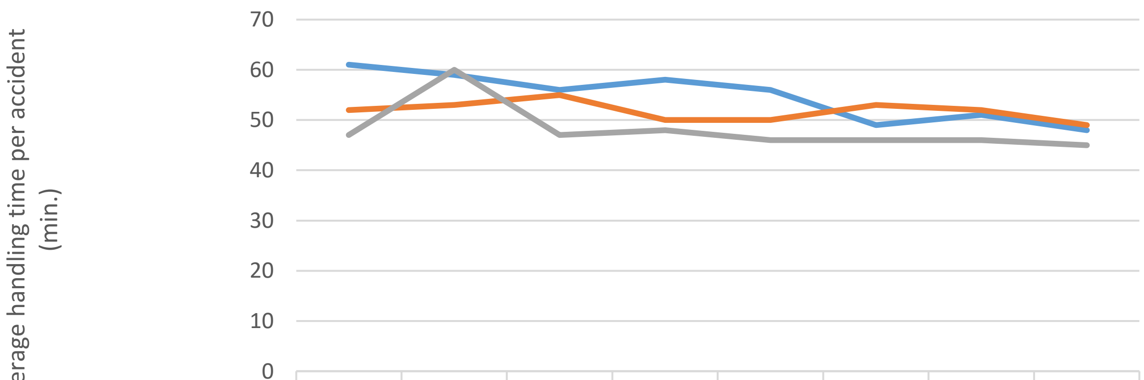
Figure 6: Number of ad-hoc congestion events in Flanders



	2012	2013	2014	2015	2016	2017	2018	2019
Saterday	9	8,8	9	9	8,6	13	10	12
Sunday	9,7	8,5	8,1	9,3	11	11	10	11
Working day (excl. school holidays)	15	17	17	18	19	22	22	24

Source: Vlaams Verkeerscentrum (2020)

Figure 7: Handling time for ad-hoc congestion events in Flanders



	2012	2013	2014	2015	2016	2017	2018	2019
Saterday	61	59	56	58	56	49	51	48
Sunday	52	53	55	50	50	53	52	49
Working day (excl. school holidays)	47	60	47	48	46	46	46	45

Source: Vlaams Verkeerscentrum (2020)

Figures 6 and 7 show that Flanders is a suitable case for demonstrating and validating the congestion cost calculation. Next, section 5 will tailor the model from section 3 to the Flemish congestion situation as described here, and calculate corresponding cost values.

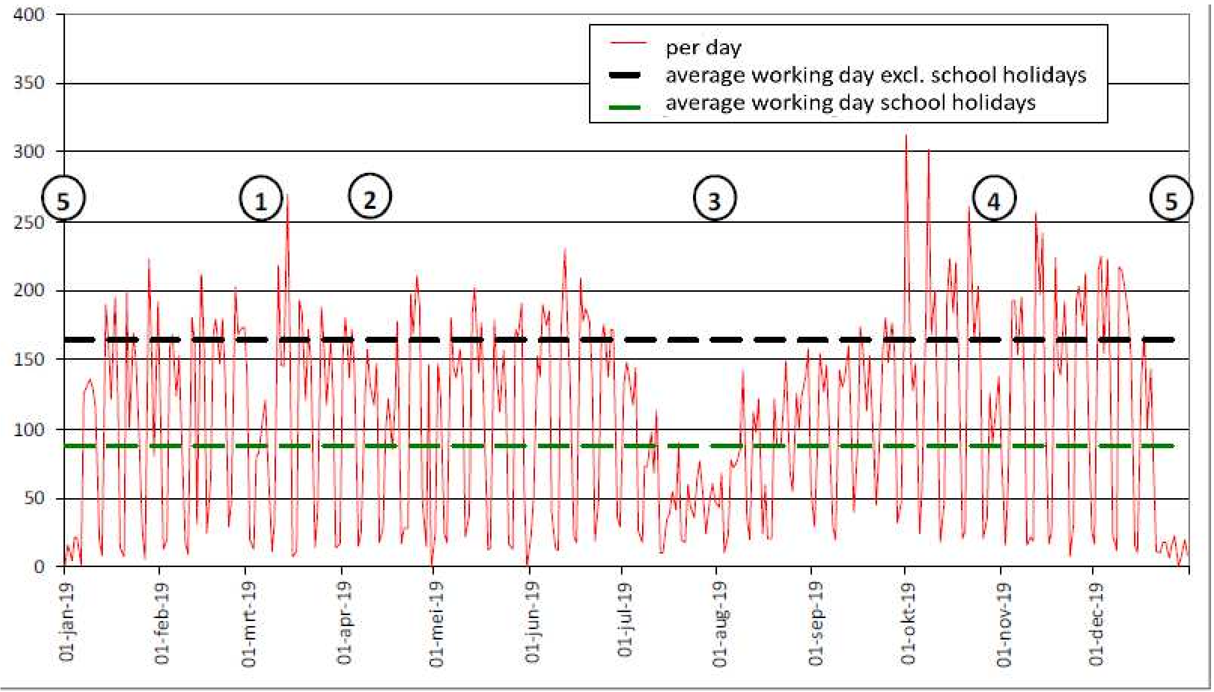
5. Determining total affected traffic volume, user types and cost unit values for Flanders

For calculating the costs of congestion for Flanders, the steps outlined in section 3 are followed here. Hence, first the volume of involved cars and the weights of the various user types are determined, after which the level of costs for all individual items is determined.

5.1 Congestion traffic volume and weight of user types

The number of cars implied in congestion is determined by the length of the congestion event, the number of lanes on the road, the length of the vehicles, the speed and the braking and stopping distance. The total congestion length for Flanders is reported on a daily basis (Figure 8).

Figure 8: Congestion length highways Flanders



Vlaams Verkeerscentrum (2020)

The length of the vehicles differs significantly between passenger cars, small freight vehicles and large freight vehicles. The length is expressed typically in 'passenger car equivalents' or pce, whereby a passenger car equals 1, a small freight vehicle 1.5, and a large freight vehicle 2. The length of a passenger car is standard put at 4m.

The speed is determined by the type of road on which the congestion is encountered. The road classification of section 2.2 is used, with the modification that for the middle category, the lower speed is 70 kms/h. It is shown by VIAS (2013) that the average real speed on the various types of roads deviates from the theoretically allowed one (Table 1). The braking and stopping distances are a function of the speed and the weather condition (dry or wet). The combination of speed and stopping distances leads to the safety distance that ideally between two vehicles needs to be kept.

Table 1: Average observed speeds and stopping distances

Maximum speed		Average speed (km/h)	Stopping distance – dry road surface	Stopping distance - wet road surface	Safety distance (2 seconds rule) taken into account average speed (m)
Max. 50 km/h	Passenger cars and freight vehicles	52.5	+/- 26.8 m	+/- 31.4 m	29.17
Max. 70 km/h		71.9	+/- 44.7 m	+/- 53.8 m	39.94
Max. 90 km/h		82.1	+/- 55.1 m	+/- 67.0 m	45.61
Max. 120 km/h	Passenger cars	117.9	+/- 74 m	+/- 134.3 m	65.50
	Freight vehicles	89. 2	+/- 66.7	+/- 81.8	49.56

Source: VIAS (2013)

The weights given to the different types of users are assigned based on their share in the total traffic volume (Table 2)[9]. Next to the differences between working days and weekend days, the fractions also change according to the moment of the day. On working days, the share of commuting traffic will be much higher during peak hours than during off-peak hours, while the reverse goes for private traffic. The share of trucks and vans is supposed to remain equal.

Table 2: Vehicle type shares in Flanders

	Main road network (highway)			Secondary road network		
	Working day	Saterday	Sunday	Working day	Saterday	Sunday
Passenger cars	71.17	86.67	89.49	79.87	86.35	89.32
Vans	9.17	8.82	8.49	11.55	10.77	9.35
Freight vehicles (articulated and unarticulated)	19.66	4.51	2.02	8.58	2.88	1.33

Source: FOD Mobiliteit en Vervoer (2007)

To make the distinction among passenger cars for commuting and private usage, use is made of Verhetsel, Vanoutrive & Zijlstra (2014)[10]. They distinguish among traffic traveling between house and work, and work-related traffic. In the morning peak (6-9am) and evening peak (4-7pm), 36% appears to be commuting traffic, while during off-peak hours, the commuting share is estimated at 3.2%. About all day long, 2.5% of the total traffic is assumed to be work-related. In weekends, commuting traffic is assumed to be between 0 and 5.7%.

In sum, the final weights can be determined for highways (table 3) and secondary roads (table 4).

Table 3: User type weights highways

Highways	Peak hours working day	Off-peak hours working day	Saterday	Sun- and holiday
Freight vehicles (α_1)	19	19	5	2
Vans (α_2)	9	9	9	8
House and work, and work-related traffic	38,5	5,7	0 – 5,7	0 – 5,7
Private usage (γ)	33,5	66,3	86	90

Source: own composition

Table 4: User type weights secondary roads

Secondary roads	Peak hours working day	Off-peak hours working day	Saturday	Sun- and holiday feestdag
Freight vehicles (α_1)	9	9	3	1
Vans (α_2)	12	12	11	9
House and work, and work-related traffic (β)	38.5	5.7	0	0

[9] No more recent figures are available for the same level of detail. However, a comparison was done with overall traffic figures for the three vehicle categories based on vehicle-kilometres performed in 2017 (FOD Mobiliteit en Vervoer, 2019). Freight vehicles represent 14%, vans 11% and passenger cars 75%. This is more or less in line with the 2007 figures, so it is decided to keep the detailed 2007 figures.

[10] The figures that are calculated on the basis of this source are, of course, assumptions. In Practice, the fractions may be different and may be location specific. For specific calculations, the most specific data must therefore be used..

Private usage (γ)	40.5	73.3	86	90

Source: own composition

5.2 Unit values for all cost components

This section details the values used for the Flemish case for all cost categories of section 3.

5.2.1 Direct costs

The time component of the direct costs is a function of the time cost coefficient and the total time spent. Through congestion, only the total time will change, not the time cost coefficient. The latter needs to be diversified according to the type of user. Generically, it consists of interest and depreciation (fixed tariff); insurance; transport taxes; wage; other costs (buildings, management, administration). Applying the calculations by Vlaamse Overheid (2013) leads to the time cost coefficients of table 5.

Table 5: Hourly coefficients for the Flemish case (2020)

	Hourly coefficient (€)
Light freight vehicles	40
Heavy freight vehicles	42.73
House and work, and work-related traffic	13.06
Private usage	7.75

Source: own composition and indexation based on Vlaamse Overheid (2013)

It is important to also take into account the number of passengers in the cars. The total time cost is the sum of the time costs of the individual passengers in a car. Occupation degrees in Flanders are 1.400 passengers per passenger car for highways, 1.350 for secondary roads, and 1.270 for urban areas. For trucks and vans, the occupation degree is assumed to be 1.

The main element of the distance component of the direct costs is the fuel cost. The longer the distance over which a vehicle drives, the higher the fuel costs will be. It is assumed that the distance under congestion remains the same as without congestion, which implies that driver do not make detours to avoid the congestion. In reality, they may do so, but it is then very case-specific what the actual size and impact of the detour will be, and the detour itself may lead to congestion elsewhere, so that the marginal gain usually is minimal. As such, there is then no impact of the congestion situation on the total distance driven. However, as vehicles consume more when driving slower, the distance coefficients d_1 and d_2 will be higher than under normal driving conditions. The impact is calculated in table 7 for a specific situation, with the help of the key figures calculated in table 6, where the additional driving time is linked with the average speed, so as to calculate the equivalent extra distance that virtually has been driven. The fuel cost of course depends on the fuel type. It is found that for Flanders, 62% of all cars run on diesel, while all trucks and vans are assumed to run on diesel (Federaal Planbureau, 2014). The other distance-related cost elements are maintenance, tyres, and the remaining part of interest and depreciation. The latter are all shown to be minimal compared to the fuel cost size (Blauwens et al., 2015).

Table 6: Key figures relating driving time to virtual extra driven distance

	Extra driven distance	Normal average speed (km/h)	Key figure (km)
Heavy freight transport	80.44 minutes (or 1.34h)	89.2	119.59
Vans/Light freight vehicles	82.92 minutes (or 1,38u)	117.9	162.93
House and work, and work-related traffic	82.92 minutes (or 1,38h)	117.9	162.93

Private usage	82.92 minutes (or 1,38h)	117.9	162.93

Source: own composition

Table 7: Distance coefficients for the Flemish case (2020)

	Share of cost in distance coefficients	Normal driving conditions		Congested driving conditions	
		Light freight €/100 vkm	Heavy freight €/100 vkm	Light freight €/100 vkm	Heavy freight €/100 vkm
Interest and depreciation (variable tariff)	13.33%	3.80	7.83	3.80	7.83
Fuel	73.33%	20.91	43.06	198.44	477.99
Tyres	3.33%	0.95	1.96	0.95	1.96
Maintenance, herstelling and fees	10.00%	2.85	5.87	2.85	5.87
TOTAL (distance coefficient)		**28.51**	**58.72**	**206.05**	**493.64**

Source: own composition and indexation based on Vlaamse Overheid (2013)

The indicator values of the external direct transport costs are as given in Table 8. As all cars implied in a congestion situation will experience similar direct cost impacts from the congestion situation, the external direct transport costs will not change, and hence should not be taken into account when calculating the cost difference between a congested and a standard driving situation.

Table 8: External direct transport costs for Flanders (€/100 vkm

		Passenger cars and vans (< 3,5 ton)	Freight vehicle (and bus)
Main roads Flemish Diamond	Peak	4.64	9.26
	Off-peak	4.01	8.01
Main roads outside Flemish Diamond	Peak	3.29	6.59
	Off-peak	2.84	5.69
Regional roads	Peak	6.17	12.33
	Off-peak	3.61	7.23
Urban roads	Peak	9.43	18.88
	Off-peak	3.18	6.35
Average Flanders		5.04	10.09

Source: indexed from Vlaamse Overheid (2013)

5.2.2 Indirect costs

Indirect costs can still be split up into immediate and derived component. The immediate component stems from the need for re-planning deliveries and/or meetings. The derived component stems for instance from the need to make administrative staff work longer to organize re-planning, hence leading to increased wage costs. These costs can be extremely case-specific. No standard indicators can be developed.

5.2.3 Societal costs

Under the societal costs, we consecutively deal with emissions (air and noise), accidents and infrastructure. Given the focus on Flanders, unit values for societal cost sub-categories are all taken from Vlaamse Overheid (2013). An alternative would have been van Essen et al. (2019), which has the advantage of Europe-wide comparability of its findings, but the drawback of being less specific for Flanders, which is the case subject of this paper[11].

Air emission costs comprise both greenhouse gas and local air pollution. Their impact value depends among others on the type of vehicle, the speed and the state of the road. The standard impact indicators can be found in table 9, whereby speed is linked to the road type. The state of the road obviously is very case-specific.

Table 9: Air emission impact indicators Flanders (€/100vkm, 2020)

		Direct greenhouse gas	Direct air pollution	Indirect greenhouse gas	Indirect air pollution	Sum
Passenger cars	Highway	0.41	0.89	0.06	0.55	1.90
	Urban	0.61	3.28	0.09	0.82	4.80
	Rural	0.41	0.81	0.06	0.55	1.83
	Average all road types	0.45	1.35	0.06	0.61	2.48
Light freight vehicles	Highway	0.67	2.76	0.10	0.88	4.41
	Urban	1.02	8.83	0.15	1.32	11.32
	Rural	0.83	3.69	0.12	1.07	5.71
	Average all road types	0.84	4.65	0.12	1.09	6.70
Heavy freight vehicles	Highway	1.88	7.97	0.27	0.11	10.22
	Urban	2.74	20.87	0.40	3.58	27.60
	Rural	2.15	9.20	0.31	2.80	14.47
	Average all road types	2.17	10.91	0.32	2.83	16.23

Source: indexed from Vlaamse Overheid (2013)

Noise emissions depend on the type and state of the tyres, the type and state of the road, and the type of fuel used. These elements are very case-specific, and therefore not diversified for. Taken into account are the speed – through the type of road – and the type of vehicle (Table 10).

Table 10: Noise emission impact indicators Flanders (€/vkm, 2020)

	Between cities	Urban traffic	Average
Passenger cars	0,02	2,83	0,61
Light freight vehicles (<12 ton)	0,11	14,14	3,34
Heavy freight vehicles (>12 ton)	0,20	26,02	4,85

Source: Vlaamse Overheid (2013)

Accident impacts are expressed by the marginal accident costs (Table 11)[12].

Table 11: Marginal accident impact indicators Flanders (€/100 vkm, 2020)

	Marginal accident

[11] Interesting is also the drawback specifically mentioned by Crozet (2017) in applying van Essen et al. (2019) for accident costs.

[12] For reasons of not making the analysis in this paper overly complex, accident rates and impacts are assumed constant here for a specific setting. In reality, accident functions are complex and strongly non-linear. With lower speeds more accidents occur, but with significantly less severe consequences.

		costs
Passenger cars	Highway	2.50
	Other roads	5.16
	All roads	4.23
Freight vehicles	Highway	3.68
	Other roads	5.96
	All roads	4.51

Source: Vlaamse Overheid (2013)

As it is assumed that infrastructure damage does not change under congestion, this cost is not taken into account.

Using the above traffic shares and unit costs, calculations will be made in section 6 for a concrete congestion situation in Flanders.

6 Applying the model to a specific Flemish congestion situation

This section applies the developed model to a specific congestion situation in Flanders. Imagine an event on the E19 motorway between the Dutch border and Antwerp on a working day after the morning peak, over a distance of 15.1kms, leading to an average speed of 10kms. The E19 motorway there has two lanes, allowing for a maximum speed of 12kms/h.

Figure 9: Selected Flemish highway congestion event

Source: own composition based on Vlaams Verkeerscentrum (2020b)

The length of the congestion event is used to calculate the number of vehicles involved. Applying the principles of table 1, the stopping distance at a speed of 10kms/h is 5.56m. Table 3 learns us that on the highways in Flanders off-peak, the traffic is composed 19% of trucks, 9% vans, 5.7 work-related traffic and 66.3% private traffic. Hence, the length of the congestion equals

$$15{,}100 = 0.19Q\ (8 + 5.56) + 0.81\ Q\ (4 + 5.56)$$

Or

$$Q = \frac{15{,}100}{10.32} = 1{,}463$$

Given the above-mentioned fractions of the various vehicle types, it can be calculated that there are 278 trucks, 131 vans, 83 work-related passenger cars and 970 private cars.

The extra time needed for trucks amounts to 80.44 minutes for trucks and 82.92 minutes for other user types. This extra time needs to be multiplied by the applicable time coefficient from table 5, and then by the number of impacted vehicles, as calculated above. This in turn has to be multiplied by the respective occupation degrees, leading to the total time costs of the congestion event (table 12).

Table 12: Time costs of the selected Flemish highway congestion event

	Unit time costs per vehicle category (€)	Number of vehicles	Number passengers per car	Total time cost (€)
Trucks/heavy freight	57.29	556	1	31,853.86
Vans/Light freight vehicles	55.28	262	1	14,482.14
House and work, and work-related traffic	18.05	166	1.4	4,195.40
Private usage	10.71	1,940	1.4	29,090.08
TOTAL				79,621.47

Source: own composition

For the additional fuel costs, assuming a unit cost for diesel of €1.21 and for gasoline of €1,4135, and taking into account an increase of the distance coefficient to 4.9364 for trucks and 2.0605 for vans due to the congestion (see table 7), the adapted fuel costs can be calculated for each vehicle type (table 13).

Table 13: Total fuel costs of the selected Flemish highway congestion event

	Extra fuel consumption (l)	Extra fuel cost per vehicle fuel to lower average speed (€)	Number of vehicles	Total fuel cost (€)
Trucks/heavy freight	41.02	49.63	556	41,573.83.
Vans/Light freight vehicles	22.81	27.60	262	10,710.00
House and work. and work-related traffic - diesel	10.10	12.22	102	1,246.74
House and work. and work-related traffic - gasoline	12.71	17.96	62	1,113.73
Private cars - diesel	10.10	12.22	1,196	14,618.63
Private cars - gasoline	12.71	17.96	742	13,328.85
Total				82,591.78

Source: own composition

The external direct transport costs applicable to this case and taken from table 8 amount to €8.01 and €4.01 for trucks and others respectively. Multiplying by the respective number of vehicles leads to €4,453.60 for trucks and €1,049.32 for vans, €667.84 for commuting, and €7,769.76 for private transport, or a total external direct congestion cost of €13,937.52 for the entire congestion event.

The total societal air emission costs (table 14) can be calculated by combining the unit emission costs of table 9 with the key figures from table 14 and with the number of vehicles.

Table 14: Total societal air emission costs of the selected Flemish highway congestion event

	Key figure (km)	Cost per 100 vkm (€)	Emission harmful substances	Number of vehicles	Total emission cost harmful substances (€)

			per vehicle type (€)		
Trucks/heavy freight	119.59	10.22	10.4713	556	6,798.21
Vans/Light freight vehicles	162.93	4.41	6.1539	262	1,882.60
House and work. and work-related traffic	162.93	1.90	2.6558	166	514.76
Private cars	162.93	1.90	2.6558	1,940	6,015.89
Total					15,211.46

Source: own composition

Similarly. the unit noise emission costs from table 10 can be combined with the key figures from table 14 and the number of vehicles to obtain the total societal noise emission costs (table 15).

Table 15: Total societal noise emission costs of the selected Flemish highway congestion event

	Key figure (km)	Cost per 100 vkm (€)	Noise emission per vehicle type (€)	Number of vehicles	Total noise emission cost (€)
Trucks/heavy freight	119.59	0.20	22,0883	556	13,354.18
Vans/Light freight vehicles	162.93	0.11	16,2767	262	4,635.48
House and work. and work-related traffic	162.93	0.02	3,1445	166	568.45
Private cars	162.93	0.02	3,1445	1940	6,643.31
Total					25,201.42

Source: own composition

Finally, the unit accident costs from table 11 can be combined with the key figures from table 14 and the number of vehicles to obtain the total societal accident costs (table 16).

Table 16: Total societal accident costs of the selected Flemish highway congestion event

	Key figure (km)	Cost per 100 vkm (€)	Accident cost per vehicle type (€)	Number of vehicles	Total accident cost (€)
Trucks/heavy freight	119.59	3.68	404.21	556	2,445.68
Vans/Light freight vehicles	162.93	2.50	374.74	262	1,066.66
House and work. and work-related traffic	162.93	2.50	374.74	166	675.82
Private cars	162.93	2.50	374.74	1,940	7,898.16
Total					12,086.32

Source: own composition

Summing the total values for all of the above cost categories leads to the total cost figure caused by the congestion event of €202,766.91 (table 17). Direct costs, both time and distance, appear to be the biggest contributors.

Table 17: Total costs for the selected Flemish highway congestion event

Cost elements	Cost	Percentage distribution
Private direct costs – time	€ 79,621.47	35.9%
Private direct costs - distance	€ 82,591.78	34.9%
Private external direct costs	€ 13,937.51	5.9%
Societal costs – emission of harmful substances	€ 15,211.46	6.4%
Societal costs – noise emission	€ 25,201.42	11.4%

Societal costs – accident costs	€ 12,086.32	5.5%
TOTAL	**€ 216,563.6**	**100%**

Source: own composition

7 Conclusion and contribution

Road transport remains an important factor in the current-day economy, despite lots of policy initiatives to bring more balance in the modal split. All future prognoses expect a further increase in freight and passenger transport. Equally, and for reason of that growing dependence on road transport, a country's logistics competitive position depends largely on the extent to which it can keep its road transport fluid. Statistics show that road congestion in most industrial and economic centers in the world is increasing. To date, the impact of concrete congestion situations and events was hardly ever quantified in a fully transparent and scientifically founded way. The main reason is that an instrument for such uniform quantification was non-existing. This paper has developed such instrument. By doing so, the paper has both a scientific contribution as well as a contribution to business practice and policy.

Contribution to scholarly knowledge

This paper first of all contributes to shedding light on the magnitude of road congestion, by providing the results of a broad literature review. That shows the components of congestion costs, which comprise both private and societal elements, direct and indirect, and it also identifies that transport can be split up in truck, van, work-related and private trips, each of which has its relevant cost characteristics. The review also shows where which types of data sources can be found to quantify congestion costs. It is found that some components can hardly be quantified, since the impacts can be very case-specific. Furthermore, in order to allow for the quantification, a generic framework is developed, that is tested and validated with real-life data for the case of Flanders. A main conclusion from the first application is that the largest share of the total congestion cost can be attributed to the private direct costs.

By using the indications of where to search for which type of data, the framework can be applied to any other context wherever in the world. However, caution needs to be taken there, since various inputs to the provided framework may be different. First of all, allowed vehicle speeds differ between countries. Logically, that implies that observed speed reduction impacts will be different. For instance, in Flanders in 2020, secondary roads only allow for 70 kms/h speeds, while France allows for 80 kms/h. That implies that a same observed actual speed on a road in France and in Flanders, would mean a stronger reduction to the normal speed in France, and hence a more severe congestion situation. Second, also vehicle type shares between countries are different. That impacts on the total obtained congestion cost, as the congestion cost is different for a truck as compared to a passenger car, as demonstrated in this paper. Third and finally, unit cost values are different between countries. For the internal direct costs, that is true especially for insurance, transport taxes, wages and other costs (buildings, management and administration). The same cost categories determine the differences in indirect costs observed between countries, be it that those will in any case remain very case-specific as to their magnitude. Also societal costs will differ among countries: especially air pollution and noise impacts will feature different unit impact values, due to different population density, different mitigation measures taken, etc.

An identified scientific need is the calculation of new key figures for monetizing internal, external and societal costs. Most values are at the border of being outdated, since simple indexing does not suffice. Stated preference research could help in valuing the time loss that both passenger and freight transport experiences. Ideally, this is done on a regular basis.

Contribution to business practice and policy

The developed calculation instrument is useful for both business practitioners and policymakers. For the sector and business practitioners, the instrument provides uniform insight into the magnitude and impact of congestion in a specific area or on a specific road. The resulting monetary values can first of all be used in negotiations by trucking companies with customers, for agreeing on transparent calculation of congestion surcharges. The results can also be used for determining a company location where congestion impacts are lower. Finally, resulting monetary values can be used by producers to see how competitive are the alternative modes rail and barge in terms of total generalized costs, not based on theoretical figures, but on calculations taking into account real cost and time impacts.

Policymakers can use the results first of all to identify areas where the impact of congestion is high, and which should get priority in setting up solutions. Second, they can use the instrument and its results to test the effect of congestion mitigation measures (e.g. road pricing). It is thereby important that a scientifically sound and universally valid and accepted approach like the one developed here, is used. Caution is needed here too, for the same reason that unit congestion and cost values cannot just be transferred from one country or even region to another, and therefore specific values need to be collected when applying to a different context.

Also towards policymakers, a recommendation applies. Given that a lot of data sources on congestion are getting outdated, as mentioned higher, it is important that public authorities keep tracking the evolution of congestion in a consistent and uniform way, so that they can verify how the congestion situation evolves, where which measures are needed, and whether the measures actually lead to the improvements they promise.

Acknowledgment

The authors wish to thank the participants to the expert meeting held in Antwerp on 16 June 2014.

References

Armelius, H. (2005), An integrated approach to urban road pricing, Journal of Transport Economics and Policy, 39(1)

Blauwens, G., De Baere, P. and E. Van de Voorde (2016) Transport Economics, De Boeck, Antwerp

Bovy, P. and H. Salomon (1999), A Prospective Assessment of Traffic Congestion in Europe, Traffic congestion in Europe - OECD report Round Table 110,, 85-154

Christidis, P. and J.N. Ibanez-Rivas, (2012), Measuring road congestion, European Commission Joint Research Centre, Sevilla

Cerwenka, P. and O. Meyer-Rühle (2008), Sind Staukosten externe Kosten?, Internationales Verkehrswesen, 60(10), 391-396

Crozet, Y. (2017), Insécurité et congestion : comment évaluer les coûts externes ? , Transports, 503, 35-39

European Commission (2020), EU Transport in Figures – Statistical Pocketbook 2019, consulted online on https://op.europa.eu/en/publication-detail/-/publication/f0f3e1b7-ee2b-11e9-a32c-01aa75ed71a1 on 24 January 2020

Federaal Planbureau (2014), Transport Databases, consulted on 21 February 2020

FOD Mobiliteit en Vervoer (2007), Algemene verkeerstellingen 2005 deel IV - Vijfjaarlijkse verkeerstellingen van de voertuigcategorieën inbegrepen het aantal personen per voertuig, en de evolutie van het zwaar vervoer volgens de voorschriften van het Bureau van de Verenigde Naties te Genève (UNECE)

FOD Mobiliteit en Vervoer (2019), Kilometers afgelegd op het Belgisch Wegennet

Golob, T.F. and A.C. Regan, (1999), Impacts of Highway Congestion on Freight Operations: Perceptions of Trucking Industry Managers, Transportation Research A, 34(8), 587-605

Goodwin, P. (2004), The Economic Costs of Road Traffic Congestion, University College London, consulted online on https://discovery.ucl.ac.uk/id/eprint/1259/1/2004_25.pdf on 16 July 2020

Gunn, H. and P. Sillaparcharn (2007), An introduction to the valuation of travel time-savings and losses, in Hensher, D. (ed.), Handbook of Transport Modelling - Volume 1, Emerald, London

Inrix (2020), Scorecard, consulted online on https://inrix.com/scorecard/ on 24 January 2020

Kristoffersson, I. (2013), Impacts of time-varying cordon pricing: Validation and application of mesoscopic model for Stockholm, Transport Policy, 28, 51-60

Lindsey, C.R. and E.T. Verhoef (2000), Congestions Modelling, Handbook of Congestion Modelling, Vol. 1., Elsevier Science, Oxford

Maerivoet, S. and I. Yperman (2008), Analyse van de verkeerscongestie in België,

Nash, C. and B. Matthews (2005), Measuring the marginal social cost of transport, Elsevier, Oxford

Notter, B., Keller, M., Althaus, H.-J., Cox, B., Knörr, W., Heidt, C., Biemann, K., Räder, D. and M. Jamet (2019), HBEFA 4.1 Development Report, consulted online on https://www.hbefa.net/e/documents/HBEFA41_Development_Report.pdf on 16 July 2020

Ntziachristos, L., Gkatzoflias, D., Kouridis, C. and Z. Samaras (2009), COPERT: A European road transport emission inventory model, Information Technologies in Environmental Engineering, 491-504

Olszewski, P. and L. Xie, (2005), Modelling the effects of road pricing on traffic in Singapore, Transportation Research Part A, 39, 755-772

Piccioni, C. (2011) Territorial accessibility and dynamics in road infrastructure use: an integrated planning approach, Ingegneria Ferroviaria, 7(8), 621-641

Santos, G. (2004), Urban Congestion Charging: A Second-Best Alternative, Journal of Transport Economics and Policy, 38(3), 345-369

Schallaböck, K.-O. and R. Petersen (1999), Traffic Congestion in Europe – Germany, Report of the hundred and tenth round table on transport economics

Sessa, C. and R. Enei (2010), EU Transport GHG: Routes to 2050? – EU transport demand: Trends and drivers, consulted online on http://temis.documentation.developpement-durable.gouv.fr/docs/Temis/0063/Temis-0063686/17714.pdf on 26 January 2020

TomTom (2020), Traffic Index, consulted online on https://www.tomtom.com/en_gb/traffic-index/ on 20 February 2020 van Essen, H., van Wijngaarden, L., Schroten, A., Sutter, D., Bieler, C., Maffii, S., Brambilla, M., Fiorello, D., Fermi, F., Parolin, R., El Beyrouty, K., Handbook on the External Costs of Transport, consulted online on https://ec.europa.eu/transport/sites/transport/files/studies/internalisation-handbook-isbn-978-92-79-96917-1.pdf on 16 July 2020

van Hassel, E., Meersman, H., Van de Voorde, E. and T. Vanelslander (2020), The impact of the expanded Panama Canal on port range choice for cargo flows from the U.S. to Europe, Maritime policy and management, 1-19 published online

Van Woensel, T. and F.R.B. Cruz, (2008), A stochastic approach to traffic congestion costs, Computers & Operations Research, 36(6)

Verhetsel, A., Vanoutrive, T. & Zijlstra, T. (2014), Het woon-werkverkeer in Vlaanderen: zoektocht naar indicatoren, Steunpunt Goederen en Personenvervoer, Universiteit Antwerpen, 56p., consulted online on https://www.uantwerpen.be/images/uantwerpen/container33836/files/MOBILO%20Het%20woon-werkverkeer%20in%20Vlaanderen.pdf on 26 January 2020

VIASVias (2013), Nationale gedragsmeting snelheid – 2012, consulted online on https://www.vias.be/nl/onderzoek/onze-publicaties/nationale-gedragsmeting-snelheid-2012/ on 26 January 2020

Vlaams Verkeerscentrum (2020), Verkeersindicatoren, consulted online on https://www.verkeerscentrum.be/studies/rapport-verkeersindicatoren-snelwegen-vlaanderen-2018 on 29 March 2020

Vlaams Verkeerscentrum (2020), Verkeerssituatie, consulted online on https://www.verkeerscentrum.be/verkeerssituatie on 21 February 2020

Vlaamse Overheid, Departement Mobiliteit en Openbare werken (2013), Standaardmethodiek voor MKBA van transportinfrastructuurprojecten. Kengetallenboek, consulted online on https://docplayer.nl/59129162-Standaardmethodiek-voor-mkba-van-transportinfrastructuurprojecten.html on 26 January 2020

Wardman, M. (1998), The value of travel time: A review of British evidence, Journal of Transport Economics and Policy, 32(3), 285-316