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How to make urban freight transport by tram successful?

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Abstract

Many national and international bodies, such as the European Commission, encourage the use of environment-friendly transport modes. Local and national authorities take more and more measures, for instance road pricing, loading/unloading spaces and low-emission zones, to prevent negative transport-related externalities in urban areas. Hence, transport and logistics operators consider alternative ways to deliver goods in urban areas by using electric vehicles, cargo bikes, inland vessels and rail transport. Which of these alternative modes is appropriate for which transport flow depends on multiple factors, including the available transport infrastructure, the goods volume, the time of the transport, the measures taken by the authorities and the presence of congestion. This paper focuses on urban freight transport by tram and the conditions for a successful implementation. A successful implementation is defined as an implementation that is viable, i.e. the difference between the change of the costs and the change of the benefits exceeds a certain threshold value. The viability is studied from a business-economic and a socio-economic perspective for a dedicated freight tram, a freight wagon behind a passenger tram and the transport of parcels by a passenger tram. A viability model is developed, based on a social cost-benefit analysis. The working of this model is illustrated by applying it to the city of Antwerp. The main findings reveal as critical factors the transported volume, the efficiency of the current road transport, the timing of the transport, the need for post-haulage and the operational costs of both road and rail.

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Keywords: urban freight distribution; tram; social cost-benefit model; sensitivity analysis; sustainability

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1. Introduction

Many national and international bodies, such as the European Commission (2018) and the United Nations (2018), encourage the use of environment-friendly transport modes. At local and national level, more and more measures are taken by authorities (Letnik, Marksel, Luppino, Bardi, & Božičnik, 2018), for instance road pricing, loading/unloading spaces and low-emission zones, to prevent negative transport-related externalities in urban areas (Cavallaro, Giaretta, & Nocera, 2018; Chang, Tseng, Hsieh, Hsu, & Lu, 2018; Maes, Sys, & Vanelslander, 2011). These measures make delivering goods in urban areas by road vehicles more challenging (Cruz & Montenon, 2016).

Hence, transport and logistics operators consider alternative ways to deliver goods in urban areas by using electric vehicles, cargo bikes, inland vessels and rail transport (Diziain, Taniguchi, & Dablanc, 2014; Maes, 2017; Mirhedayatian & Yan, 2018; Trojanowski & Iwan, 2014). In this context, one of the themes in the city logistics literature investigates the use of rail for urban freight distribution instead of traditional road transport. When using rail to transport urban freight, either available rail infrastructure in the urban area can be used, new infrastructure can be constructed, or both the existing and new infrastructure can be utilised.

Combining passenger and freight operations on the existing urban passenger transport networks is recently getting more attention in the city logistics and the operations research literature. Many urban areas possess rail infrastructure, but seldom is this infrastructure used for freight activities. Using the passenger infrastructure to transport goods is one way to reduce the current urban road traffic (Behiri, Belmokhtar-Berraf, & Chu, 2018). Moreover, Macario et al. (2011) and Bektas et al. (2016) see some attractive business opportunities by combing the transport of passengers and freight in the same vehicles, leading to economies of scope including lower rolling stock and personnel costs. As passenger demand varies during the day, the spare capacity of the urban passenger transport network in off-peak moments could be used to transport freight (Pimentel & Alvelos, 2018). In this context, Chiron-Augereau (2009) examines the potential role of a public transport operator in Paris for urban freight distribution. Behiri et al. (2018) and Pimentel & Alvelos (2018) develop a mixed integer programming model combining passenger and freight flows on a city bus network. Cleophas et al. (2018) provide an overview of different vertical and horizontal collaborations in urban transport, with a focus on recent operations research concepts. Ozturk & Patrick (2018) develop a decision support framework for optimised freight transport by urban rail and apply mixed integer linear programming.

Pimentel & Alvelos (2018) find that the combination of passenger and freight flows is almost inexistent in the last-mile literature and thus, it is an interesting topic to examine. Therefore, the objective of this paper is to investigate the use of rail for urban freight transport and the conditions for a successful implementation. A successful implementation means that the use of a rail-based scheme is viable from a business-economic and a socio-economic viewpoint (Sartori et al., 2015)[2]. From a business-economic perspective, the rail-based scheme is viable if the change of private benefits minus the change of private costs exceeds a certain private threshold value. From a socio-economic viewpoint, the scheme is viable if the difference of the change of the social benefits minus the change of the social costs exceeds a certain socio-economic threshold value. The analysis is done from the perspective of the infrastructure owner, in this case the authorities. Indirect effects, such as employment effects, are not included in the analysis (Aronietis, Sys, & Vanelslander, 2016). In general, rail comprises heavy rail, light rail, trams and metros (Kikuta, Ito, Tomiyama, Yamamoto, & Yamada, 2012; Motraghi & Marinov, 2012). This paper focuses on the use of trams. Trams were often used to transport goods (Annys et al., 1994; Van Heesvelde, Troubleyn, De Troy, & De Meyer, 2018) until the car and truck became more popular in the course of the 20th century thanks to their flexibility. Given the increasing congestion and air quality issues, it is most interesting to examine whether the use of trams for urban freight transport could provide a solution. Cochrane et al. (2017) highlight the need for an economic analysis of rail-based urban freight strategies. These authors state that an urban rail-based scheme should be modelled in order to estimate the operational and environmental effects. Therefore, in the current paper, a novel viability model is developed based on a social cost-benefit analysis. This model allows calculating the business-economic and social-environmental costs and benefits that emerge when goods are transported by tram instead of by truck or van. Moreover, the model makes it possible to

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[2] Sartori et al. (2015) use the terminology "financial analysis – return on investment" for what is considered here as the business-economic analysis and the terminology "economic analysis" for what is considered here as the socio-economic analysis.

measure the effect of a change of one or more variables characterising the tram initiative on the costs and the benefits by providing sensitivity analyses. As an illustration of the viability model, the decision is made to show calculation results for the city of Antwerp (Belgium).

This paper extends the vast body of literature on city logistics and on combined passenger and freight flows in two ways. Firstly, the key strength of the paper is the novel methodological framework that is offered and that can be applied to other urban areas. The model allows understanding how one feature of for instance the urban area or the tram infrastructure can alter the success potential of using a tram for freight purposes. Moreover, in the newly developed model freight can be loaded on the tram at multiple points and multiple deliveries can be made. This is new compared to most existing studies treating freight transport by tram. Secondly, the paper adds knowledge on the possibilities of using available tram infrastructure for freight purposes in Belgium. Furthermore, the paper can help demonstrating for instance public transport operators the added value of applying cost-benefit analyses when making decisions with respect to infrastructure and operations. Vigren & Ljungberg (2018) show that public transport authorities seldom use cost-benefit analyses, whereas literature states that this method is very appropriate to support such decisions (Blauwens, De Baere, & Van de Voorde, 2016; Gonzalez-Feliu, 2016).

The rest of this paper proceeds as follows. Section 2 provides a synopsis of the urban rail freight literature. Section 3 presents the viability model. In Section 4, the data used in the model application are clarified. Section 5 shows the results of the application of the viability model for the city of Antwerp. Ultimately, some conclusions are drawn and further research is proposed in Section 6.

2. Urban freight transport using the public transport network

Considering a tram, goods can be transported using a dedicated freight vehicle, in a freight wagon behind a passenger tram, or a small amount of parcels can be transported in a passenger tram. These three types of transport differ amongst others concerning the volume that can be transported and the capital investment needed. Hence, the literature review in the following subsections is split into these three types of tram transport.

2.1 Dedicated freight vehicle

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

In the academic literature, several authors pay attention to the possibility of using a dedicated freight tram. Arvidsson (2010) suggests to use old passenger tram vehicles to transport freight. Arvidsson & Browne (2013) examine the success of the City Cargo freight tram project in Amsterdam. Regué & Bristow (2013) investigate the use of the tram infrastructure in Barcelona for the transport of retail products and waste and conduct a cost-benefit analysis. Gonzalez-Feliu (2016) examines the costs and benefits of the TramFret project in France. Ozturk & Patrick (2018) also describe the latter project, confirming that for this case study too, recycled passenger trams are used. Cochrane et al. (2017) analyse different freight on-transit strategies, including the transport of packages between the airport and the central station in the Greater Toronto and Hamilton area by dedicated freight trains, and supplying retailers in a large shopping centre by a dedicated metro. Cleophas et al. (2018) describe the CargoTram and E-Tram in Zurich, which is a dedicated freight tram using the available public tram infrastructure. The GüterBim in Vienna is another case study discussed by these authors, where a dedicated freight unit also used the available passenger tram infrastructure. Some new tram sections had to be constructed in order to deliver the goods to some stores and restaurants in the city.

2.2 Freight wagon behind a passenger vehicle

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

2.3 Freight in a passenger vehicle

The most known example of transporting freight in public transport vehicles is the transport of mail. Examples of mail transport by passenger buses or trams are especially found for the 19th and 20th century, for example in Belgium and Germany (Annys et al., 1994; Cleophas et al., 2018; Fredriks.de, 2018). Since 2007, Citipost has placed mail boxes in trams in Bremen, in which passengers can depose their mail (Posttip.de, 2007). Kikuta et al. (2012) organised a pilot in which a hand cart was loaded on board of a passenger subway wagon in the Japanese city Sapporo. In more recent studies, both the use of a bus and a tram and train is examined. Cochrane et al. (2017) examine the transport of low-priority mail and packages in freight compartments in commuter trains. Pimentel & Alvelos (2018) propose a model in which the city bus network is used to transport parcels. The model is applied to buses following a fixed route. Hence, the system can be compared to an urban tram network, having as an intrinsic characteristic that the trams also have to follow a fixed route.

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

3. Developing the viability model

In order to investigate whether and how using a tram for urban freight distribution can be successful, a generic model is developed. A social cost-benefit analysis is used as the starting point. Fig. 1 shows schematically how the viability model is constructed and how it works.

The viability model displayed in Fig. 1 consists of three main parts, being the input, the calculations and the output. Firstly, data concerning the reference and project scenario are used as input. Secondly, the appropriate module of the calculations part is activated. Currently, three modules are available in the model, being module 1.1: dedicated freight tram, module 1.2: freight wagon behind a passenger tram, module 1.3: freight in a passenger tram. The model leaves the possibility to add as many modules as wanted. Thirdly, the business-economic and socio-economic results of the calculations are available in the output. The following sections provide more detailed information on the different parts of the viability model.

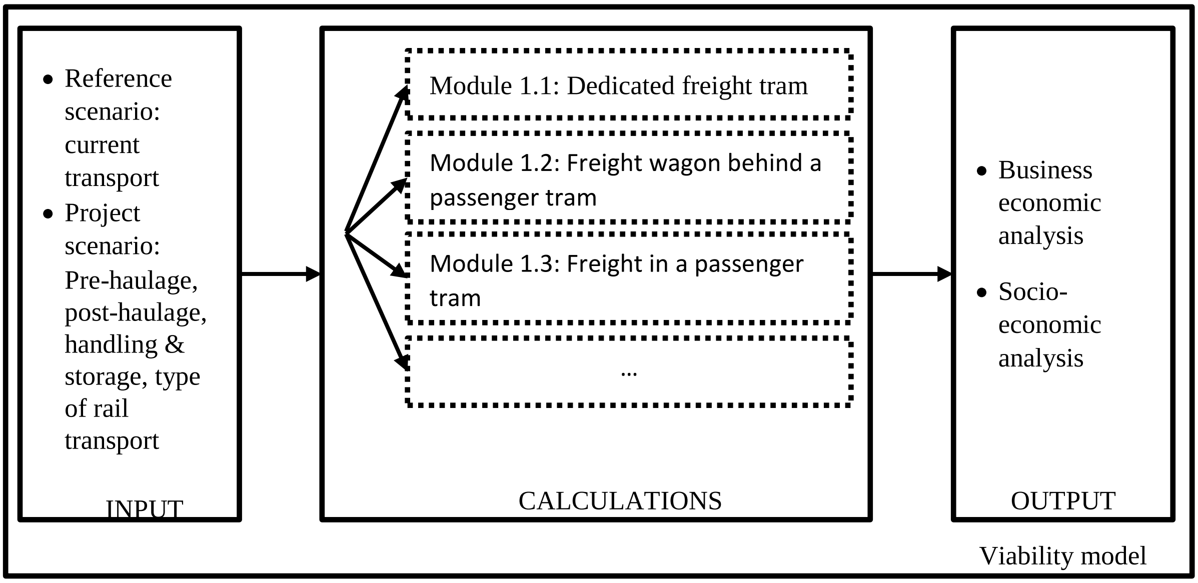

Fig. 1. Viability model for urban freight by tram

3.1 The input

In the input part, data are collected for five subjects: the current transport by road, the potential additional handling and storage when shifting from road to rail, the potential road pre-haulage, the potential road post-haulage and the rail leg.

Firstly, some characteristics of the current transport by road have to be specified. Examples of data needed here for every conducted round trip are the current distances covered to reach the customer in the urban area, the timing of the transport, being peak-hour, off-peak hour or during the night, the main product type that is transported, the value of the goods delivered at the customers and the location of the customers. A round trip is defined in this research as the transport of goods from one supplier to one or more customers in an urban area and the trip back to the supplier's premises. Additional information that is required for each round trip is the goods volume delivered at each customer and some vehicle characteristics such as the fuel type, the tonnage and the euro standard. Ultimately, the average speed of the road vehicles to fulfil the round trips has to be indicated.

Secondly, some decisions have to be made with respect to the handling and storage when the shift from road to tram is made. It has to be decided at which location at the edge of the city the goods are loaded on the tram, as well as at which point in the city centre the goods are unloaded from the tram. For both handling points, it has to be indicated whether the goods are only transferred (transit platform), or also stored for a while (distribution centre).

Thirdly, for each roundtrip, the distance that has to be covered between the supplier and the location at the edge of the city, where the goods are loaded on the tram, has to be clarified.

Fourthly, for each customer receiving goods, the nearest tram stop has to be chosen. Other information that is required is the distance that still has to be covered between the tram stop and the customer and the way the post-haulage transport (if needed) is done. Currently, six possible ways of post-haulage are available in the model: the tram stops in front of the customer, a shop employee walks to the tram stop and picks up the goods, a member of the tram personnel brings the goods to the customer, a traditional cargo bike service is used, an electric cargo bike service is used, or an LGV is used. In case of the use of an LGV, the euro standard of the LGV, as well as whether the LGV operates on petrol, diesel or electricity, has to be added. Moreover, if the goods are stored at the tram stop for a while, the timing of the post-haulage transport can be chosen.

Fifthly, some tram characteristics are specified. These features include the length of additional sidings to the existing tram network that have to be constructed, the type of tram vehicle, the way electricity is generated, the amount of advertisement space sold on the tram vehicle and whether the tram has its own right of way, or whether this is shared with road traffic. Moreover, the tram trips are specified in the sense that for each tram trip the handling and storage point at the edge of the city, and the tram stops in the city centre are indicated, as well as the timing of the tram trips.

3.2 The calculations

The calculations are executed for each module separately. Depending on the type of tram transport selected in the input part, another module is activated. Hence, the business-economic and social-environmental costs and benefits of using that particular type of tram transport are compared to the current transport by road. Four main components of costs and benefits are identified, being the private cost, private benefit and external cost and benefit.

3.2.1 Private cost

The private cost of using rail instead of a truck or van consists mainly of the capital investment and the operational costs. Capital investment includes the potential investment in sidings, i.e. tracks and switches, rolling stock and handling and storage points, such as transit platforms or distribution centres. For the capital investment calculations, the life span of the infrastructure is taken into account, as well as the replacement costs and potential residual value. The need for capital investment varies a lot depending on the type of tram transport.

The operational costs comprise the costs of operating the tram, the track access charges to use the public tram network, the costs of operating the road pre- and/or post-haulage, potential road pricing in the road pre-haulage leg, and the costs of operating the transit platform and/or distribution centre where the goods are moved from truck to rail or vice versa.

3.2.2 Private benefit

The private benefit consists of the revenue generated by the tram service operator and potential customers' benefits. The revenue of the tram service operator related to the freight transport is difficult to estimate, since the service currently does not exist. Therefore, it is assumed that the shipper does not want to pay more than what he is paying today for the transport by road. Potential customers benefits comprise saved shop surface, saved shop personnel, a reduced inventory carrying cost and advertisement revenue. In case the goods are delivered by tram in smaller and more frequent quantities, the customers in the urban area can use more space for sales purposes instead of storage purposes. However, if the goods are delivered by tram in larger and thus, less frequent quantities, this benefit becomes an additional cost for the customers, since more storage space is needed (Blauwens et al., 2016). Shop personnel can be saved if the delivery by tram occurs such that the shop personnel can work more efficiently. A reduced inventory carrying cost is obtained if there are time gains by transporting the goods by tram instead of by truck or van. Ultimately, some advertisement revenue is potentially present if advertisement space on the tram is sold to third parties.

3.2.3 External cost and benefit

The external cost includes all costs related to externalities caused by the tram, the road pre- and/or post-haulage and the handling and storage. External cost components considered are accidents, air pollution and climate change, congestion, infrastructure damage and noise (Korzhenevych et al., 2014). The external cost of potential up- and downstream processes, such as the generation of electricity, is included in the other cost components. The external benefit of using a tram instead of a truck or van is equal to the reduction of road external cost.

3.3 The output

The third part of the developed model shows the business-economic and socio-economic results of the viability model. The business-economic analysis evaluates the consolidated project viability. The methodology used to calculate this viability is the discounted cash flow method. Since the authorities are leading the investment, the needed equity is considered to be part of the national capital. Hence, no capital financing costs are considered to calculate the return on investment. However, if the capital owner is a private stakeholder, costs of financing by using own equity have to be taken into account by adding equity opportunity costs to the calculations. Moreover, an analysis can be made of the return on capital, by assuming that part of the capital investment comes from a bank loan. Following Sartori et al. (2015), a financial discount rate is used, which represents the opportunity cost of capital.

The socio-economic analysis appraises the contribution of the project to welfare. Some effects are not valued in the market and are therefore not included in the business-economic analysis. However, from a welfare perspective, they contribute to the costs and benefits related to the project. Thus, in the socio-economic analysis these effects are added by using shadow prices. A social discount rate is used in this analysis, which represents the social view on how costs and benefits should be compared to the present ones (Sartori et al., 2015).

For both analyses, the resulting net present value and internal rate of return are calculated in order to assess whether the project should be put in practice.

4. Illustration of the viability model

This section provides an illustration of the developed viability model. The aim of this illustration is to show how the developed model can be used in practice.

4.1 Reference and project scenario

The reference scenario is designed for a round trip by road transport in the situation illustrated in Fig. 2. All round trips in the rest of the paper, are considered to have the same characteristics. The supplier transports goods to three customers, located in an urban area. This transport is done by a rigid diesel van of 3.5 tonnes gross weight and a euro standard 4. The van operates during off-peak hours, carries non-food items and has an average speed of 35 km/h. The distance covered to reach the first customer, is set at 60 km. In this total distance, the van drives 40 km on motorways, 10 km on urban roads and 10 km on suburban roads. If the van is 100% filled, customer 1 and customer 2 each receive 200 kg of goods, while customer 3 gets 600 kg of goods delivered. Furthermore, the average value of the goods is approached by 2 euro per kilogram. This approximation is altered in the sensitivity analyses.

Roundtrip	Customer 1	Customer 2	Customer 3
Volume	200 kg	200 kg	600 kg
Value	€ 400	€ 400	€ 1,200

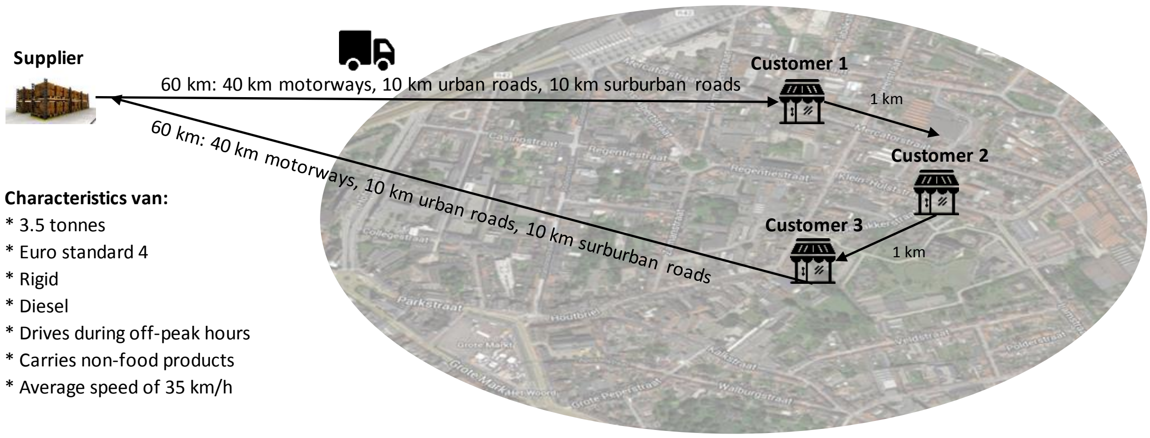

Fig. 2. Characteristics of the reference scenario (current road transport)

The project scenario is developed for a round trip by tram transport complemented by road pre-haulage in the situation illustrated by Fig. 3. The vans of the current road transport are still used, but now only for the road pre-haulage until a certain handling and storage point at the edge of the city centre. Over there, the goods are loaded on a tram[3] and the tram transports the goods towards a tram stop located in the neighbourhood of the customers. It is assumed here that no road post-haulage is needed. The tram uses 100% green electricity, drives during off-peak hours following Behiri et al. (2018) and shares it way with the road traffic, slightly reducing its average speed from 18 km/h to 15 km/h.

For both scenarios, the financial discount rate is set at 4% (Blauwens et al., 2016; Sartori et al., 2015) and the social discount rate at 4% (Kidokoro, 2004; Sartori et al., 2015). The time horizon is considered to be 30 years for urban rail projects (Sartori et al., 2015) and all values are expressed in real euros based on the consumer price index.

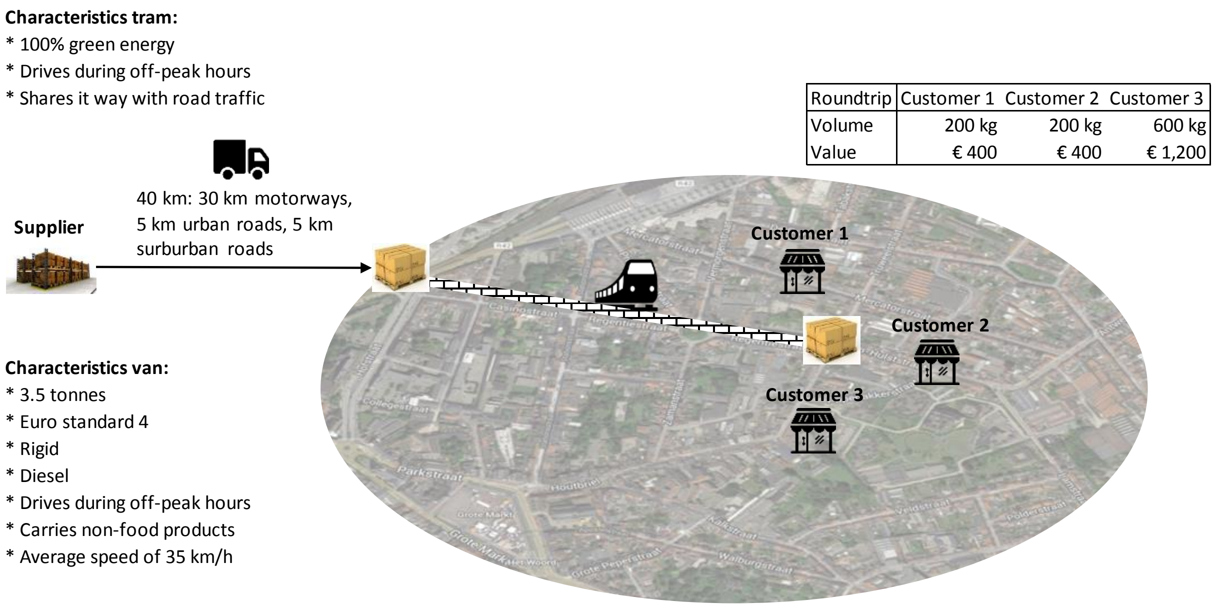

Fig. 3.Characteristics of the project scenario (tram)

4.2 The city of Antwerp as a study area

The viability model is now illustrated for these round trips in the city of Antwerp, which is the second largest city of Belgium in terms of population. In January 2018, 524,501 people were living in Antwerp (Stad Antwerpen, 2018). The city has an urban tram network, which is currently being extended. Antwerp suffers from congestion, with an average congestion level[4] in 2016 of 30%, an average morning peak level of 51% and an evening peak level of 62%. As shown in Fig. 4, most of the delay hotspots are located on the main motorways leading to Antwerp and especially on the ring road around Antwerp, which makes it challenging to enter the Antwerp urban area by road. Moreover, the city introduced a low emission zone in February 2017, covering the area enclosed by the ring road, as well as a part of the left bank of the river Scheldt (Slim naar Antwerpen, 2017). Ultimately, in Belgium, trucks of more than 3.5 tonnes have to pay a road pricing fee when they drive on the motorways and on some main roads (Viapass, 2018).

[3] Depending on the type of tram chosen, the goods will be transferred to a dedicated freight tram (module 1.1), a freight wagon attached to a passenger tram (module 1.2), or a courier takes the goods in the tram (module 1.3).

[4] The congestion level is the additional time needed to cover a certain distance compared to the free flow traffic.

Fig. 4. Delay hotspots in Antwerp in 2016

Source: TomTom (2017a)

4.3 Results

The results of the viability model differ depending on the type of tram transport that is used. Therefore, the following sections discuss the results for each of the three tram types separately.

4.3.1 Dedicated freight tram (module 1.1)

The first illustration of the viability model concerns the use of a dedicated freight tram. Firstly, the model was run given the inputs and data described above. Secondly, the model was altered with respect to the transported volume. Following Campos & Hernández (2010) and Regué & Bristow (2013), the question rises which volume is minimally required to have a viable tram-based solution. The transported volume in the current situation can be altered in four ways: by considering larger or smaller trucks, by considering higher or lower load factors of the existing vans, by adding additional round trips, or by adding new customers receiving goods in the urban area. In this research, it is chosen to keep the type of vehicle fixed to vehicles of 3.5 tonnes gross weight, as well as to keep the number of customers served in the urban area unchanged. Hence, the variables ‘load factor’ and ‘number of round trips’ are altered in order to see the effect of a volume change on the viability of the tram-schedule. It is assumed that a load factor of a van can be 50%, 60%, 70%, 80%, 90% or 100% and the number of round trips considered equals either three, four, five or six. The possible number of round trips is chosen such that the point at which the tram-based solution becomes viable, in terms of net present value and internal rate of return, is found to be in this range.

For all combinations of these number of round trips and load factors, the net present value and internal rate of return are calculated from a business-economic and socio-economic perspective. The respective resulting net present values are displayed in Fig. 5 and Fig. 6. For each combination of a number of round trips and load factor, the net present value is shown. The interesting point, where the net present value becomes positive, is presented as the line between the black and grey shaded area on the business-economic graph (Fig. 5), whereas on the socio-economic graph all NPVs are positive (Fig. 6). In Fig. 5 and Fig. 6, the net present value decreases when the load factor of the truck increases. Along the axis displaying the number of round trips, it can be seen that the net present value increases when the number of round trips increases. For the internal rate of return, a similar pattern exists.

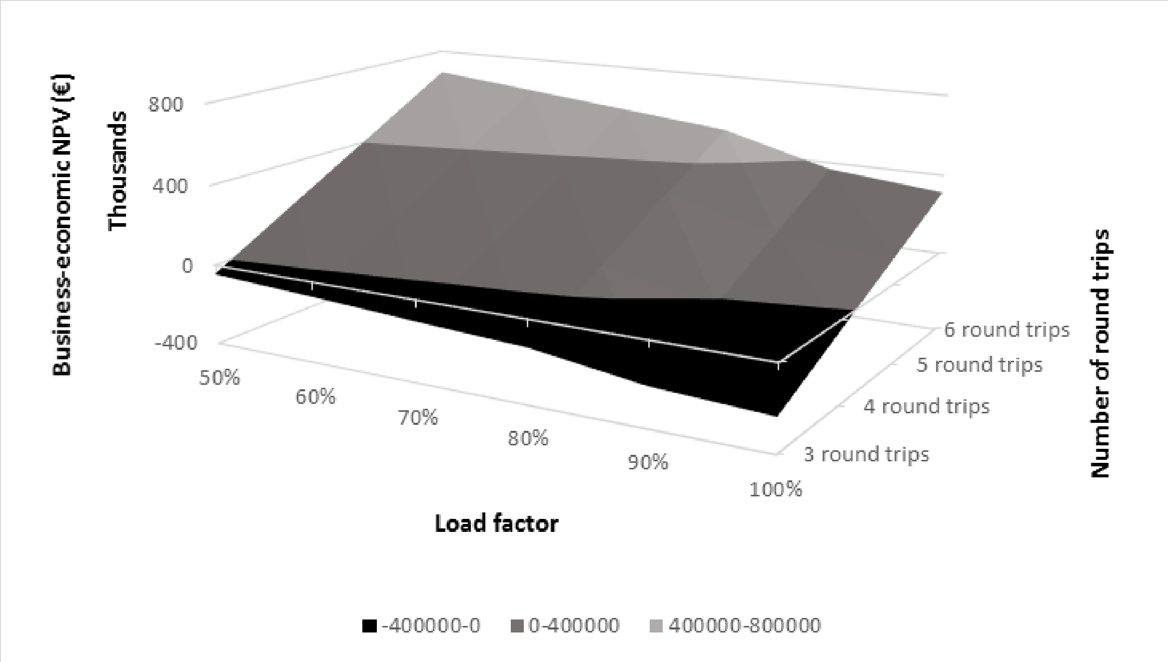

Fig. 5.Business-economic net present value of using a dedicated freight tram (in 2016-euros)

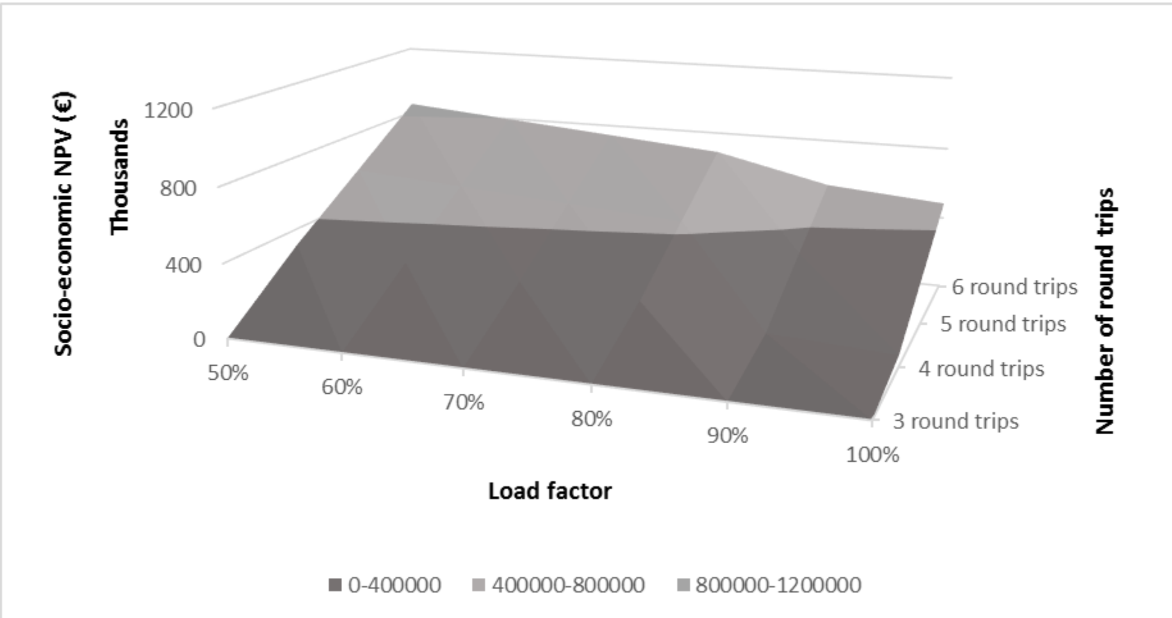

Fig. 6. Socio-economic net present value of using a dedicated freight tram (in 2016-euros)

The tram-based solution is only interesting to be put in practice if the business-economic and socio-economic net present value is positive, and the internal rate of return equals at least respectively the financial and social discount rate used in the calculations (Blauwens et al., 2016; Sartori et al., 2015). This is the case for the given tram-based solution when six round trips are executed at a load factor of maximum 70%. The total volume transported equals then 4,200 kg[5]. A business-economic net present value of €569,973 is reached, accompanied by a business-economic internal rate of return of 4.22%. The socio-economic net present value equals €741,854, complemented by an internal rate of return of 6.38%. The business-economic net present value already becomes positive starting from four round trips, until a load factor of 80% or lower. The socio-economic net present value is for a load factor of 50% and 60% already positive for three round trips, whereas the socio-economic internal rate of return exceeds the social discount rate starting from five round trips, until a load factor of 70%. The business-economic internal rate of return is the strictest in this specific case, only exceeding 4% for six round trips and a load factor of 50%, 60% or 70%.

After having determined the viability of the tram-based scheme given a number of round trips and a certain load factor, it is now interesting to investigate how this viability changes if some other variables alter. Fig. 7 displays the changes in net present value due to a 1% change of the displayed variables. The variables are ranked according to a decreasing business-economic NPV. The vertical dotted lines show the -1% and 1% boundary respectively, which is by Sartori et al. (2015) considered to be the start at which variables can be called 'crucial' for the viability of the project. As can be seen in Fig. 7, the operational cost of the current road transport, as well as the marketing revenue are the main variables affecting the net present value in the positive sense. On the contrary, the operational cost of the tram-based project, the speed of the current road transport, the initial capital investment needed and, for the business-economic analysis, the financial discount rate influence the viability in a negative way.

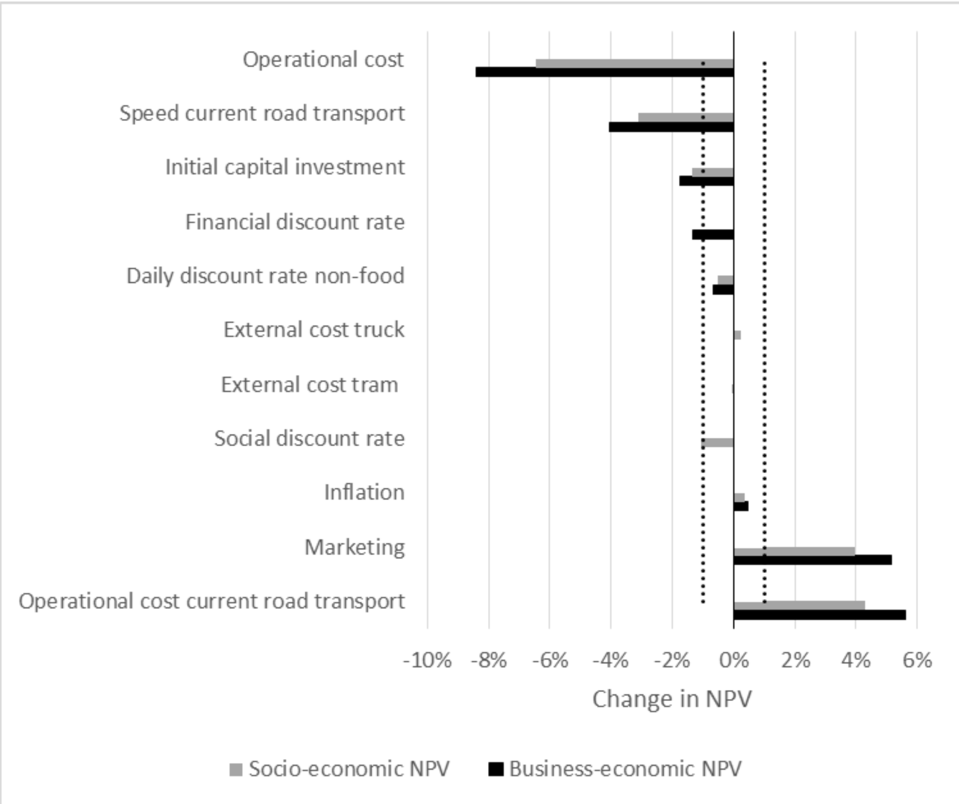

Fig. 7. Changes of NPVs due to a 1% change of the variable

[5] 4,200 kg is obtained by multiplying six round trips by one tonnes net weight and by a 70% load factor.

4.3.2 Freight wagon attached to a passenger tram (module 1.2)

The second cost-benefit illustration comprises the transport of goods in a freight wagon, which is attached to a passenger tram. The same approach was used here as for the calculations in the previous section. Fig. 8 displays several combinations of load factors and number of round trips and provides the resulting business-economic net present values. Fig. 9 shows the same information regarding the socio-economic net present value. For the business-economic NPV (Fig. 8), the line between the black and grey shaded area represents the boundary where the net present value becomes positive. For the socio-economic NPV (Fig. 9), all shaded areas are positive. It was found that the tram-based solution becomes viable, i.e. has a positive net present value and an internal rate of return larger than the discount rate, starting from six round trips and a load factor of 90%. Hence, the total volume transported here equals 5,400 kg. The resulting business-economic net present value equals €59,430 and is characterised by an internal rate of return of 4.33%. The associated socio-economic net present value is €4,091,629 and goes with an internal rate of return of 170.88%. These high values for the socio-economic analysis can be explained by the fact that by adding a freight wagon behind a passenger tram, the marginal external costs of the freight wagon are very low, whereas the high external costs of the current road transport are avoided. Hence, the net external benefits are very high for the tram-based solution.

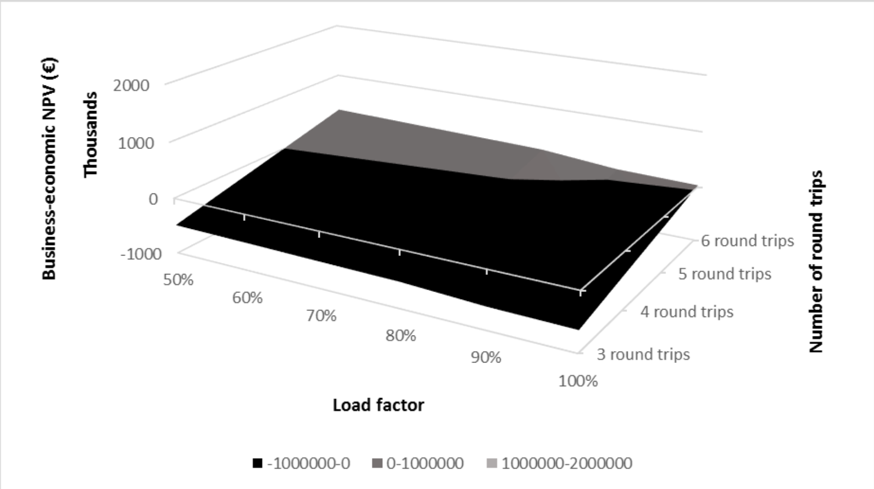

Fig. 8. Business-economic net present value of using a freight wagon attached to a passenger tram (in 2016-euros)

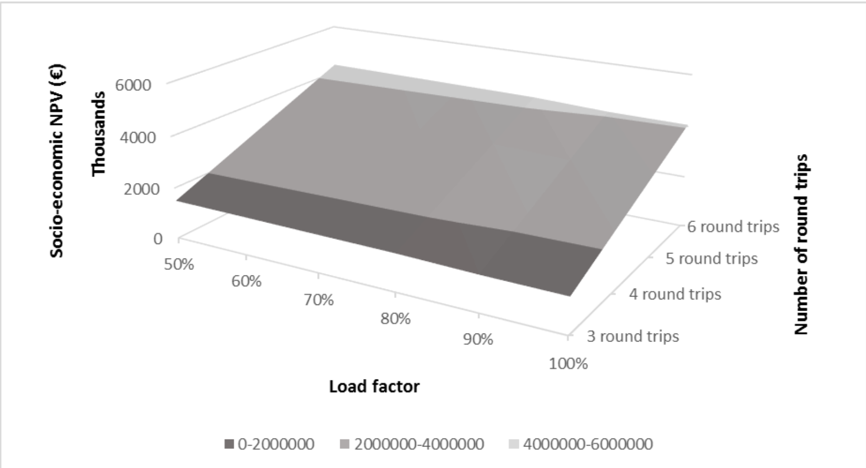

Fig. 9. Socio-economic net present value of using a freight wagon attached to a passenger tram (in 2016-euros)

Analogously as in the analysis for a dedicated freight tram, the viability is tested for a number of variables. Fig. 10 displays the percentage change of the net present value for a one percent change of certain variables. The variables are ranked according to a decreasing business-economic NPV. The vertical dotted lines represent the -1% change line and the +1% change line. Four variables clearly exceed the 1% boundary with respect to the business-economic NPV. Concerning the socio-economic NPV, no changes of more than 1% in absolute values are found. The reason for this is the very high value for the socio-economic NPV to which changes are calculated in relative terms. The four crucial variables are: the operational cost of the current road transport (very positive), the operational cost of the tram-based solution, the speed of the current road transport and the daily discount rate of non-food products (all three negative).

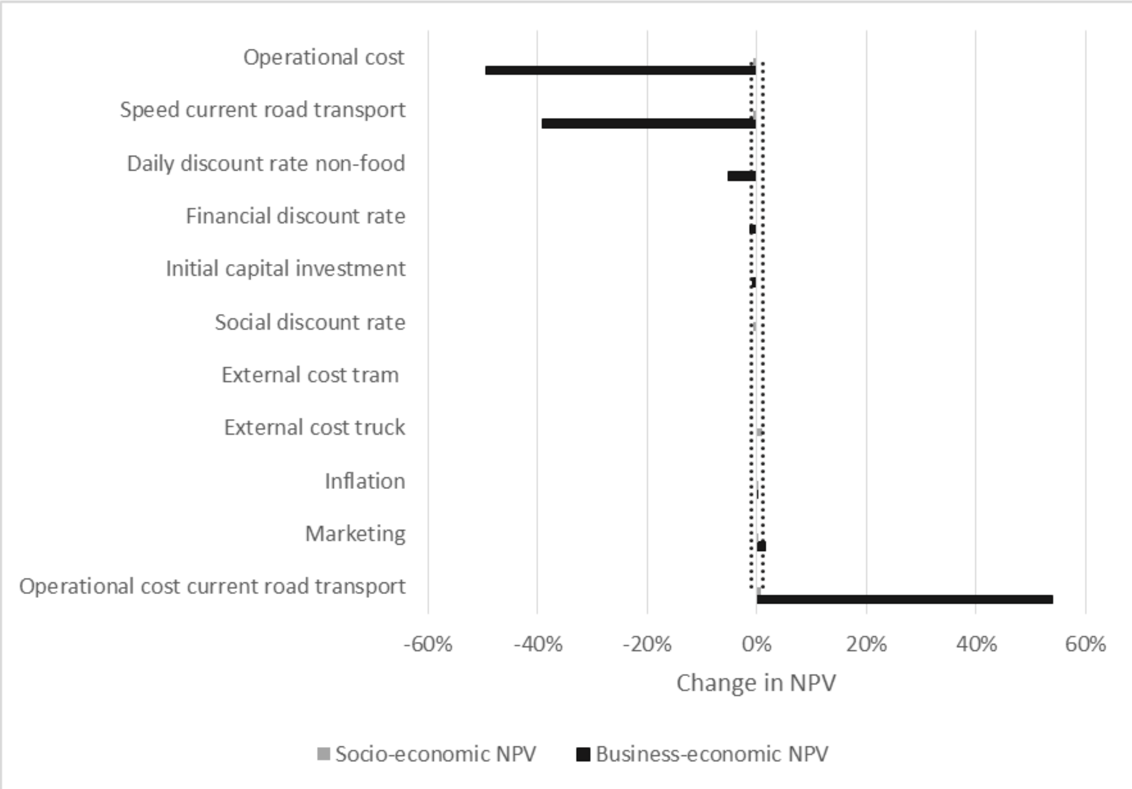

Fig. 10. Changes of NPVs due to a 1% change of the variable

4.3.3 Freight in a passenger tram (module 1.3)

The third illustration is the transport of a small amount of freight in a passenger tram. It is assumed that a courier transports the cargo in for instance a backpack and delivers it at the customers by using the tram. The courier has to carry the goods and therefore, the maximum weight that can be taken is small. It is assumed that a courier can maximum carry 10% of its own weight. Assuming an average weight of a courier of 80kg, a maximum weight of 8kg per tram trip is allowed. Hence, the combinations of round trips and load factors of the vans differ in this scenario largely from the two scenarios discussed above. The load factors considered here are 1% and 2%. From 3%, the business-economic net present value becomes very negative already. Fig. 11 displays the business-economic NPV for different combinations of load factors and number of round trips, while Fig. 12 displays the same information concerning the socio-economic NPV. With respect to the business-economic net present value (Fig. 11), the line between the black and grey shaded area represents the combinations where the net present value becomes positive. Concerning the socio-economic net present value (Fig. 12), all shaded areas are positive. The tipping point in this module is one round trip and a load factor of 2%. The transported volume here is 20 kg. The resulting business-economic net present value is equal to €11,736, with an internal rate of return of 137.9%. The associated socio-economic net present value is €726,575, with an internal rate of return of 8,345.27%.

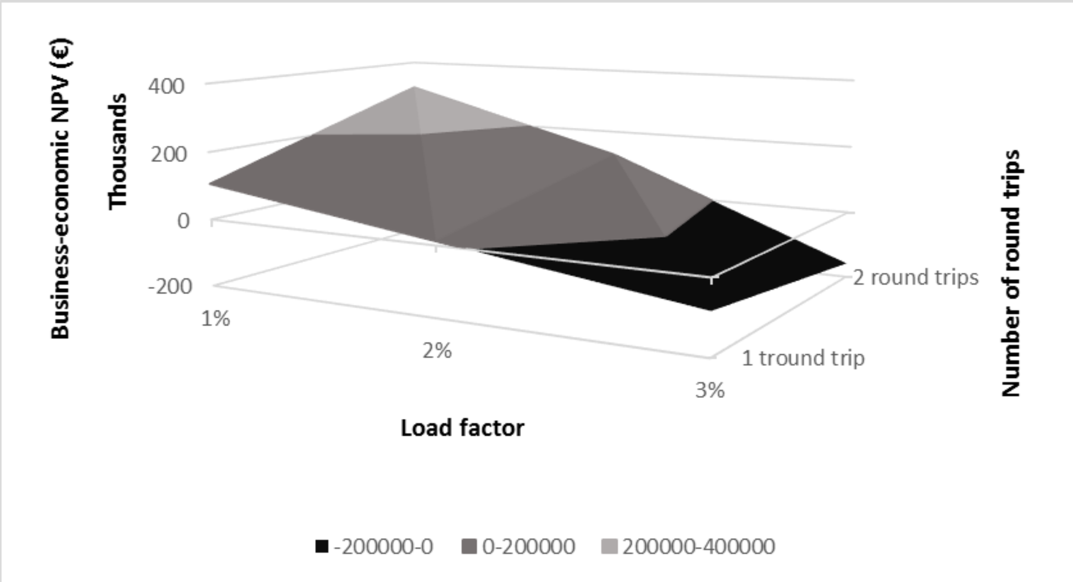

Fig. 11. Business-economic net present value of transporting freight in a passenger tram (in 2016-euros)

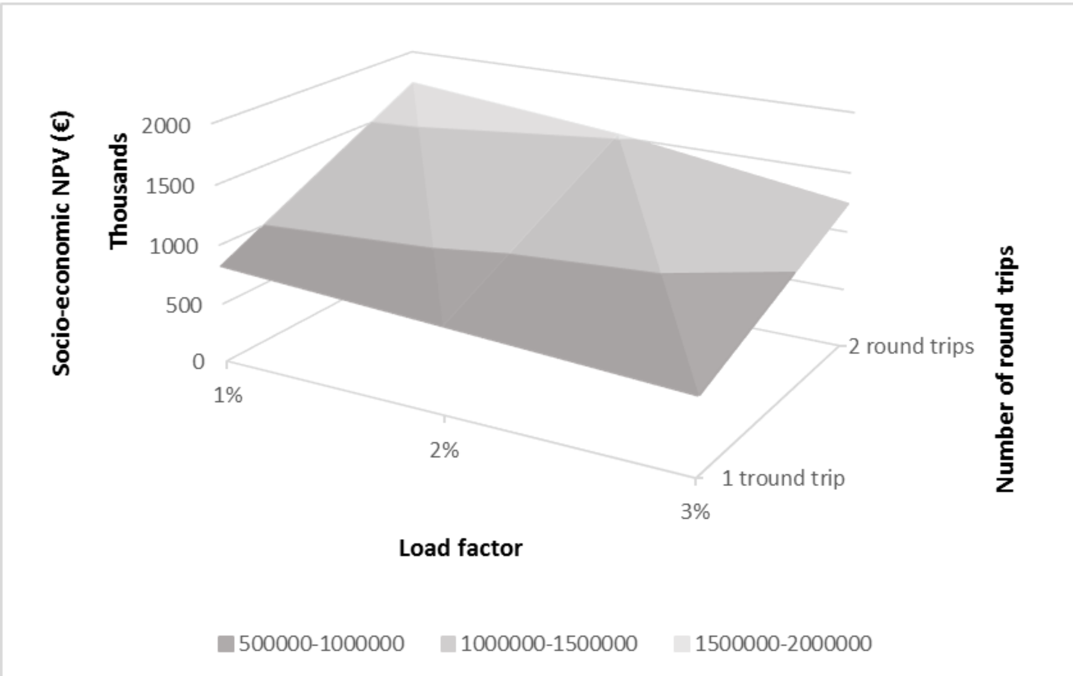

Fig. 12. Socio-economic net present value of transporting freight in a passenger tram (in 2016-euros)

In this module too, sensitivity analyses are carried out with respect to some other variables. The results are shown in Fig. 13. The variables are again ranked according to a decreasing business-economic NPV and the vertical dotted lines represent the -1% and 1% boundaries. The crucial variables with respect to the business-economic NPV are: the operational cost of the current road transport (positive effect), the operational cost of the tram-based solution and the speed of the current road transport (both negative effect). The reason why the variables are not crucial from a socio-economic perspective is again the high NPV in absolute terms.

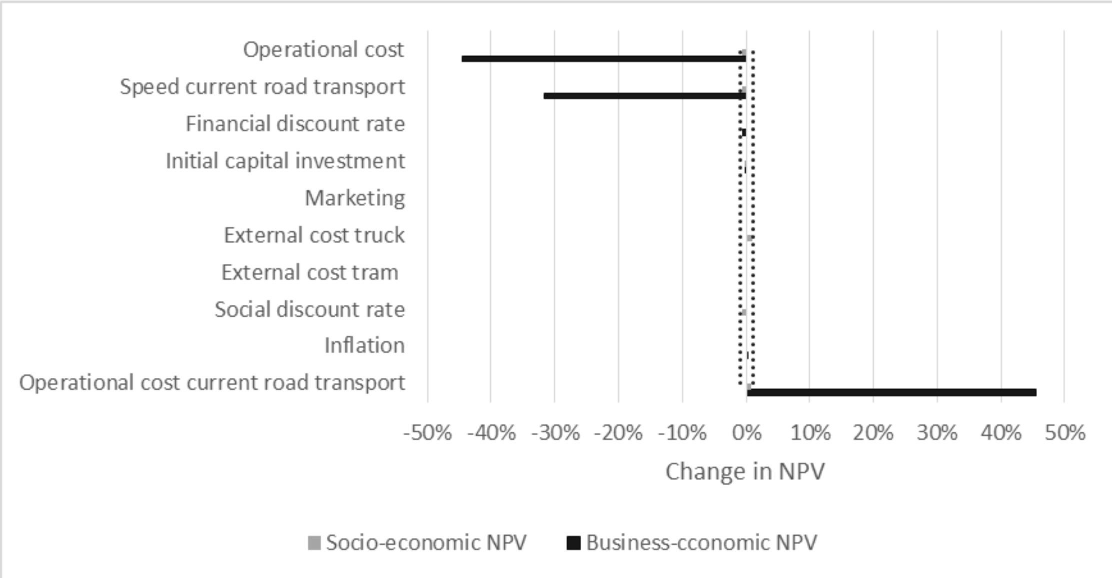

Fig. 13. Changes of NPVs due to a 1% change of the variable

4.4 Synopsis

The main findings of these three illustrations of the viability model differ according to the type of tram transport used. Firstly, the calculations for a dedicated freight tram lead to a positive net present value and an internal rate of return that exceeds the discount rate, both from a business-economic and from a socio-economic perspective, if six round trips are executed and the vans are loaded for maximum 70%. In this case, a total of 4,200 kg of non-food products is transported. Secondly, the transport by a freight wagon behind a passenger tram is viable if six round trips are carried out, given a 90% load factor of the vans. In total, 5,400 kg of goods are transported here. Thirdly, if a courier transports some goods by using the tram instead of a van, the tram solution is viable if one round trip is done and the van is only loaded for 2%. In this case, the courier transports 20 kg of goods, spread over three tram trips. It has to be noted here that it will not happen very often that a van of 3.5 tonnes is driving a distance of 60 km to deliver 20 kg of goods in a city centre. This is still a limitation of the current model that will be elaborated on in further research.

Moreover, it is shown that the net present value of the tram-based scheme decreases, from a business-economic and from a socio-economic viewpoint, if the load factor of the vans increases. In other words, the more efficiently the road transport is organised, the less viable shifting to a tram becomes for the three cases examined in this study. On the other hand, the business-economic and socio-economic net present value increase if the number of round trips covered by vans increases. This means that more volume has a positive effect on the viability of the tram-based solution.

Some other variables are still very interesting to check upon their impact on the viability of the tram-based scheme, but cannot be altered by increasing them by 1% as was done before. Fig. 14 provides an overview of the change in the business-economic (BNPV) and socio-economic (SNPV) net present value for each variable that is altered for the three types of tram transport considered in this paper. The variables are ranked according to a decreasing BNPV. The variables with the highest positive impact in favour of the tram-based scheme, are twofold. Firstly, the shift of the transport to peak-hours instead of off-peak-hours results in an increase of the business-economic NPV and an increase of the socio-economic NPV for all three types of tram transport. It has to be added here that using a tram for freight purposes during peak hours might not be feasible from an organisational perspective, since the public tram network may be saturated. Secondly, if road pricing would be extended to trucks of less than or equal to 3.5 tonnes gross weight, this would also have a positive effect on the viability of a shift to tram transport. At the right side of Fig. 14, it can be seen that adding road post-haulage to the tram solution, as well as moving the transport from off-peak hours to the night, results in a business-economic and socio-economic loss for all types of tram transport. The change to euro 5 or euro 6 vans does not lead to large changes in the NPV.

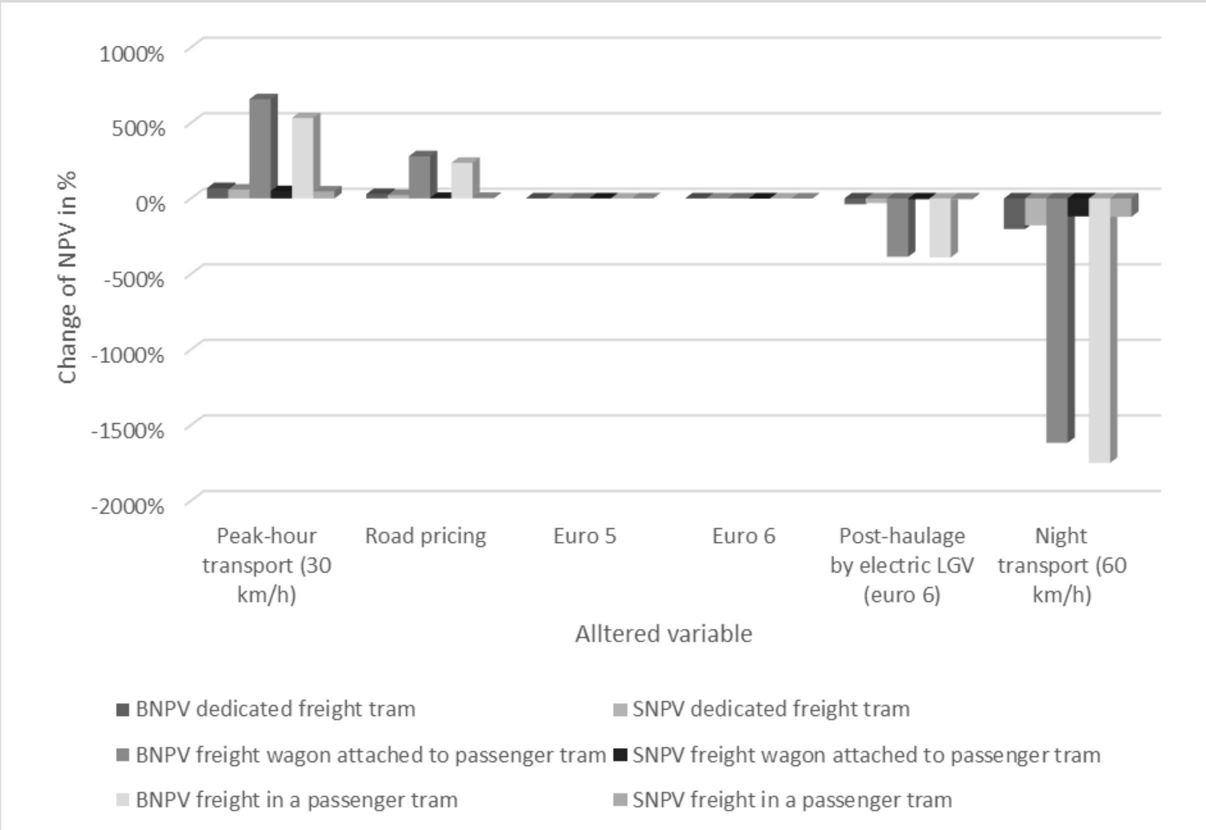

Fig. 14. Effect of a change of a variable on the net present value

5. Conclusion

This paper investigates how urban freight transport by tram can be viable from a business-economic and from a socio-economic perspective. A viability model is developed and illustrated by three types of tram transport for some round trips in the city of Antwerp: a dedicated freight tram, a freight wagon attached to a passenger tram, or a courier transporting a small amount of freight in a passenger tram.

Some variables are more crucial in the determination of the viability of the tram solution than others. For all three tram types, it was found that the operational cost of the current road transport has a positive effect on the viability of transporting goods by tram. On the other hand, for all three types it was shown that the operational cost of the tram-scheme and the speed of the current road transport negatively affect the viability of using a tram for urban freight distribution. Moreover, it would be beneficial for all three types to conduct the tram transport during peak-hours. However, some organisational limitations due to the saturation of the public tram network have to be taken into account here. If road pricing would be extended to all types of vans, this would be in favour of the tram. On the contrary, if road post-haulage is needed to reach the customer, or if the transport takes place during the night, shifting from road to tram is disadvantageous.

The results of this paper are most interesting for a number of stakeholders. Authorities can use the insights as part of their sustainable urban logistics plans (SULPs). Tram operators can be assisted in understanding how they can extend the scope of their activities. Suppliers and retailers can learn under which conditions shifting from road to rail can become interesting from a business-economic viewpoint.

Some interesting avenues for further research exist. Firstly, the business-economic analysis will be extended by including the calculation of the return on capital and the return on investment if the investor is a private actor. Secondly, the evaluation measures will be extended by the calculation of the benefit-cost ratio in order to make the decision framework more robust. Thirdly, additional variables will be tested on their effect on the NPV. Examples are the presence of more customers in the urban area and other types of vehicles. Ultimately, the knowledge gathered here on costs and benefits, and on crucial variables affecting the viability of using a tram for urban freight can be used as input for mixed integer programming models.

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