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Assessing the value of travel time reductions in (sub)urban freight transportation

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INDEX

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Growing urbanization in the last years have caused concentration of people and economical activities in urban areas all around developed countries, causing high levels of traffic congestion in roads. Freight transportation is one of the most affected sectors by the congestion, as it generates uncertainty in time travels. However, a high percentage of on time deliveries is crucial for companies to have an efficient and optimized supply chain. High cost is associated with unreliable time deliveries, but the value of this cost, the value of reliability, has never been calculated before in Sweden. Considering this value in the Cost Benefit Analysis (CBA) of transportation and infrastructure projects will lead to have more accurate information about the economic impact, thus achieving better decision making. Through the theoretical study of the concept of reliability, its causes and its consequences, and through surveying and interviewing freight transportation and logistics companies, it has been found out how much the companies are willing to pay to get more reliability, and also for less travel time, in their transport journeys. These new empirical values of travel time and reliability have been obtained using random utility maximization approach with discrete choice modelling, defined by the analysis of the preferences of carriers and suppliers through a stated preference survey. These preferences have been analysed according to many variables, of which the sector of the company and the capacity of vehicles have proved to be significant. The ÅSEK report, which is a summary of CBA principles and values to be used in Swedish transport sector, recommends to use the value of reliability as twice the value of travel time savings, but the output of this thesis revealed that the value of reliability is 3,23 times higher than the value of travel time savings. This thesis is part of the global project called "Ringroad logistics - efficient use of infrastructure" which seek to dynamically prioritize socially valuable freight and increase the capacity of existing infrastructure by streamlining transport in roads in urban areas.

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It should also be taken into consideration that this thesis would not have been possible without the support of all the organizations that are part of the "Ringroad logistics - efficient use of infrastructure" project that is being carried out: DB Schenker, CLOSER, Chalmers, KTH, Trafikverket, Västra Götaland and Mind Connect. In particular, we would like to thank Emelie Klasson from DB Schenker, for giving us the contact of the companies that were interviewed.

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1. INTRODUCTION AND BACKGROUND

In the last decades, the world population has undergone a change of tendency in the economic field and in the demographic scope (Thaller, Niemann et al., 2017). About demographic change, there has been a phenomenon of increasing urbanization in developed countries, which consists in the gradual concentration of economic activities, causing the displacement of the population from rural areas to cities. In 1951, 79% of the population lived in rural settlements (Bloom & Khanna, 2007). By 1967, half of the population was already living in urban areas, and nowadays more than 54% is living in urban territories. It is estimated that by 2050 more than 70% of the world population will live in cities, continuing the trend followed for some decades (Thaller, Niemann et al., 2017). In Sweden, this is not an exception, it is a more significant case, as in 2015 85,8% of the population was already living in urban areas, with an average increasing rate of 0,83% per year in the last five-year period (United Nations, Department of Economic and Social Affairs et al., 2014). It is expected that by 2050 the percentage of urbanization will increase to 90%. The fact that so many people are living in concentrated areas generates a freight attraction to the cities to satisfy the needs of their population, in terms of food and consumer products (Thaller, Niemann et al., 2017). This attraction causes a traffic congestion not only in commercial areas as some years ago, but nowadays in living areas too.

About the economic field, there has been a very important boom in e-commerce both at a global and national level, generating an increase in the number of vehicles in urban freight transport, caused by several factors (Bakos, 2001). The first factor is the increment in sales volume (Thaller, Niemann et al., 2017). E-commerce was worth 75,7 billion kronor in 2013 in Sweden (E-commerce news, 2017). Five years later, there has been an annual average growth of 9,2%, reaching 109,5 billion kronor. *Figure 1* shows the evolution of e-commerce sales in Sweden in the last five years. The second factor is the reduced delivery period since customers want the products purchased to be delivered as soon as possible, raising the frequency of travels (Thaller, Niemann et al., 2017). In addition, it is necessary a higher reliability in e-commerce to avoid failed deliveries that would cause higher costs as customers are requiring reduced time window deliveries. Moreover, it is important to consider the rise in storage costs, as urban soil is now more expensive because of increasing urbanization and it makes companies to have smaller storehouses.

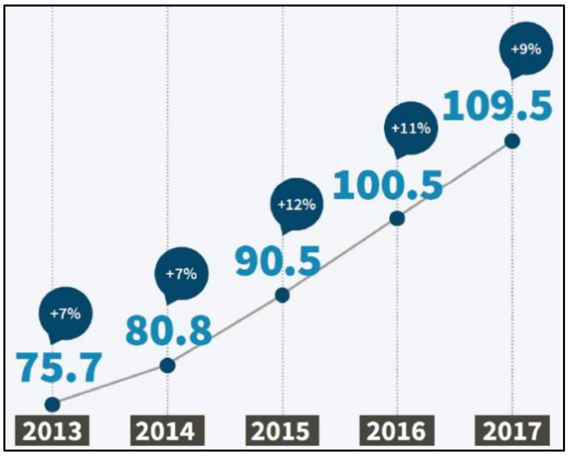


Figure 1 - Evolution of the e-commerce sales in Sweden
Source: E-commerce news, 2017

Both factors, demographic and economic, have risen the number of freight travels and the concentration of these in urban centres, causing growing traffic congestion (Trafik Analys, 2017). In fact, Stockholm and Gothenburg (the two largest cities in Sweden) are among the 50 European cities with the highest level of congestion, being respectively 12th and 43rd position of the ranking (TomTom International, 2015). Congestion entails multiple challenges, especially for freight transportation operators, as it forces them to reduce the speed of transport, having higher an uncertainty travel times, and consequently, recurrent delays. One potential solution to avoid congestion in freight transportation could be off-hours deliveries, as this significantly increases reliability (Holguín-Veras, Sánchez-Díaz et al., 2016). However, in supply chain and logistic terms, shippers make agreements with the customers to deliver the shipment within the agreed timeframe, and unfortunately most markets receivers have more market power than carriers and suppliers, then the delivery ends up being scheduled at the receivers will, which is often during business hours and highly congested hours (Jin & Shams, 2016).

In this context the project entitled "Ringroad logistics - efficient use of infrastructure" was proposed. It started after a feasibility study that revealed potential benefits, in terms of both capacity and technology, to dynamically prioritize socially valuable freight and increase the capacity of existing infrastructure by streamlining transport in roads in urban areas. Therefore, the objective is to investigate the socio-economic potential benefits and costs of a streamline in ring roads freight transportation, through dynamic priority. This means giving access to the priority lane to some types of freight vehicles. It is expected to result in a proposal for a full-scale demonstration, based on a study of the feasibility and business benefits via cost-benefit analysis (CBA). The main applicant of the project is Closer at Lindholmen Science Park, and collaborative partners are DB Schenker, the Transport Administration, Västra Götaland, Chalmers, the Royal Institute of Technology, Gothenburg city, City of Stockholm and Midconnect, which collaborate in the 7 working packages of the project.

As a partner of the project, the research team at the division of Service Management and Logistics of Chalmers is in charge of the *Working package 3*, which studies valuation of time savings and delivery precision haulage, including definition of socially useful goods transport. Time savings and delivery precision are directly related to travel time. As congestion directly affects the travel time, and transportation has a major impact (indirect) in several stages of the supply chain, the effect caused by congestion must be minimized in order to achieve a supply chain as efficient as possible.

This thesis focuses on researching the concept of value of reliability. Reliability is a complex concept, related to the uncertainty of unknowing the travel time of a freight transport with precision. The complexity lies in the number of agents (stakeholders) involved (Sánchez-Díaz & Palacios-Argüello, 2017):

1. Shippers that manufacture a commodity and sell it to get a profit.
2. Receivers that buy shippers' products and use them in other activities.
3. Carriers that are in charge of the transport of the product and can be carried out by the shipper or by a third party.
4. Urban dwellers that are who benefit from having access to all types of goods to fulfil their needs.

In addition, there are other relevant variables that can vary widely, such as modes of transport (road, train, ship or plane), types of goods and its singularities (perishability, value, etc.), the weight and the size, the distance of the transport, and units and methods to quantify the reliability and to value it. All these variables make reliability a complex concept as many unpredictable factors can modify it. For this reason, companies want to minimise uncertainty and have high levels of reliability in freight transport. In this thesis it will be studied the amount of money (willingness to pay) that companies would be willing to pay to have more reliability in their travel times.

There are different factors that have motivated to carry out this thesis. First, it is the increasing importance of the travel time reliability for the companies. Every company looks to reach the best possible level of service at the lowest price, but as the traffic congestion in urban areas is becoming higher, travel time variability and uncertainty are raising (Trafik Analys, 2017), thus the cost associated is increasing too. For this reason, some solutions are being studied (e.g. Ringroad logistics project). However, before deciding which solutions have to be applied, real economic effect needs to be calculated. There is any transport that is not economically affected by reliability, but are the ones involving urban and suburban areas, that they are much more affected (Ando & Taniguchi, 2006). Also from the social point of view, not only the companies can get benefits of increasing reliability. Society seen as consumer would be benefited as companies could offer more reliable deliveries, with reduced time window. This can be specially applied to those socially useful goods, important for society, such as medical supplies. In addition, freight transportation shares the roads with passengers' transportation, therefore, the most efficient are the journeys of companies, everyone would be more benefited in terms of fewer cars on the road and with less maintenance and pollution (Eliasson, Hultkrantz et al., 2009).

Public sector is another stakeholder involved in the topic, as it is noteworthy that building and management of roads are done by the public companies (e.g. Trafikverket). Then it is necessary the interaction between the public and the private sector to optimize the flow of vehicles in the roads. Because the public sector has to ensure the common good, and not the individual profit, the impact of all decisions must be taken into account. In this case, the methodology to analyse the impact is through the Cost Benefit Analysis (CBA), with which it is possible to know the economic impact of a project, allowing predicting the profitability and whether it is worthwhile to carry out the project (Florio & Vignetti, 2003).

To consider reliability cost in the CBA it is necessary to know the values of reliability (De Jong, Kouwenhoven et al., 2009), that is, the cost generated by the uncertainty of not knowing exactly the travel time of certain journey. The aim of this thesis is to calculate these values to be able to use them the in the CBA. Currently, for Sweden, the values used are the ones recommended by the Swedish Transport Administration (Trafikverket) in its ÅSEK manual (Bångman, 2016). This manual "is a summary of the recommended CBA principles, costs, prices and shadow-prices presented in chapter 5-15 of the ASEK report. The principles and values are recommended to be used in social cost-benefit analyses (CBA) in the Swedish transport sector. The recommendations are mainly applied in CBA of publicly provided infrastructure investments". The values recommended for evaluating the reliability are approximations, as they are not based on empirical studies, thus with this study new values empirically calculated will be obtained.

Although reliability is the main objective of this project, results regarding value of travel time will also be obtained in the same study to assess the value of reliability. It is noteworthy that travel time, together with reliability are the two key factors that generate cost in the transport of goods. The quantification of value of travel time will also be used in cost-benefit analysis to take decisions that can maximize the benefit of the company.

1.1 Aim

The objective of this master thesis is to understand the concept of reliability, related to travel time precision, and how can it add value to the companies. For this, the thesis will evaluate the impact of traffic congestion, in ring roads for shippers and carriers, separated according to the type of goods. More specifically, it will study the relevance, in terms of costs, of uncertainty in delivery accuracy, i.e., reliability in the transport of goods.

In the development of this master thesis, an exhaustive study will be carried out in order to answer the following questions:

1. What is the meaning of reliability of freight transport? How can it be measured?
   It is not possible to know the exact travel time of a transport involved in the supply chain due to unpredictable factors (e.g. congestion) causing high variance in journeys duration. For this reason, it would be useful to know deeply the concept of reliability in freight transport and determine the best way to calculate or measure it to deal with it and improve the efficiency of transport of goods.

2. What factors affect the value of reliability?
   As companies want higher reliability in their travel times, it is important to know what factors affect the value of reliability. It will not be the same value for every company and every journey, so the variables on which the reliability value depends will be studied.
3. What is the value of reliability?
   Knowing the value of reliability will make possible to calculate economic cost of travel time variability in freight transport. It will be useful for decision making about transport logistics projects, as the real economic impact will be known in advance.
4. What is the value of time?
   Along with reliability, knowing these two parameters, will allow to know in detail the impact generated by a transport of goods, through the cost-benefit analysis.

Thus, it is a matter of studying in depth the concept of reliability, knowing the impact it has on companies and determining its importance in the transport of goods and all the steps of the supply chain.

1.2 Limitations

The possibilities for this study are widespread, so they must be limited to carry out the work successfully. Due to the time restriction of the thesis, the project will focus on the geographic area of the city of Gothenburg and its ring road, not the freeways, nor the city centre. However, the results should be generalized once the project has been finished.

Moreover, passenger transport and freight transport by boat, by train or by plane will not be taken into account, as the solution proposed by the overall project is to give priority to the bus lane to some type of goods. Therefore, this study is limited to freight road transport.

This thesis will be carried out mainly in a quantitative level as there will be an analysis to quantify the value of reliability. However, this study will be complemented with a qualitative part by a previous literature review and later interviewing to some companies to validate the results obtained with the quantitative part of the project.

In the quantitative part, values of reliability for Sweden will be calculated, defined for certain types of goods in road transport in the ring road of the city of Gothenburg. The interviews will be restricted due to the difficult get contact with big companies, so they will be focused in a particular type of companies, the most representative ones in Gothenburg area, which have a greater socially useful goods transport.

Within the impact of the reliability or value of reliability, only trucks operational costs and product value depreciation, associated with transportation for such uncertainty will be analysed. As only shippers and carriers companies will be interviewed and surveyed, placing and order and inventory costs will not be taking into account in this thesis.

2. THEORETICAL FRAMEWORK

Literature about time travel reliability in freight transport has been written since 1981, but the complexity of the concept makes difficult to extrapolate results obtained before in to Suburban Logistics project. Different countries than Sweden and other transport modes (train and boat) have been used in other studies, but not values of reliability for road transport in Sweden. For this reason, a deep review of the existing theoretical framework has been carried out first, in order to obtain all the necessary knowledge to carry on our own reliability study based on capturing the preferences of shippers and carriers, focused in the suburban area of Gothenburg city.

In this section, it has been looked into the definitions of travel time reliability, value of time, the advantages that they entail and the factors that they are caused by. Moreover, methods to assess reliability have been also investigated and consequently, the value of reliability and the models used so far to determine it.

2.1 Reliability in supply chain

The supply chain comprises the business processes, people, organization, technology and infrastructure that allow the transformation of raw materials into intermediate and final products and services that are offered and distributed to consumers to satisfy their demand. The dynamism of the chain entails a constant flow of information and products between the companies involved in each stage. There are many agents that take part in the supply chain, including all stakeholders involved in the production, distribution, handling, storage and commercialization of a product and its components. These agents are shippers, manufacturers, distributors, carriers and retailers. Therefore, the chain links many companies, from suppliers of raw materials until the final consumers (Ellram & Cooper, 1990). It is highly difficult to get a proper functioning of the whole supply chain, as any disruption in the system can appear for multiple reasons such as labour actions or weather events (Snyder, 2003), or parameter estimations can be inaccurate because of measurement errors, bad forecasts or other factors (X. Miao, Xi et al., 2009). However, it is essential that all parts of the chain have a good relationship and collaborate to achieve good management of the supply chain, since the common goal is to meet the needs of the client in the most efficient way (Vilana, 2011). For this reason, all the organizations that take part of a supply chain need to work together, constructively and cohesively towards a big objective (Awasthi & Grzybowska, 2014).

According to the Council of Supply Chain Management Professionals (CSCMP), Supply Chain Management (SCM) “encompasses the planning and management of all activities involved in the supply, acquisition, transformation and all logistic activities. It is important to note that it is also including collaboration and coordination with channel partners, which can be suppliers, intermediaries, third-party service providers and customers. In essence, the supply chain management integrates supply and demand management within and across companies” (Vitasek, 2006).

It is necessary an efficient SCM to establish continuous communication between the companies involved in it. If it is achieved, problems that arise can be solved easily and proactively (Golinska, 2014). Increasingly, an efficient SCM is necessary as there are competitive pressures to reduce costs, improve quality of the process and increase productivity of the organizations. For this reason, it is important to implement effective SCM techniques arising in last years that make it easier for companies involved in a chain to work together. SCM tries to form alliances and stable relationships among all the members in order they have access to all the data that can allow them to take better decisions and increase level of service of the company (Vilana, 2011).

The advantages that can be obtained by companies through integrated SCM are really important, such as increase revenue, reduce inventory or improve productivity of staff (Catalunya Innovació, 2012). It seems logical to assume that many companies will be part of integrated supply chain to be able to benefit from all the improvements mentioned above. However, SCM projects are complex and not always produce the expected results due to it requires high levels of trust and collaboration between the members (Vilana, 2011).

The SCM is a key element for the competitiveness of companies because of the importance of business results through profit margin, delivery terms, product/service quality and the customer satisfaction (Golinska, 2014). With the emergence of new technologies, SCM has seen an important opportunity to improve due to the decrease in costs of interaction with suppliers.

In order to achieve a synchronized supply chain, it is not enough to carry out isolated actions. It is also necessary to develop a joint strategy that provides advantages to all members and envisages a fast and reliable exchange of information, a coordinated workflow and indicators that allow controlling the management of the chain.

It is also necessary a good management of the flow of materials to get the supply chain working fluently and achieving the objective of satisfying the customer’s needs in the most efficient way. The flow of materials is the one that goes from the raw material supplier to the final customer and it is which has to send the physical product to the customer (Vilana, 2011). It is noteworthy that urban freight reliability is very important for an optimal SCM since it has a significant impact on the execution time of the logistic process, on the supply chain’s logistic costs and on the quality and integrity of delivered parties (Lukinskiy, Churilov et al., 2014). Marlin Thomas was the first who defined the concept of Supply Chain Reliability (SCR). He said that it was “the probability of the chain meeting mission requirements to provide the required supplies to the critical transfer points within the system” (Thomas, 2002). Nevertheless, after he showed this concept, some other authors have studied SCR, but from other perspectives such as potential failure (Quigley & Walls, 2007) and arrival time (Van Nieuwenhuyse & Vandaele, 2006).

In general, a supply chain is reliable in case it performs well when the parts of the chain fail (X. Miao, Xi et al., 2009). The critical thing is to get that the goods arrive to delivery places at the desired time. To get it, it has to be taken into account the complexity of all the previous supply chain processes and the continuous flow of information between companies that is necessary continuously (Lukinskiy, Churilov et al., 2014). For this reason, some way to solve these difficulties has to be found out in order to improve reliability and also the methods used to assess reliability in supply chain. Thus, it would be possible to optimise and insure the efficiency and effectiveness of the processes involved in the supply chain (Burkovskis, 2008). A high level of reliability with the minimum travel time is essential because it will allow companies to have a higher level of service and minimize their costs such as the one produced by uncertainty in travel times. *Figure 2* (Turmero, 2007) shows all the parts of the supply chain. Between each one there is a flow of material, with its travel time, and here is where a fast and precise transport is important.

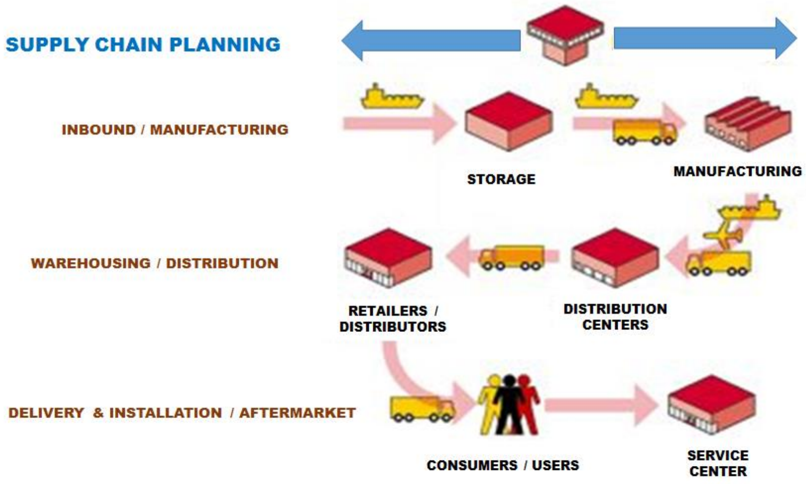


Figure 2 - Parts of the supply chain
Source: Turmero, 2007

This thesis will focus the research of value of reliability in transport. It will only be studied one of the last parts of the supply chain, which comprises the transport between the distribution centres and retailers. This fact is due to the majority of transport comprised between storage and manufacturing, or between manufacturing and distribution centres are not located in urban area. So, as this thesis is located in Gothenburg surroundings, it will only be taken into account transport at the end of supply chain.

It is essential to know as quickly as possible the needs of the client so that the deadlines are short. The information is the basis of a better management in the supply chain, and for this reason, it is necessary to know when the needs of the market are faster (Tseng, Yue et al., 2005). Otherwise, if the information passed slower and there were delays and errors in product deliveries to customers, the inventories would increase and the service would get worse, causing a decrease in the reaction capacity. Transport is the part of the supply chain which is the principal linker between producers and retailers. It is in charge of sending goods to the right place and at the correct time in order to satisfy consumers’ preferences (Golinska, 2014). That is why the part of the transport within the supply chain is very important, since if it does not work correctly and deliver orders with delays, there may be a repercussion of very high costs for the company. In this way, companies have to try to optimize the routes to achieve logistics efficiency.

2.2 Value of travel time

2.2.1 Freight value of time (VOT) definition

The value of time is one of the most crucial factors for transport planners, modellers and policy makers (Abrantes & Wardman, 2009). A lot of studies have been carried out in order to estimate this "parameter" in different situations depending on the type of vehicle, user and circumstances. It is expressed in monetary values (Abrantes & Wardman, 2009) and it is used in the cost-benefit analysis (CBA) to examine the feasibility of projects related to infrastructure and traffic (Sánchez-Díaz & Palacios-Argüello, 2017).

The first who introduced the concept of value of time was Gary Becker. He considered that the combination of two different factors defined the real value of any good (Becker, 1965). These two factors were the time that was necessary to have a good prepared to be consumed, and the market cost of this good (Zamparini & Reggiani, 2007). A single time unit represented the value that was defined by Becker. It was also estimated considering a single person hourly salary. Later, M. Bruce Johnson introduced work time (Johnson, 1966) and Jan Oort travel time in the utility function (Oort, 1969).

Up to now, there are a lot of authors who have been studying the value of travel time and have defined it in different ways. Next, there is a table with some of these definitions.

Definition	Authors and Year
"VOT is the rate of substitution between travel cost and time".	(Feo-Valero, García-Menéndez et al., 2011)
"VOT is the opportunity cost of travel time".	(Q. Miao, Wang et al., 2014)
"VOT is the ratio of the time coefficient to the cost coefficient".	(De Jong, 2007)
"VOT is the time-marginal transport cost", which is the one that changes in consequence of variations in transport time.	(De Jong, Kouwenhoven et al., 2014)
"VOT is the ratio of the marginal utilities of time and money".	(Wardman, 2004)

Table 1 - VOT definitions
Source: author's interpretation of Sánchez-Díaz & Palacios-Argüello,2017

To measure value of time, it is necessary to identify the main aspects that it is affected by, as the transportation time is not the only one (Sánchez-Díaz & Palacios-Argüello, 2017). The factors distinguished are different depending on the authors.

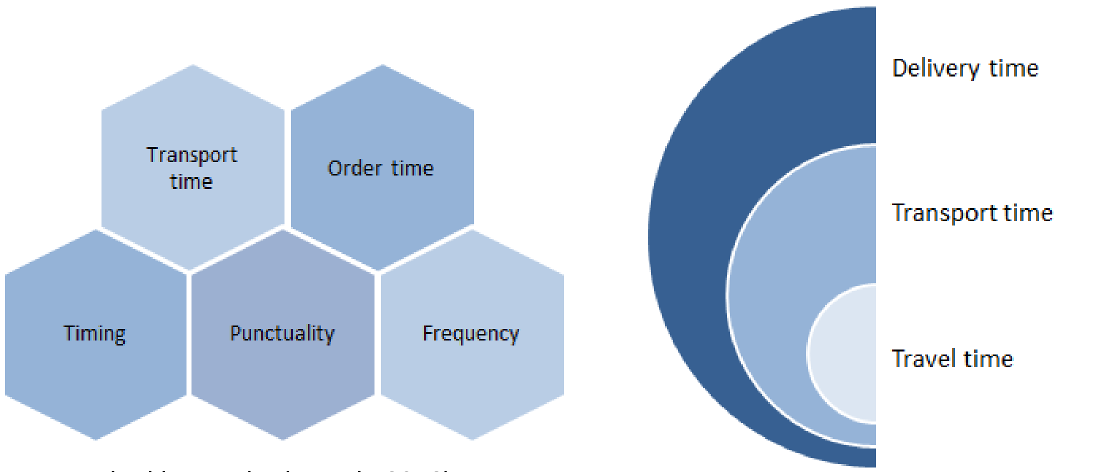
Pekin, Macharis et al., (2013) consider that the different aspects that influence values of time are transport time, order time, timing, punctuality and frequency.

- Transport time: time that takes a trip considering the duration of transport (proportional to distance), the traffic time, and the road constraints.
- Order time: necessary time to get ready the ordered good before the departure.
- Timing: planned time of departure and arrival for the ordered good.
- Punctuality: quality of arriving at the scheduled time.
- Frequency: rate of departures within a given period.

However, there are some authors who consider other factors to determine the value of time. Wigan, Rockliffe et al., (2000), Zamparini and Reggiani (2007), and Massiani (2014) identify that the activities for the VOT unit of analysis are delivery time, transportation time, and travel time.

- Transportation time: time that comprises all the process from the shipment' departure in origin until the arrival to its destination. It also considers all logistics operations involved such as the loading time, unloading, warehousing and stocking among others.
- Travel time: duration comprised between the departure times from the origin until the arrivals to its destination without taking into account logistics operations that are involved in the travel.
- Delivery time: time comprised from the moment the shipper orders until the good is delivered to its destination.

Figure 3 shows a diagram explaining the different approaches for the VOT unit of analysis.



(Pekin, Macharis et al., 2013)

(Wigan, Rockliffe et al., 2000), (Zamparini & Reggiani, 2007) and (Massiani, 2014)

Figure 3 - Units of analysis value of time
Source: own elaboration

2.2.2 Freight value of travel time saving (VTTS) definition

Value of travel time saving (VTTS) is a concept also used in cost-benefit analysis of network projects. It is commonly the largest benefit of a transport project (De Jong, Tseng et al., 2007). Many authors have been studying this concept and have defined it differently from others. *Table 2* shows some definitions of value of travel time saving:

Definition	Authors
"VTTS is the opposite of time losses" (expressed in terms of money units per hour).	(De Jong, 2007)
VTTS is the profit derived from reducing a unit on the time comprised between the origin and the destination when shipping a good.	(Zamparini & Reggiani, 2007)

"VTTS is a ratio between marginal utilities of time and money. It depends on budget and time constraints. VTTS is related to the value of the activity taking place".	(Gwilliam, 1997)
"VTTS is the marginal rate of substitution between transport time and transport cost".	(Bergkvist, 2001)
"VTTS is the sum of the value of getting the goods to the destination more quickly (VJT), savings in drivers' wages (DWS), reductions in vehicle costs (VCS), and reduced disutility from being able to make a later start or earlier arrival (VAE, VAL). The VOT could vary according to the freight movement organisation".	(T. Fowkes, 2007)

Table 2 - VTTS definitions

Source: author's interpretation of Sánchez-Díaz & Palacios-Argüello,2017

2.3 Definition of travel time reliability

Usually, people measure how long it takes to drive from one point to another to choose the route that is shorter in order to arrive earlier at the final destination. For this reason, travel time is an efficient factor for measuring transport network performance and shows the effectiveness of the road network (Tavassoli Hojati, Ferreira et al., 2016). However, it is not the only factor to take into account.

Frequently, when travel time for a specific route is longer than expected, it is due to demand exceeding road capacity causing congestion because of an increase in the number of vehicles at a peak period time (predictable peak period traffic). If congestion is repeated regularly (recurrent congestions), a user of this route may predict it and choose an alternative route to ensure that he will not arrive late at the desired destination (Tavassoli Hojati, Ferreira et al., 2016). This is the Wardrop's first principle, the "user equilibrium", which says the entire demand for vehicles in paths with the same origin and the same destination, knowing predictable congestions, end up being distributed on all roads so that it takes the same time to make the journey for each one of them (Wardrop, 1952). However, congestions are not always recurring because they can be unpredictable (Tavassoli Hojati, Ferreira et al., 2016). This kind of congestions are called non-recurring congestions and are caused by unexpected accidents, work zones and adverse weather, among others.

Travellers who seek to avoid late arrivals allocate additional time or adjust the departure time because the unexpected deviation from the estimated duration of travel can make the journey longer than predicted (Jin & Shams, 2016). To know the additional time needed, it is necessary to know the travel time reliability that defines the range of time it can take the trip (without considering catastrophic events). It should be noted that a higher reliability would be reached by a lower variability, since these two concepts are opposite. However, a doubling of the variance does not necessarily mean a halving of the reliability (Nicholson, 2003). Consequently, travel time reliability is a measure of lack of travel time variability.

It can be differentiated two points of view about the travel time reliability: the first one based on the variation in travel time, and the second one related to the possibility of success or failure against a pre-fixed threshold travel time (Jin & Shams, 2016). Over the years, a lot of definitions of travel time reliability have been made. Here are presented the most relevant ones ordered chronologically:

- "Variability that can be measured using the standard deviation of transport time. Transport models are needed to supply quantity changes in reliability and standard deviation is relatively easy to integrate in models" (Krüger, Vierth et al., 2013).
- The range between, e.g., the 0,5 and the 0,9 quantiles of the distribution of durations (Brownstone & Small, 2005).
- "Percentage of travel that can be successfully finished within a specified time interval" (Nicholson, 2003).
- "The range between the earliest possible arrival time and the 98th percentile of arrival times" (A. Fowkes & Whiteing, 2006).
- "The degree to which randomness in journey time is realized. Although this randomness is hard to measure, travel time reliability can be quantified statistically based on the variance of travel times" (Jin & Shams, 2016).
- Uncertainty associated with travel time because the exact result of a known experiment in successive attempts it is not fully predictable, so it is uncertain. "Consistency or dependability in travel times, as measured from day-to-day and/or across different times of the day" (Rakha, El-Shawarby et al., 2010).

As it can be observed, the reliability is not a closed concept, but different interpretations are given according to each author. Over the years, the concept has evolved increasingly towards something more tangible and quantifiable, thus being more useful for companies to be aware of it, to measure it, and to be able to manage it to be more efficient.

2.4 Advantages of increasing reliability

The fact of having higher travel time reliability in a route and therefore, less variability in it, provides many benefits to the supply chain and to the companies involved in it that are explained next (A. Fowkes & Whiteing, 2006).

For example, companies transporting products that lose value over time quickly (e.g. perishable food) are conditioned by the duration of travel. Defining the maximum time the product can be in transit before it has lost too much value, if the variability of the route is lower, the maximum travel time of the route is reduced. Therefore, it is possible to plan the departure of the route in a wider (and later) time range than in the case with higher variability, ensuring the same quality of the product (Arvis, Marteau et al., 2010). In road transport, this advantage may mean that tolled routes or performing 'double shift' movements (when two drivers are needed to avoid having to stop the truck during mandatory breaks) can be avoided with the consequent savings for the company (A. Fowkes & Whiteing, 2006).

It is also possible to reduce the safety margin that companies use when scheduling freight transport to be sure to arrive on time, by reducing the variability of the travel time. Therefore, turn round times estimated may be more tight and reliable, leading to better planning of routes (Halse & Ramjerdi, 2011). This could reduce the number of trucks and drivers necessaries, ensuring the same level of service provided so far, meaning having the same probability of arriving on time or the same risk of being late.

Otherwise, if the number of drivers and trucks used is maintained, as well as the same schedule planned, there will not be any savings in direct transportation costs, but the quality of service will be increased, gaining benefits of having goods at the destination earlier, if there is any profit.

Therefore, if there is an increase in travel time reliability, the global benefits of the company will be increased, either to arrive before, to be able to make departures later, to reschedule routes saving resources (lorries and drivers) or avoiding tolled routes. In this way, the carriers will have greater reliability in the travel time, the operational costs will be reduced and deliveries will be consolidated or even plan for two-way operations. It is considered that, in terms of generalised travel costs, including time, distance, vehicle operating costs and public transport fares, travel time uncertainty represents an important cost due to the fact that is about 15% of time costs on a usual urban path (Fosgerau & Karlström, 2010).

In addition, the receivers will also get benefit from the availability of reliable transportation networks, as they will reduce the amount of delays in deliveries, and consequently, the losses caused either by lack of stock, the need for extra stock or need for extra personnel in the company. In recent years, many companies of manufacturing firms have implemented cost effective strategies such as just-in-time (JIT) which is an inventory strategy to increase efficiency and decrease waste (Shams, Asgari et al., 2017). In this type of strategy, company relies on its supply chain's reliability and operates with very low inventory levels. Therefore, in this type of strategies the reliability is even more important.

Below, *Figure 4* exposes a summary diagram which specifies the advantages of having a higher reliability.

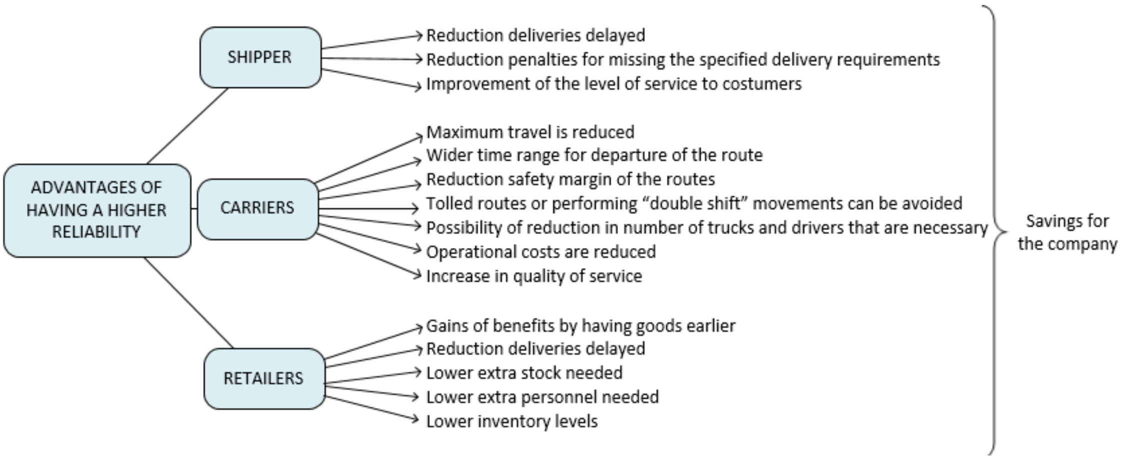


Figure 4 - Advantages of having a higher reliability
Source: own elaboration

2.5 Factors of reliability

Travel times that vehicles experience can be affected by many factors (Zheng, Liu et al., 2017). These factors are variables that cause uncertainty and everyone is under their effect. Fluctuations in traffic demand and supply, signal control at intersections, turning vehicles from cross streets, bus manoeuvres at bus stops, parking vehicles along the roadside or crossing pedestrians and cyclists are some examples that nobody can avoid. It is necessary to know these variables that cause uncertainty to take into consideration when planning journeys to avoid or minimize their effect. Only in this way, the companies will be able to reach optimum reliability services and avoid the disturbances causing recurrent delays (Shams, Asgari et al., 2017).

There are infinite factors like the ones mentioned above, that can interact with any normal trip so they are classified in four types of disturbances according to the magnitude (length of delay) and frequency of the disruption they cause, defined below and in *Figure 5* (Andersson, Berglund et al., 2017).

1. Expected risks. These events occur frequently and have a minor impact (e.g. 15 minutes delay). Companies can take this type of disturbance into account in the planning as they are expected. Planning safety margins or having extra stock can be some solutions. They generate an impact on all transport systems whether or not they are delayed, as all transports have to be ready to absorb the consequences of these risks if they occur. It can be the case of small traffic congestion caused by demand variation or bad weather conditions.
2. Contingencies. Contingencies have a small/medium impact, but they do not happen that often. Therefore, they are not usually planned as they rarely occur, but some disruptions can have action plans associated to be ready to manage them when they happen. It can be the case of special events (music shows, sports events...), strikes, road-works, accidents on road, etc. They only have an impact on directly affected transports.
3. System killers. These types of disturbances are those that occur on a regular basis and have a very high impact on the journey time. This is why they can be ignored, since any company that suffers system killers disturbances can't survive in the current market.
4. Catastrophic events. Given that these events hardly ever occur, such as extreme weather events, seismic movements, terrorist attacks or other really cataclysmic events, they are unpredictable at all. Due to their improbability and their magnitude, they should not be considered for the calculation of reliability, and they should be analysed in separate risks analysis.

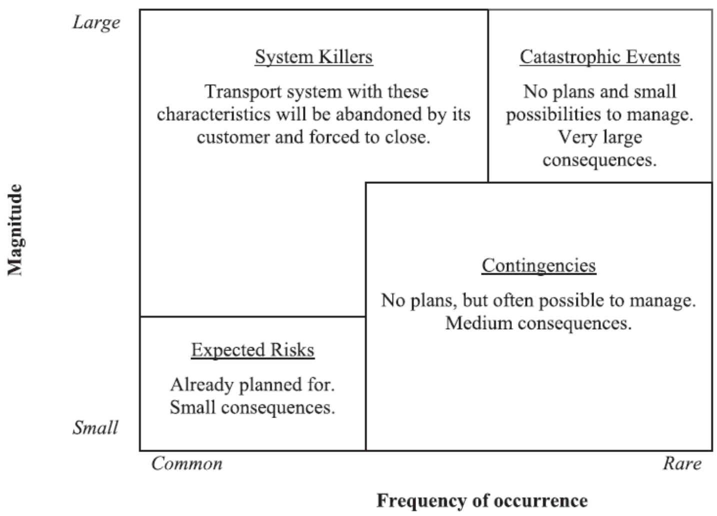


Figure 5 - The four types of disturbances
Source: Andersson, Berglund, Flodén, Persson & Waidringer, 2017

All these disturbances cause variability in travel time duration, but they affect in different frequency and periods of the day, month or year, so depending on its nature, reliability caused by them can be classified into three different categories (Bates, Dix et al., 1987) (Noland & Polak, 2002).

1. Variability in day-to-day travel times. It might be caused by demand fluctuations, accidents, road-works and weather conditions. After taking into consideration the day of the week, holidays and seasonal effects, it is considered that day-to-day variability is purely random. Inter-day reliability.
2. Variability over the course of the day. Traffic congestion will vary during all the day, so travel time will differ highly when departing during rush hours and when departing during off-hour time. Inter-period reliability.
3. Variability from vehicle to vehicle. Mainly due to individual behaviour while driving (speed, parking, traffic signals). Depending on drivers in road habits, vehicle flow might be fluent or congested. Inter-vehicle reliability.

Historically, inter-period and inter-vehicle reliability have had little interest for being studied (Zheng, Liu et al., 2017). Inter-period variability is rarely useful for carriers because, as it has been mentioned before, market receivers are usually who fix the arrival time for their commodities. Besides, there are clearly known differences between rush hours and off-hour periods, but there are no great differences between hours in each period. In reference to inter-vehicle variability, it makes low impact on traffic congestion and its study would not contribute to a better scheduling or increase reliability. That is why the majority of studies have focused on inter-day variability and why most of them define reliability as a random variation in travel time (Bates, Polak et al., 2001; Hollander, 2006; Hollander & Gleave, 2009).

2.6 Assessing reliability

2.6.1 Value of travel time reliability

As it has been seen above, reliability is a key concept that crucially affects the transport of goods. Advantages caused by improving reliability have been mentioned but the real economic effect can only be valuated with the value of reliability (VOR) (Jin & Shams, 2016). The value of reliability is created at the time that due to uncertainty in time deliveries is necessary to have overstocks, use additional vehicles or drivers, extra personnel in the warehouses or advance scheduled departure times (Landergren, Berglund et al., 2015). Then, it refers to the monetary value that users are willing to pay to reduce travel time variability when carrying commodities from the origin to the destination to avoid this additional measures (De Jong, Kouwenhoven et al., 2009).

More specifically, there are three elements needed for including travel time reliability in CBA (cost-benefit analysis) (De Jong & Bliemer, 2015):

1. Deriving a monetary value of reliability, the Value of Travel Time Reliability (VTTR) or Variability (VTTV).
2. Taking into account the reaction of users to travel time variability in transport forecasting models.
3. Forecasting the influence of infrastructure projects on reliability.

The second element (2) is necessary because the value of travel time reliability only reflects preferences at an individual level, and it is not considering the global react of users to a change in travel time variability (De Jong & Bliemer, 2015). De Jong and Bliemer propose two ways for the valuation of travel time reliability. First option is to carry it out completely in an extra post-process step, which is the simplest, but then there is no feedback into the transport model. Second option entails to continue first option by including travel time reliability in the cost of travel in the medium run. Thereby, there is feedback into the transport model, although it is limited to mode and route selection. Neither option affects to departure time scheduling.

The next table shows some valuations for truck freight travel time reliability in Europe and Australia, that correspond to studies made until now.

Study Region	Data Collection Method	Evaluation Method	Definition	Valuation	Units	USD	Year	Mode
Norway	SP CE		Standard Deviation	27	NOK/STD		2010	Truck < 3,5 t
Norway	SP CE		Standard Deviation	131	NOK/STD		2010	Truck > 3,5 t
Netherlands	SP	Regression	Standard Deviation	14	€/hour	18,85	2010	Truck
Netherlands	SP CE	N/A	Standard Deviation	0,8	VOR/VOT		N/A	Truck
Australia	SP	Regression	Expected Delay	1,93 avg.	AUS per 1 reduction	1,82	1998	Truck

Table 3 - Freight Values of reliability studies
Source: Hirschman, Da Silva, Bryan, Strauss-Wieder & Tompkins, 2016.

2.6.2 Methods to assess reliability

To get the value of time travel reliability it is necessary to know how to measure or quantify reliability first. In this way, the experiments are each of the travels made, and the result obtained is the real time travel it takes (Rakha, El-Shawarby et al., 2010). Each travel time trip may differ more or less, depending on all the circumstances related to the route taken (distance, type of vehicle, state of the road, congestion, etc.). The degree of reliability of the path will be defined by this variation of real travel times (Andersson, Berglund et al., 2017).

In order to measure the reliability there are different possible definitions or criteria to use. One of the most widespread approaches to assess reliability is determining the transport system behaviour when there is congestion in the road (Sharov & Mikhailov, 2017). Congestion is interpreted as a state at which transport demand begins to exceed transport supply capacity (Sharov & Mikhailov, 2017). Historically, the following quantitative criteria have been used in studies carried out to date:

1. Standard deviation (Black, Hashimzade et al., 2017): mathematically, it is the average of the squared differences from the mean and it is represented by σ. It is commonly used to measure the dispersion of a set of observations of time

travels. A low standard deviation means that the travel time observations are closely around the mean while a high standard deviation shows that the data can be over a widely spread of time. Standard deviation is useful to standardize a way to know what can be considered normal, and what can be considered extra early or extra late. It is the only one criteria mentioned that allows knowing the probability to get at destination at any possible time. *Figure 6* (McNeese, 2009) shows an example of how standard deviation changes the normal distribution. The three distributions have an average of 100, but different standard deviation: 5 (blue curve), 10 (purple curve) and 20 (red curve). Distribution with standard deviation of 20 (the largest one) corresponds to the wider normal distribution.

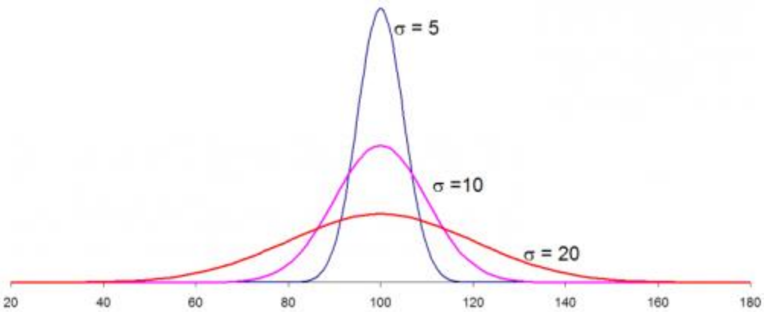


Figure 6 - Normal distribution depending on standard deviation
Source: McNeese, 2009

2. Variance (Black, Hashimzade et al., 2017): it is the result of the squared standard deviation of the travel time from its average value and it is represented by σ^2. It measures how far a set of random samples are spread out from their mean time. Unlike standard deviation, it is not represented with the identical units than the case study data. It is expressed with the square of the units of the variable itself.
3. Buffer time (Sharov & Mikhailov, 2017): it can be applied to calculate economic costs, incurred by the user in the way of scheduling extra time for departures because of the uncertainty of the transport system.

$$T_b = T_{90\%\ (95\%)} - \bar{T} \qquad (1)$$

With T_b being buffer time, $T_{90\%\ (95\%)}$ is 90% or 95% percentile of trip duration, and $\bar{T}$ is the average trip duration. Additionally, the buffer index can be determined following the next expression:

$$I_b = \frac{T_b}{\bar{T}} 100\% \qquad (2)$$

Both factors, T_b and I_b, define the reliability or uncertainty of the transport systems studied. The extra time used because of the uncertainty, defined by the buffer index allows estimating the costs incurred due to earlier departures to assure being in time at destination.
4. Percentage of shipments that are delayed (Andersson, Berglund et al., 2017): it is valuable (but incomplete) to know the ratio of shipments delayed. It is easy to get, but it is not giving any information on the magnitude of the delay.

5. Schedule delay (Andersson, Berglund et al., 2017): it is the difference between the expected arrival time and the real arrival time. It is differentiated between Schedule Delays Early (SDE) and Schedule Delays Late (SDL), as the coefficients associated with these variables are different in the models.

The coefficient of variation of arrival times (standard deviation divided by the mean) is also a useful parameter, which is derived from standard deviation. It allows comparing variabilities of journeys with different travel time mean. When referencing to travel times calculation, this ratio is also called "Reliability Ratio" (Andersson, Berglund et al., 2017). The following graphic (De Jong & Bliemer, 2015) shows that the standard deviation its derivations are the most widely applied measure of time travel reliability, being the most appropriate for use in CBA.

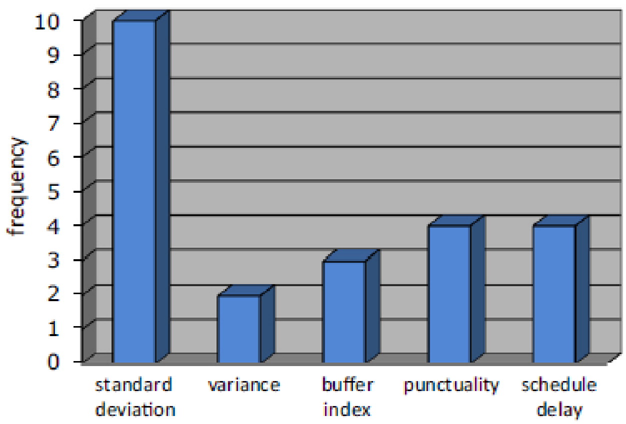


Figure 7 - Frequency of answers of the experts about the most suitable definition of reliability
Source: De Jong & Bliemer, 2015

As the most used one, these are the advantages (+) and disadvantages (-) of choosing standard deviation to measure reliability (De Jong & Bliemer, 2015):

Advantages	Disadvantages
It can be empirically calculated.	It is rather sensitive to outliers.
Along with the mean, any distribution is well summarized.	Without knowing travel time distribution shape it is not possible to fully describe the transport model.
It is not difficult to use it in standard transport models, as it is only needed to add an extra term to consider reliability. It is not required to use a scheduling model in the global transport model.	Two standard deviations from different but consecutive paths cannot be added to calculate global standard deviation. Then, there is no additive property.
It fits very well with stated preference (SP) surveys, as the alternatives for every question differing in standard deviation values are well described by most of standard deviation models.	

Table 4 - Advantages and disadvantages of using standard deviation for measure reliability
Source: De Jong & Bliemer, 2015

With this approach, the value of reliability can be assumed as the value generated by a change of the standard deviation of trip duration. Moreover, the approaches to reliability evaluation are much more various and other measures have been used occasionally by some authors for road networks. Below, the most relevant criteria are explained.

- Average delay (Andersson, Berglund et al., 2017): it is useful to be aware of how long is the common delay. However, no information about repeatability or precision is obtained. One delay of 1 hour is not the same as twenty delays of 3 minutes, obtaining in both the same value of average delay.
- Spread (A. Fowkes & Whiteing, 2006): it is usually defined as the difference between percentiles. It is useful to know the range to which most of the trips are arriving, but within that range, no more information is known such as repeatability or precision.
- Time index (Sharov & Mikhailov, 2017): it is defined as the ratio that relates the travel time of a trip duration in conditions of free flow and in a peak period.

$$TT1 = \frac{T_{PP}}{T_{FF}} \qquad (3)$$

T_{PP} is the time spent for passing the site in conditions of a rush hour, and T_{FF} is the time spent for passing the site in conditions of a free flow. The next table (Sharov & Mikhailov, 2017) shows the reliability levels according to TT1 values for urban street and road network (SRN).

Reliability level	Extent of a site, km		Traffic conditions
A	<5	25	Deterioration in traffic conditions is not observed in peak periods
B	<1,2	<1,2	Insignificant deterioration in traffic conditions is observed in peak periods
C	1,3 – 1,5	1,3 – 1,45	Deterioration in traffic conditions is observed in peak periods
D	1,5 - 2	1,45 – 1,6	Considerable deterioration in traffic conditions is observed in peak periods
E	>2	>1,6	The road functions unreliably in peak periods. Traffic jams are possible

Table 5 - Valuation of traffic circumstances at places of principal roads
Source: Sharov & Mikhailov, 2017

3. METHOD

Main part of the thesis is based on theoretical concepts, so the first and foremost step of the project is a literature review aimed having comprehensive synthesis of existing studies related to the topic of the thesis. All scientific information related to the concept of reliability, whether books, reports, research papers, etc. has been analysed. It has been studied all the existing background in the framework of reliability, mainly related to freight transportation. The studies carried out to date that have tried to quantify the value of reliability, regardless of context (other countries, for passengers or different transport modes), also have been a great source of valuable information. "Travel time", "Reliability", "Variability", "Freight", "Transport" and "Value of time" have been the keywords selected in order to find the information required, using Boolean operators such as AND, OR, AND NOT in the search. The databases consulted are Scopus, Science Direct, Taylor & Francis, Elsevier and Google Scholar, aided by Chalmers Library database to have free access to all the information.

Next step of the thesis is the research design. A cross-sectional study has been designed in order to collect data from agents involved in freight transportation. When choosing the sample, different factors were considered. Several number of companies had to participate in the study to obtain significant results and those companies should represent a high variety of the market sectors. Taking into account these factors and the difficulty to get in contact with them and time restriction, it was decided to take advantage of Logistik & Transport fair held in the Swedish Exhibition and Congress Centre in Gothenburg during 7th and 8th November 2017. This was a great opportunity to collect a huge amount of valuable data, as some of the most important national and international companies strongly related to transportation and logistics management were meeting at the same place at the same time. Besides, DB Schenker was another reliable source to get valuable information, as it was one of the companies taking part of the project, and they could facilitate the contact with other companies that they work with.

With these two possible sources of collecting data from companies, it was decided to divide the study in two branches. The Logistik & Transport fair would be used to carry out a Stated Preferences experiment in order to capture shippers and carriers preferences. The profile of people attending the fair was mainly middle logistics management employees. On the other hand, contacts through DB Schenker would be used to arrange interviews with logistical and supply chains managers of some of the most relevant companies in Gothenburg. The aim of the interviews was to get rather qualitative information compared to quantitative in the survey.

At first, it was planned to do the interviews before the creation of the surveys to establish a first contact with the companies, know their priorities and get more information to design the survey. However, this was not possible due to the lack of availability of companies interviewed. For this reason, the survey was first designed and answers were obtained, and afterwards interviews were made with the companies, which were useful to corroborate the hypotheses previously developed in the survey.

3.1 Stated Preference Survey

3.1.1. Survey design

The purpose of surveying was to know how companies prioritize reliability compared to other attributes such as travel time and cost, and in consequence, to know how much, companies would be willing to pay for higher values of reliability. With this information, it has been possible to quantify the value of reliability and value of time for freight road transportation in Sweden.

The aim of the surveys was to know the preferences of the companies by introducing hypothetical transport offers and not by getting current information on the movements of companies, travel times, trucks, etc. This process is called stated preference (SP) survey in which respondents have to choose depending on the attributes values assigned to each alternative. This method, together with discrete-choice modelling technique, has the objective of knowing the contribution of each attribute to the utility function. In this way, it is possible to establish the value of each attribute.

To achieve that, a survey was designed, with eight choice sets of two possible answers each one. It was decided to create eight choice sets since it was a value that it was tested that it was the maximum possible in order to assure that respondents could have a high level of attention and concentration when answering the survey.

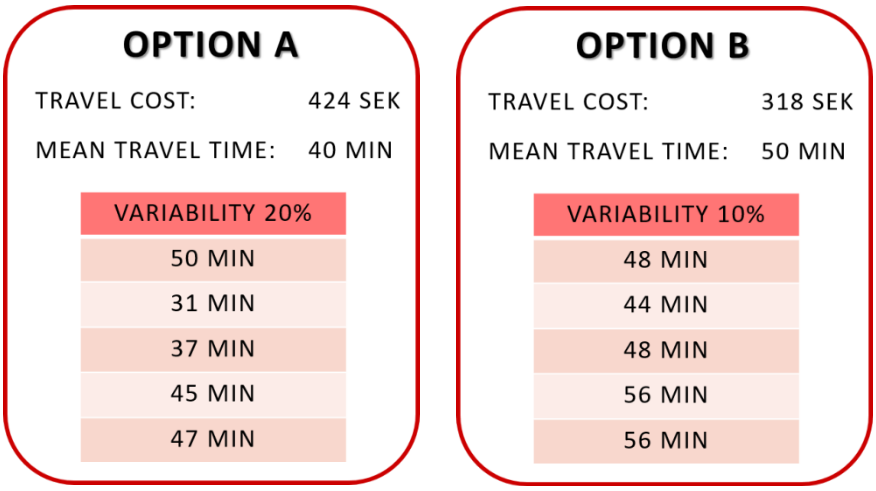


Figure 8 - *Example of a choice set*
Source: own elaboration

To design the choice sets, a 20-kilometre road section was selected from the surroundings of Gothenburg, involved in other working packages of the project (e.g. simulation). Each choice set had three attributes: cost, mean travel time and variability. To calculate the costs, all the values of time travel for each commodity were first acquired. These values were extracted from the ÅSEK tables (Bångman, 2016), which report the values of time recommended to use in cost-benefit analysis in the Swedish transport sector. Next, the operational cost for each commodity was calculated based on the tons of each truck, which included the cost of fuel and cost of goods among others. Then, the commodities were grouped into three groups: raw materials and unperishable goods, perishable goods, and machinery. For each group of goods and each type of truck, the transport cost was calculated. These costs were those that were used for the creation of the choice sets. In reference to travel time, four possible times were established for the 20 km route, according to the car's speed that varies depending on different level of traffic congestion. Finally, the variability was presented in terms of percentage referring to mean travel time. Random values for travel time were generated, according to the given mean travel time and variability, to facilitate the understanding of the concept of variability by the respondents. The two options of each choice set were assigned with the statistical software in order to assure that the combination of the three attributes did not create any dominating option.

Previously to present the choice sets, each respondent had to answer what type of truck was the most frequent in the company, as well as the type of good shipped, so the values of the choice sets were adapted. Next, taking advantage of the moments of maximum concentration, respondents were asked to answer the choice sets and then the weight they had assigned to each attribute when answering the choice sets. Finally, when their attention was decreasing they were asked for their point of view of the concept of reliability, the role of the company within the supply chain (shipper or carrier) and the sector of the company for which they worked. With all this information, apart from establishing a value of reliability, it was also possible to classify each of the respondents and thus establish different patterns or models of responses. *Table 6* shows the different categories which respondents could be classified. The number of employees of each company as well as the geography where the company served was asked or investigated after the survey finished.

Geography	Employees	Part of the supply chain involved in
Serve suburban locations	< 100 employees	Carrier
Truck movements involve border crossings	> 100 employees	Shipper
Industry	**Type of truck**	**Type of product**
Automotive	Car in commercial traffic	Machinery
Commercial services	Lorry without trailer 3 ton	Perishable goods
Electronics	Lorry LGV 14 ton	Raw materials and unperishable goods
Manufacturing	Lorry LGV 24 ton	
Pharmaceutical and healthcare	Lorry HGV 40 ton	
Textile		
Transport and storage		

Table 6 - Classification of the respondents
Source: own elaboration

Minimum number of surveys to get significant results and making possible to extrapolate results obtained to the rest of areas and companies in Sweden was set at 30 respondents, as it would mean 240 answers (30 respondents and 8 choice sets). Finally, 46 respondents was achieved, making 368 answers. It was possible to get that amount of respondents as Google forms software was used.

3.1.2. Discrete choice modelling

To analyse the answers was decided to use discrete choice modelling. The utility of discrete choice models is that they allow the modelling of qualitative variables, using techniques of discrete variables (Medina, 2005). A variable is discrete when it is formed by a finite number of alternatives that measure qualities (De Dios Ortuzar & Willumsen, 1994). This feature requires coding as a step prior to modelling. The modelling of this type of variables is known as discrete choice models, within which there is a wide typology of models. According to the function used for the estimation of the probability there is the truncated linear probability model, the Logit model and the Probit model (Medina, 2005).

In the literature, there are two approaches to the structural interpretation of discrete choice models (Jin & Shams, 2016). The first one refers to the modelling of a latent variable through an index function, which tries to model an unobservable or latent variable. The second of the approaches allows interpreting discrete choice models under the theory of random utility, so that the alternative selected in each case will be one that maximizes the expected utility (Jin & Shams, 2016).

Under random utility maximization approach, an individual must adopt a decision that allows him to choose between two or more exclusive alternatives, choosing the one which will maximize the expected utility provided by each of the possible alternatives (Shams, Asgari et al., 2017). Therefore, the individual will choose one of the alternatives depending on whether the utility provided by chosen decision is superior to the one provided by the other options. This utility can vary depending on some characteristics and the value of different factors of the product or service. In this study, utility is assigned by the companies depending on the value of the cost, the mean travel time and the variability of each transport option, and the utility could be related to economic profit obtained (De Los Santos, 2016). Depending on how utility varies, according to a change in a variable, the importance of each element can be assessed. In addition, each individual (or companies, sectors, etc.) can use different criteria for each element to influence in the utility, so it depends on each subject.

The Random Utility Maximization model that has been used is the conditional logit model (CLOGIT) (McFadden, 1973) or logistic regression model. Considering an r consumer, and j alternatives in a set of J alternatives, the utility is set as U_{rj} and it is defined by:

$$U_{rj} = V_{rj} + \varepsilon_{rj} \qquad (4)$$

Where V_{rj} is defined as the observable term and it is called the Systematic Utility, and ε_{rj} is the unobservable term, associated to an unknown heterogeneity factor associated to the consumer r and product j. Some of these factors could be gender, educational or generational influences that cannot be taken into account (Paczkowski, 2016). Systematic utility is defined by:

$$V_{rj} = \beta_1 * X_{rj} \qquad (5)$$

Being X_{rj} the value of the attribute X for product j seen by consumer r (e.g. the price of a car). β_1 is a part-worthy utility and must be estimated from data.

Assuming a probability distribution for ε_{rj}, the probabilities for consumer r choosing product j from among J products is known as the acceptance rate or take rate and it can be calculated with (De Los Santos, 2016):

$$Pr_{rj} = \frac{e^{V_{rj}}}{\sum_{k=1}^{J} e^{V_{rk}}} \qquad (6)$$

The probability for r consumer and j product is not conditioned by its total utility, but by the relative utility with respect to the other products. Thus, it depends on the possible choices available and the person making the choice. This discrete choice model has two interesting properties (Paczkowski, 2016). Equivalent Differences Property (EDP) says that an element or a variable that is constant for all J choice alternatives has no effect on the choice probability, as it would be cancelled between the numerator and denominator, so they do not need to be studied. Second property is Independence of Irrelevant Alternatives Property (IIA) that says that the ratio of choosing probabilities of two different alternatives only depends on these two alternatives and does not depend on the presence or the absence of any other alternatives.

3.1.3. Survey data analysis

To start analysing the respondents' answers, first, it was carried out a post-process to be able to work with the results obtained. First, a preliminary analysis was done in which it was found that all the answers obtained were correct. This step was completed by verifying that all the choice sets had a variety of the answers (<90%) and therefore there had not been any predominant attribute. In addition, the sample of the profiles of respondents was analysed, according to sectors, type of material, carrier/shipper, and type of truck. As commented before, it was also investigated the number of employees of each company that had answered the survey in order to analyse whether size was a factor that influenced the answers obtained.

When it was found that there were no anomalies (incoherent responses), the obtained answers were analysed. Data obtained from surveys has been statistically analysed with JMP. With this statistical software the objective was to find the concrete model that best defined the priorities of the different types of companies among the different attributes proposed. The first model simulated was only including the attributes of each option, cost, mean travel time and variability, without taking into account the characteristics of the respondent. With this model, it was intended, in a global way, to see which attributes were significant when choosing the transport option and between the three attributes, which was the most important. Later, a large number of models were run in search of the best model, looking for the significant variables besides the three attributes. It was checked the significance of each variable and the interaction between them. To know whether a variable was significant, the p-value and logWorth parameters were checked. The p-value indicates the probability that, when the null hypothesis is true, the statistical summary would be the same as or of greater magnitude than the actual observed results. Standard significance p-value is set at 0,05, thus any variable with p-value lower than 0,05 will be considered as significant. The logWorth it is showing the same information but transforming the p-value with the next equation (7):

$$logWorth = -\log(p\_value) \qquad (7)$$

In addition, in the *Parameter Estimation* section, it was checked the contribution of each variable in to the utility function, and therefore β values of the Systematic utility. This information allows knowing if the contribution of a variable adds or subtracts value in the utility function**,** so it is useful to see the coherence of the obtained model. Another factor that indicates the quality of the model is the *AICc* parameter (Akaike Information Criterion). It allows comparing between two different models, being more trustable the one with the lowest *AICc* value. Finally, the *Willingness to Pay* was calculated, which allows knowing, according to the answers obtained in the survey and by a concrete respondent profile, the amount that each profile of respondent would be willing to pay for better specific values of variability and travel time. Considering these parameters, multiple models were analysed in search of the best one, the one having a better trade-off between a low *AICc* value, conceptual validity and significant coherent factors.

In addition, a classification of similar response patterns by profiles, also known as clusters, was also carried out. With the cluster analysis, it is intended to find a set of groups to which the different individuals will be assigned by some criterion of homogeneity. Referring to the survey, the individuals are the respondents and the criterion of homogeneity are the answers to the choice sets. Unfortunately, cluster analysis done did not show any significant result as the groups were set at three, but there was no homogeneity in respondent's profiles of each group.

3.2 Interviews

3.2.1 Interviews design

It was decided to interview some of the most important companies in Sweden of different sectors that could be benefited with the project. In this way, it would be possible to understand better their process and supply chain of the entities, and it would be recollected qualitative and quantitative information about the companies' approach of time travel reliability. Moreover, it was also wanted to know the opinion and evaluation of the companies about the project that it is being carried out.

The companies that it was decided to interview were five important entities of different sectors such as transport and storage, pharmaceutical and healthcare or food and beverage. It was started contact with Volvo, the largest company in Sweden (Business Insider Nordic, 2016) and a multinational manufacturing company, and DB Schenker, a leader in logistic solutions and supply chain management. Moreover, it was contacted with Coop, a hypermarket company which has the 21,5% grocery retail market in Sweden (Coop Sverige, 2017), Mat, an online grocery store in Sweden which is becoming very important in the last years, and Oriola, a company with a lot of experience in pharmaceutical wholesale markets (100 years approximately) (Oriola, 2017).

As the aim of the interviews was to know better the point of view and the process of the companies, it was wanted to contact with the high logistics employees of the companies, such as the transport manager or the supply chain developer. As it was difficult to have access to this group of people and stablish a meeting with them, DB Schenker, a company involved in the global project, facilitated the contacts of the companies chosen to interview.

The process followed to arrange a meeting with them was the recommended by Healey and Rawlinson (1993). First, the interviewers did a telephone call to stablish a first contact with the person and explain a little bit the project that is being carried out. Then, an introductory mail was written to enclose a short outline of the objectives of the project and it was also sent the interview guide so the interviewee could be better prepared.

After a first contact with the companies, it was not possible to stablish an interview with all of them because they were not available in short term to meet for an interview. Thus, three interviews were carried out. The companies interviewed were Oriola, Coop and DB Schenker and the media of communication was by phone calls. In this way, it could not be identified non-verbal clues as facial expression, although the interviewers could realise that sometimes the respondent changed the tone of voice.

The interview created was semi-structured to get more flexibility depending on the direction that took the interview. In this way, the interviewer could change the predetermined order of the questions or also add new questions to know more about the respondent argument or to follow up interviewee's replies. Generally, qualitative interviews are used to comprehend the interviewee's point of view by having detailed answers, so the approach is less structured than a quantitative interview.

In order to achieve a useful interview, it was necessary to think about what it was needed to know to answer the research questions. Thus, the interview questions had to comprise all the areas of the research questions, but in a respondent's point of view. Some studies, for example Hirschman, Da Silva et al. (2016), were very useful to design the interview guides as the type of interviews done were very similar to the one that it was wanted to create.

Three different interviews guides were designed depending on the role of the company in the supply chain that was interviewed (shipper, carrier or receiver). Each guide is divided in three sections. *Introduction* is focused on information related to market sector, types and number of deliveries associated to the company. The second section is *Deliveries information*, where questions performed are related to time delivery requirements, delays and solutions to time travel variability. In the last section, *Project evaluation*, the companies are asked to evaluate the proposal of allowing certain types of trucks to circulate along the bus lane in the ring roads (Bryman & Bell, 2015). Interview guides can be found in *Appendix II*.

It is important to mention that the answers of some questions of the guide were coded in order to facilitate the subsequent analysis. This would clarify the understanding of the data collected and would also help with the theoretical sampling (Bryman & Bell, 2015).

During the interview, it was very important to be attentive to what the interviewee was explaining the whole time, and also be flexible in the asking of questions. The interviews were audio-recorded to make things easier and also due to the fact that in a qualitative interview not only is important what respondents say but also the way they explain it.

3.2.2 Interview data analysis

Once it was recollected all the data of the interviews, the next step was to analyse the results obtained. The method followed to analyse them was based on the grounded theory principles. Grounded theory was defined by Strauss and Corbin in 1998 as "theory that was derived from data, systematically gathered and analysed through the research process. In this method, data collection, analysis and eventual theory stand in close relationship to one another" (Bryman & Bell, 2015).

To analyse results, it was carried out a constant comparison between answers obtained in the different interviews. In this way, it was kept a close connection between conceptualization and data collected, and the relation between categories with their indicators, and concepts are maintained. Thanks to this method of constant comparison, the researcher can continuously compare the data coded under a category in order to find some theory that can be further developed.

On the other hand, as interviews were audio-recorded, they were listened by second time in order to find out some word or important sentence that the respondent had commented and it had not been reflected in the answers written in the guide.

3.3 Validity and transferability

A great emphasis has been placed on the design of both the interviews and the survey, in order to obtain the desired information to answer the research questions of the thesis. The trustworthiness of the results and conclusions obtained has to be evaluated by looking at the robustness and external validity (Easterby-Smith, Thorpe et al., 2015).

The final model used to describe the respondents answers and the willingness to pay associated can be considered robust as the statistical parameters such as the p-value associated to each variable was significantly lower than 0,05 and the AICc indicator was one the lowest in all the models run. At the same time conceptual validity and significant coherent factors were matching in the same model. Very few alteration on the values obtained would be by changes to a single data point or to data transcription errors due to high number of answers obtained, 368. Moreover, in order to ensure that there were no transcription errors, Google Forms was used and automatic data transcription into Excel was done.

External validity is an indication of how much the conclusions can be generalized outside the study (Easterby-Smith, Thorpe et al., 2015). The findings in this study, related to values of reliability and values of travel time, can be generalizable to the extent to Sweden market. Furthermore, the survey sample comprised of 46 companies not only located in Gothenburg as companies working all around Sweden came to the fair, which further strengthens the generalizability. However, since all the respondents were Swedish, it is not possible to generalize the results obtained outside the Swedish scene. It shall further be noted that the study needs to be extended with retailer's point of view to have a complete successful performance.

According to Easterby-Smith et al. (2015) one of the major concerns regarding survey designs is whether the instruments are both stable and accurate. Google Forms can be considered accurate and stable enough as the risk of choosing the wrong alternative was very low as each alternative had a big picture associated. The software did not accept sending in unanswered questions, turning the risk of a respondent forgetting to respond to a question to zero since this was not possible. Moreover, it shall be noted that the authors were present when the surveys were being carried out hence they could assure the interviewee understood each question properly.

Moreover, all the data from the interviews has been treated with confidentiality to guarantee the ethics of the thesis.

4. RESULTS AND ANALYSIS

In this section, the results obtained in the survey and the interviews are showed separately by data description (preliminary analysis of survey answers and respondents), discrete choice modelling results (application of CLOGIT model) and interview results (analysis of company's answers).

4.1 Data description

As mentioned before, it was known beforehand that maybe one of the complications of the surveys would be that the interviewees always chose the cheapest transport option, without taking into account any other attribute. *Table 7* reflects the results of the preliminary analysis of the answers, which also shows the variability of the answers for each choice seat.

	Less price		Less travel time		Less variability	
Choice set	Proportion	Percentage	Proportion	Percentage	Proportion	Percentage
1	37/46	80,4%	9/46	19,6%	37/46	80,4%
2	18/46	39,1%	28/46	60,9%	18/46	39,1%
3	29/46	63,0%	17/46	37,0%	29/46	63,0%
4	39/46	84,8%	39/46	84,8%	7/46	15,2%
5	23/46	50,0%	23/46	50,0%	23/46	50,0%
6	21/46	45,7%	21/46	45,7%	25/46	54,3%
7	41/46	89,1%	41/46	89,1%	5/46	10,9%
8	17/46	37,0%	29/46	63,0%	29/46	63,0%
Total	226/368	61,4%	208/368	56,5%	172/368	46,7%
Total respondents always choosing the cheapest option					5/46	10,9%

Table 7 - Classification of the answers obtained in the survey
Source: own elaboration

As it can be seen, there has not been overly dominant response due to some design failure because any option has been chosen in more than 90% of the answers. The most unbalanced question was the one that corresponds to the choice set 7, with an option that was selected 89,1% of the total answers. It is considered within the passable limits. It is also remarkable that only five respondents have answered all the eight choice sets for the cheapest option. At first, looking only to this preliminary analysis it can be concluded that the most relevant parameter was the price as the cheapest option was chosen 61,4% of the 368 answers. Second, travel time, and third, variability, with a non-negligible percentage of 46,7%.

This initial conclusion was reinforced by the results obtained in the question of what weights did respondents assign to each attribute when choosing between the responses of the choice sets. *Figure 9* shows that price is the most valued attribute with 47%, then travel time with 31%, and variability with 22%.

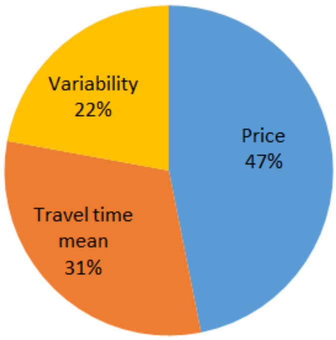


Figure 9 - Weight assigned to each attribute by respondents
Source: own elaboration

If results of carriers and shippers are compared separately, it can be concluded that shippers value more the attribute of variability and less the cost than carriers.

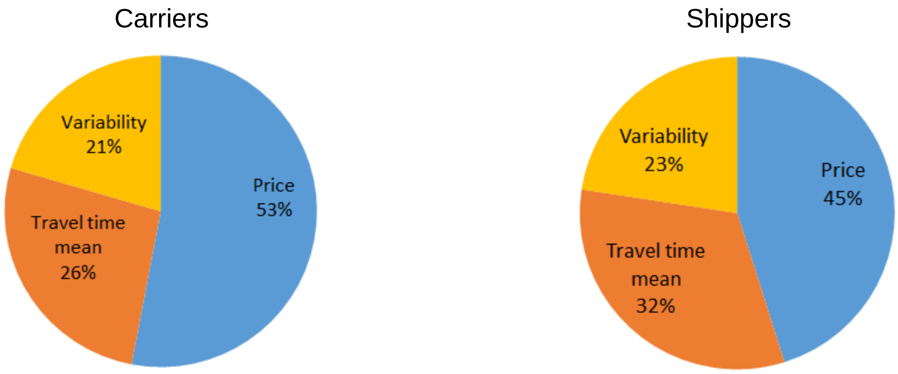


Figure 10 - Weight assigned to each attribute by carriers and shippers
Source: own elaboration

Table 8 shows the number of respondents that assigned the highest weight to the attribute price, to travel time and to variability. The same conclusions are obtained due to price is the attribute that has been assigned most weight in 23 responses out of 46, travel time 9 and variability 7.

	Number of respondents	Percentage
Price	23	50,0%
Travel time	9	19,6%
Variability	7	15,2%

Table 8 - Attribute which respondents assigned the highest weight
Source: own elaboration

As commented before, there was a part of the survey that asked what definition was preferred by the interviewees to describe the concept of travel time reliability in freight transport. The definition selected by more respondents was “percentage of on-time deliveries” with 22 answers of 46 surveys answered. *Figure 11* shows a graphic with the exact number of people that selected each definition. This reflects that the output of the literature review and the point of view of the companies is contradicting, as some companies are only focusing in whether the deliveries are on time or not.

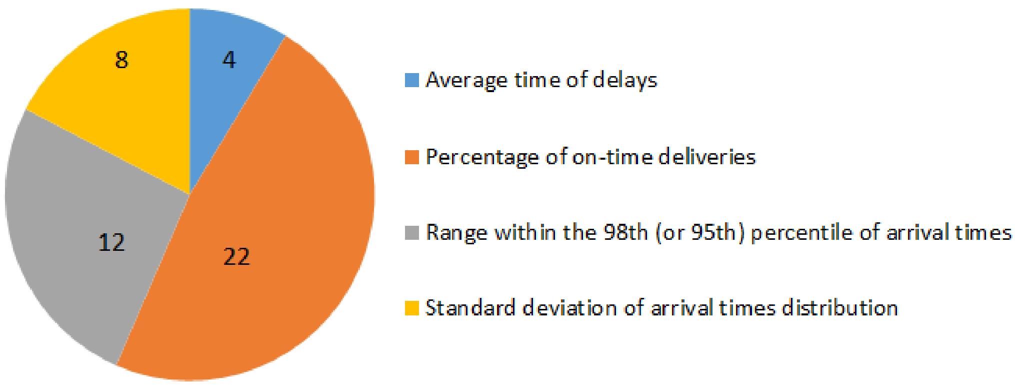


Figure 11 - Number of respondents answering each possible definition of travel time reliability
Source: own elaboration

If these answers are analysed deeply, *Figure 12* shows that both carriers and shippers mostly understand reliability as the percentage of on-time deliveries. However, only the carriers are thinking in that way by absolute majority. This is probably caused because it is how their clients evaluate their level of service, by the percentage of on-time deliveries.

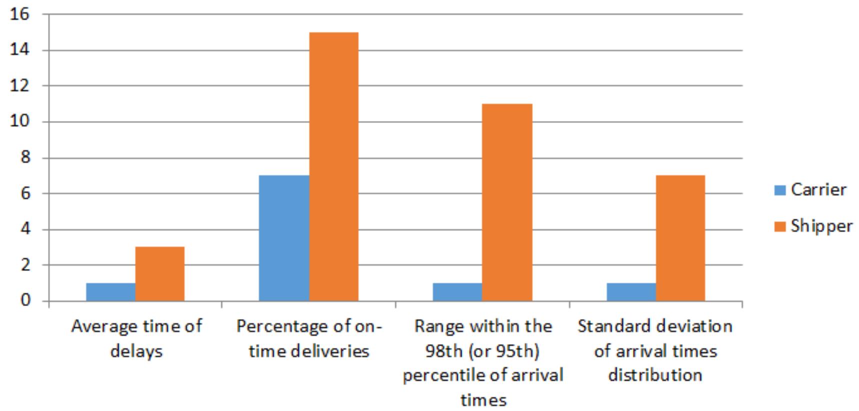


Figure 12 - Results of shippers and carriers when defining travel time reliability
Source: own elaboration

Once the answers have been validated, the sampling of data obtained according to the profile of the respondent has been analysed. Next, *Figures 13, 14, 15* and *16,* presents the distribution of the respondents depending on their characteristics. As it can be seen, most of the companies surveyed worked with raw materials and unperishable goods (*Figure 13)*.

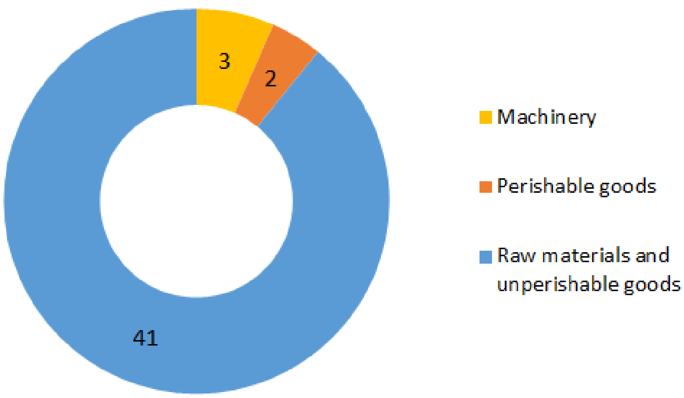


Figure 13 - Classification of respondents depending on the type of products that respondents work with
Source: own elaboration

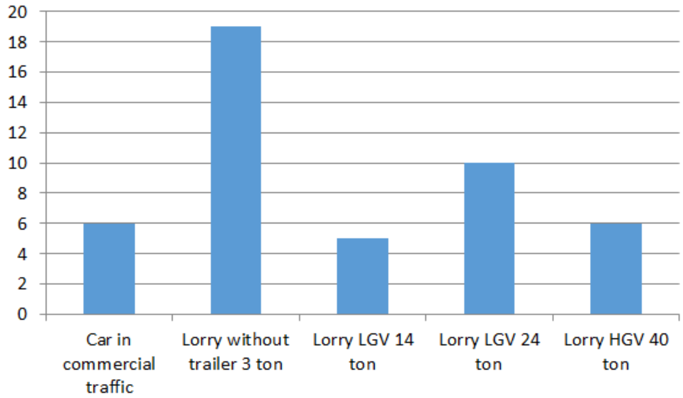


Figure 14 - Classification of respondents depending on type of vehicles of the company
Source: own elaboration

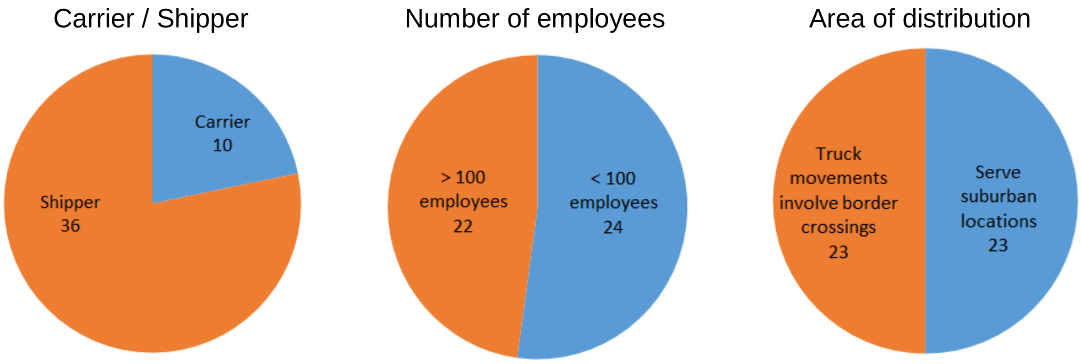


Figure 15 - Classification of respondents depending on carrier/shipper, number of employees and area of distribution
Source: own elaboration

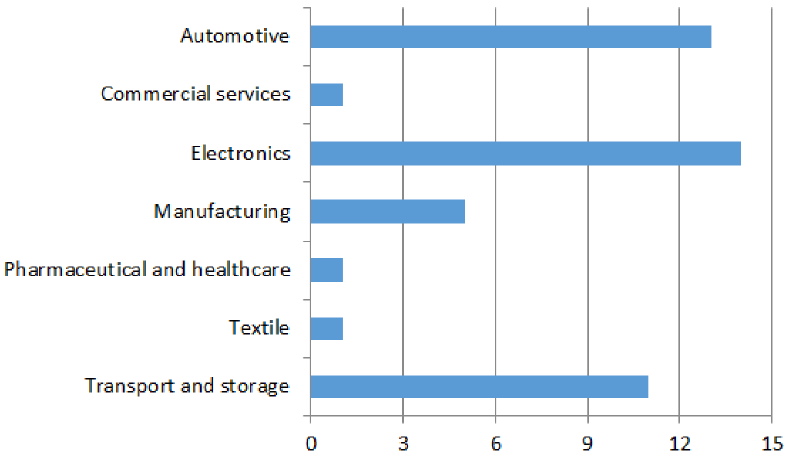


Figure 16 - Classification of respondents depending on sector of the company
Source: own elaboration

As it can be observed, there is a deficit in people surveyed in the commercial, pharmaceutical and textile sectors. This fact will make the conclusions that can be obtained from these sectors less relevant. In addition, there are few answers for the truck of 40 tons, although this is less relevant due to the fact that capacity is studied as a continuous variable, and all the answers with all vehicle capacities will define the tendency in the behaviour of this factor.

4.2 Discrete choice modelling results

Once the profiles of the respondents were analysed and validated, it was the time for running the discrete choice models. Next, *Table 9* present the first results obtained. It was the initial model only taking into account the 3 attributes (cost, mean travel time and variability).

Model		Initial model	
Effect summary	logWorth		p-value
Price	11,725		0,00000
Travel time	9,003		0,00000
Variability	5,663		0,00000
Parameter estimates	estimate		std error
Travel time	-0,04357		0,00770
Variability	-0,02829		0,00629
Price	-0,00650		0,00107
AICc		457,56728	
BIC		469,22559	
-2*LogLikelihood		451,50134	
-2*Firth LogLikelihood		417,02299	
Likelihood Ratio tests	L-R ChiSquare	DF	Prob>ChiSq
Travel time	37,338	1	<0,0001*
Variability	22,437	1	<0,0001*
Price	49,602	1	<0,0001*

Table 9 - Initial model
Source: own elaboration

From *Table 9* it also can be concluded as a preliminary analysis that price is the most relevant attribute, with 41,30%. It is followed by travel time with 33,02% and variability with a 25,63%. These results are quite similar to those obtained in the preliminary analysis. Comparing with the question of weights percentages it can be seen that people value variability and travel time higher than they think. In addition, it is observed that the signs of the *Parameter Estimates* are negative, which indicates that the more price, travel time or variability, less utility there is. This shows the coherence of the results obtained. In this case, as it is the first model, the value of the *AICc* is not relevant because it is needed at least two models in order to compare and obtain some information about this parameter.

As mentioned above, many models have been analysed. All 1 to 1 interactions have been tested between cost, mean travel time and variability with all the other variables. Interactions 2 to 2 have also been analysed, with two variables at the same time. Finally, *Tables 10* show the results of the most appropriate model.

Model	Final model		
Effect summary	logWorth	p-value	
Price	10,318	0,00000	
Travel time	10,307	0,00000	
Variability	7,135	0,00000	
Sector*Price	3,228	0,00059	
Capacity V*Price	1,405	0,03931	
Parameter estimates	estimate	std error	
Travel time	-0,049879043	0,0083731487	
Variability	-0,033551860	0,0067452948	
Price	-0,019372132	0,0044278143	
Capacity V*Price	0,000145441	0,0000716099	
Sector[Automotive]*Price	0,012359794	0,0044133643	
Sector[Commercial services]*Price	0,0044992747	0,0073701486	
Sector[Electronics]*Price	0,010363008	0,0045017506	
AICc	437,27926		
BIC	475,74384		
-2*LogLikelihood	416,66301		
-2*Firth LogLikelihood	298,28374		
Likelihood Ratio tests	L-R ChiSquare	DF	Prob>ChiSq
Travel time	43,203	1	<0,0001*
Variability	28,977	1	<0,0001*
Price	43,253	1	<0,0001*
Capacity V*Price	4,247	1	0,0393*
Sector*Price	23,707	6	0,0006*

Table 10 - Final model
Source: own elaboration

	1 T	3 T	14 T	24 T	40 T
Automotive	148,30	154,86	204,65	289,16	928,22
Electronics	114,89	118,79	146,04	184,54	317,34
Transport	101,10	104,10	124,52	157,20	231,57
Commercial	71,55	73,04	82,51	93,53	118,94
Pharmaceutical	63,47	64,64	71,95	80,19	98,18
Manufacture	44,44	45,02	48,45	52,05	59,07
Textile	18,32	18,42	18,96	19,49	20,40

Table 11 - Willingness to pay per hour of reduced travel time (SEK), by sectors and vehicle capacity
Source: own elaboration

	1 T	3 T	14 T	24 T	40 T
Automotive	488,60	510,23	674,25	952,70	2808,35
Electronics	378,53	391,38	481,18	607,98	1051,30
Transport	333,08	343,00	410,05	498,70	762,38
Commercial	235,73	240,63	271,83	308,13	391,88
Pharmaceutical	209,10	212,98	237,05	264,20	323,48
Manufacture	146,43	148,33	159,60	171,48	194,63
Textile	60,35	60,68	62,48	64,23	67,20

Table 12 - Willingness to pay per hour of variability reduction (SEK), by sectors and vehicle capacity
Source: own elaboration

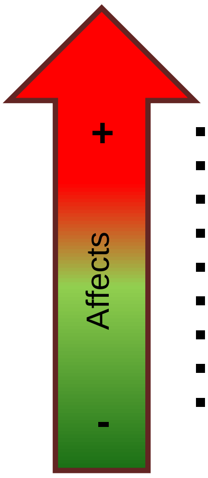
As it will be commented in section 5. Discussion and practical implication, this is a logical and consistent result, because as the vehicle is bigger, the load it carries is more valuable and therefore, the company is less sensitive to price. For this reason, they are willing to pay more money to improve in aspects such as travel time or variability. The same happens with the sector due to the fact that those who work with more expensive products such as machinery or electronics, are also less sensitive to the price and are willing to pay more money. Consequently, it can be concluded that the significant variables are those that influence the total value of the goods to be transported. However, the type of good, the size of the company and the area in which the goods are distributed, have not been significant.

4.3 Interview results

Three important companies from different sectors such as pharmaceutical and healthcare, food and beverages, and transport and storage were interviewed. The interviewees were workers with more than ten years of experience in their companies and all of them were transport managers, operation managers or supply chain developers.

First of all, they were asked some questions related to the company such as how it operates. Most of the interviewers indicated that the size of shipment they had was lower than three tons, and they sent more than 100 shipments per day. With this data it can be seen that the companies interviewed are important firms in the sector and also in the country. In addition, it should be noted that their percentage of shipments delayed is lower than 5%. It is also necessary to comment that all interviewees decided that the concept that fitted better with their idea of travel time reliability in freight transport was "percentage of on-time deliveries".

Next, interviewees were asked to rate some variables as a source of travel time variability, and they considered that accidents was the factor that most affected variability, and the least one was paperwork and language barriers at receiving facilities. *Figure 17* shows the most and least relevant factors. It is noteworthy that some company considered the factor “drivers unable to find locations” as one of the least important because it did not affect to travel time variability. This is because these companies teach their drivers in order they have a good knowledge of the route they are going to drive. Others considered that “consistent travel times for road freight moves” was not a very important factor because they only drove short distances in the surroundings of Gothenburg. However, the majority of companies had the same opinion about the most and least important factors that affected travel time reliability.



- Accidents
- Delays at loading / outbound facility
- Availability of real-time traffic information
- Weather
- Consistent travel times for road freight moves
- Drivers unable to find locations
- Road works
- Vehicle breakdowns
- Paperwork and language barriers at receiving facilities

Figure 17 - Factors that affect travel time variability
Source: own elaboration

Companies plan the journey's departure depending on the fixed delivery time, and they organise the trips with the carrier although other firms establish the routes depending on the truck's space. Besides, interviewees answered that delivery requirements are mostly defined by consistent delivery within a multi-day delivery window, and if some shipment is delayed the carrier is more responsible than the shipper. If it happens, companies stipulate penalties for missing the specified delivery requirements to their transport company, and the customer also stipulate penalties to them. In addition, they were asked for the measure that they take to assure deliveries arrive on time, and they answered that they follow up every month all the shipments, and carriers use a type of scanner or app to report delivery times.

Finally, it is noteworthy that interviewees considered that the project being carried out is very interesting and they would be willing to pay in order to have more reliability in their mean travel time and also less traffic queues.

5. DISCUSSION AND PRACTICAL IMPLICATIONS

As it has been shown in chapter 4.2 Discrete choice modelling results, the first model analysed, the one that only takes into account the three attributes (cost, mean travel time and variability) produces predictable results. The three variables emerge as significant, which shows that all of them are important for the companies when choosing among different alternatives for transport of goods. Moreover, the order of significance it was also predictable, as the cost is the most significant one, followed by mean travel time first, and reliability later. It can be also proved with the *Willingness to Pay* tool that the companies are willing to pay more money to reduce mean travel time from 75 minutes to 40 minutes than to reduce variability from 50% to 10%.

After analysing several models, trying with all the combinations with the variables of study, the final model is the one presented in *Table 10*. In this model, besides the three attributes, capacity of the vehicle and sector are also significant for the price, but not for the travel time and variability. *AICc* for this model is 437, which is highly better than AICc for the first model, 457, although it is not the model with the best *AICc*. *Parameter estimates* section shows that the estimation for the three attributes is negative, which means that as more cost, travel time or reliability, there is less utility. According to the estimation for each attribute, it can be suspected which sectors are going to be more sensitive to the price.

About the *Willingness to pay* (WTP) tool, associated to the final model, the results are interesting. It can be observed two patterns. The first one is the growth of the WTP for both travel time and reliability, as the capacity of the vehicle is higher, for any sector. So as bigger size of vehicle, the companies are willing to pay more to get better transport conditions. The other pattern observed is the change in the WTP according to the sector studied. In this way, for the same vehicle capacity, automotive and electronics sector are willing to pay six times more than textile or manufacture sectors. Both patterns can be explained by the value of the goods transported. Thus, as more value of goods there is in the trucks, either for quantity (vehicle capacity) or quality (sector), companies are willing to pay more for lower mean travel times or higher reliabilities.

Comparing the values obtained in the WTP tool for travel time, with the values in the ÅSEK tables for transport of goods in Sweden, the first ones are lower than the official ones. In the ÅSEK tables it is differenced the Value of Travel Time Savings (product cost) according to vehicle type (Lorry with trailer, Lorry without trailer and Car in commercial traffic), SAMGODS-commodity groups and STAN-commodity groups. Comparing, for example, the operational cost and product cost for machinery (SAMGODS-commodity group) and for a 40 ton truck, the value is 1657,08 SEK/ton*hour while the value of the study is 928,22 SEK/ton*hour. This difference, which is similar for other groups and other capacities, can be explained since in the ÅSEK tables can be found costs while in this thesis it has been valued the WTP of the companies, and this is never going to be higher than costs, as maximum the same, probably lower. Moreover, the respondents profile is focused on shippers and carriers, and it is not taking into account the receivers, who would add more value on travel time saving as they could save some money in different supply chain stages.

Regarding to variability values, they are regularly considered in the ÅSEK tables as twice the value of travel time savings. In the same example mentioned for value of time travel savings, the relation is 3,02. In this study, global comparison between values of travel time savings and values of reliability with all the sectors and capacities raise a mean relation of 3,29. Then, these values are different from the ÅSEK tables ones and they should be updated.

With the new and different values of reliability, it can be concluded that it was necessary to carry out this study in order to use more accurate values when making cost-benefit analysis. These values will help companies and governments to have more precise data and economic impact valuations when making decisions related to transport and infrastructure projects. Related to Suburban Logistics project, as this thesis is just one of the seven working packages, it cannot be determined the final type of vehicles that should be allowed to circulate along the bus lane as other factors than the economical are also important (e.g. social value). Anyway, looking exclusively for economic savings criteria it can be determined that automotive, electronics and transport trucks are the ones who should be allowed first (depending on number of trucks for each sector and road capacity).

Table 3 - Freight Values of reliability studies, shows values of reliability of previous studies. As these studies have been carried out in different countries or with different methods, they can differ, but comparison can be interesting to see the differences. In the Netherlands one, all transport modes and both passenger and freight transports were analysed. They obtained a value of reliability for road freight transport and 2-40 tons trucks of 38€/hour using standard deviation method. This value was calculated with price level of 2010 and it is not including VAT. The next table shows the values of reliability obtained in this thesis for 21 tons trucks.

	21 tons
Automotive	674,25
Electronics	481,18
Transport	410,05
Commercial	271,83
Pharmaceutical	237,05
Manufacture	159,60
Textile	62,48

Table 13 - Values of reliability for 21 tons
Source: own elaboration

As the values depend on the sector analysed, it cannot be directly compared, but the Netherlands value of reliability is comprised between the lowest and the highest values of this study. As the values of *Table 13* are including VAT, it should be considered lower values to compare both studies.

Referring to the Norwegian study carried out in 2010, it was studied with the same method the value of reliability per vehicle for road transport, based on results from shippers with hired transport. However, as the results are shown in NOK per hour standard deviation, it cannot be compared with the values obtained in this thesis.

The interviews carried out were useful to corroborate the outcome obtained with the analysis of the survey responses. Companies have proved that variability is a relevant concept for their shipments, which they try to minimize in order to be as efficient as possible. Related to that, it has been revealed some of the measures they take to avoid time travel uncertainty. However, as it has been seen in the surveys, the cost is the most relevant concept as the companies, when talking about reliability, their first priority is to get the delivery on time, and not to get the maximum precision.

In addition, interviewees have explained the causes of variability in time travel journeys, and that they are responsibility of both the carrier and the shipper, so all the stakeholders have to be involved in order to avoid delays and get an efficient supply chain.

To achieve that, companies think that the idea of allowing some trucks to circulate along the bus lane could be interesting for them, and they would really be willing to pay for that, even they have not quantified how much.

6. CONCLUSIONS

First of all and the most important conclusion of this thesis is that after this study there are already values of reliability for freight road transportation in Sweden, based on theoretical foundation. This is a powerful tool for the correct management decision-making, which allows quantifying economically the impact of uncertainty in travel time. The cost repercussion of reliability will be available to be considered in the cost-benefit analysis, as it was expected when research question 3 arose.

The first example to this utility will be in the Ringroad logistics project, where the data collected will allow transforming the reliability gain into economic profit, in order to consider this positive impact to decide the feasibility of the project, among other considerations. Due to the classification of values of reliability per sector and vehicle capacity, it will not only help to decide about the feasibility, but also about which companies and trucks should be allowed to circulate along the bus lane. In addition, companies interviewed and surveyed have shown strong interest in the project as they consider it would be useful for them to have access to the bus lane.

Throughout the course of the thesis, with the theoretical framework research questions 1 and 2 have been answered, proving that travel time reliability for freight transportation is a key concept, which is growing, as many studies are coming out in the last few years. Although there are many companies who are not still considering it, everyone involved in the supply chain is affected by the variability in deliveries. For this reason, it will gain more relevance and the companies will start looking for innovative solutions to increase reliability, to improve their efficiency, increasing the level of service and reducing operative costs.

Values of reliability have been obtained as it could have been expected. It was obvious that companies would be willing to pay for less travel time and less variability. It was also predictable that the willingness to pay patterns were behaving in function of value of goods transported, expressed in terms of vehicle capacity and sector. Moreover, the obtained values are close to others calculated in previous studies carried out with similar methodology in other countries. Besides, interviews with most relevant companies in Sweden from different sectors have also ratified the values. Consequently, the validity of the results is more consistent.

For further research, it should be considered to carry out a study, which considers the point of view of receivers, as in this thesis it has not been possible to contact some receiver's companies in Sweden. Retailers would also get potential benefits of higher reliabilities as they could also get strong efficiency improvements in several stages of supply chain and these benefits could increase the values of reliability obtained. In addition, more companies from some sectors could be surveyed to get more significant results, and also it could be used a more powerful statistical software to make a deeper analysis of the information extracted from the surveys.

Individually, this project has allowed us to go in depth in a very important subject of goods transportation and logistics, as it is the travel time and travel time reliability. A strong knowledge has been acquired throughout the course of the thesis, which will be useful for future experiences.

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APPENDIX

Appendix I – Time travel reliability survey

Hej! We are two students of Chalmers University of Technology doing our Master Thesis about travel time reliability. We would appreciate it if you could dedicate 5 minutes to answer this questionnaire.

We would like you to behave in the same way that if it was in real life and you had to choose between the following options. Think what would be the best option for the company.

1) What type of truck do you use for the shipment?
   - □ Car in commercial traffic
   - □ Lorry without trailer 3 ton
   - □ Lorry LGV 14 ton
   - □ Lorry LGV 24 ton
   - □ Lorry HGV 40 ton
   - □ Lorry HGV 60 ton
   - □ Lorry HGV 74 ton

2) What type of product are you delivering or being delivered?
   - □ Raw materials and unperishable goods
   - □ Perishable goods
   - □ Machinery

Choice set

Imagine you have to choose one of the next options to ship your goods:

3) Choice set 1/8

OPTION A	
TRAVEL COST:	424 SEK
MEAN TRAVEL TIME:	40 MIN
VARIABILITY 20%	
50 MIN	
31 MIN	
37 MIN	
45 MIN	
47 MIN	

OPTION B	
TRAVEL COST:	318 SEK
MEAN TRAVEL TIME:	50 MIN
VARIABILITY 10%	
48 MIN	
44 MIN	
48 MIN	
56 MIN	
56 MIN	

4) Choice set 2/8

	OPTION A	OPTION B
TRAVEL COST:	212 SEK	318 SEK
MEAN TRAVEL TIME:	75 MIN	50 MIN
	VARIABILITY 40%	VARIABILITY 50%
	101 MIN	80 MIN
	50 MIN	81 MIN
	113 MIN	49 MIN
	54 MIN	34 MIN
	84 MIN	33 MIN

5) Choice set 3/8

	OPTION A	OPTION B
TRAVEL COST:	424 SEK	212 SEK
MEAN TRAVEL TIME:	40 MIN	75 MIN
	VARIABILITY 40%	VARIABILITY 20%
	27 MIN	89 MIN
	61 MIN	69 MIN
	29 MIN	62 MIN
	46 MIN	103 MIN
	51 MIN	76 MIN

6) Choice set 4/8

	OPTION A	OPTION B
TRAVEL COST:	318 SEK	212 SEK
MEAN TRAVEL TIME:	60 MIN	40 MIN
	VARIABILITY 40%	VARIABILITY 50%
	37 MIN	33 MIN
	52 MIN	42 MIN
	90 MIN	19 MIN
	63 MIN	66 MIN
	80 MIN	60 MIN

7) Choice set 5/8

	OPTION A	OPTION B
TRAVEL COST:	424 SEK	318 SEK
MEAN TRAVEL TIME:	50 MIN	40 MIN
	VARIABILITY 10%	VARIABILITY 50%
	48 MIN	33 MIN
	44 MIN	42 MIN
	48 MIN	19 MIN
	56 MIN	66 MIN
	56 MIN	60 MIN

8) Choice set 6/8

OPTION A	
TRAVEL COST:	318 SEK
MEAN TRAVEL TIME:	60 MIN
VARIABILITY 10%	
58 MIN	
66 MIN	
54 MIN	
64 MIN	
55 MIN	

OPTION B	
TRAVEL COST:	212 SEK
MEAN TRAVEL TIME:	50 MIN
VARIABILITY 40%	
82 MIN	
53 MIN	
32 MIN	
33 MIN	
66 MIN	

9) Choice set 7/8

OPTION A	
TRAVEL COST:	318 SEK
MEAN TRAVEL TIME:	75 MIN
VARIABILITY 10%	
86 MIN	
75 MIN	
84 MIN	
76 MIN	
68 MIN	

OPTION B	
TRAVEL COST:	212 SEK
MEAN TRAVEL TIME:	60 MIN
VARIABILITY 20%	
52 MIN	
49 MIN	
75 MIN	
55 MIN	
75 MIN	

10) Choice set 8/8

OPTION A	
TRAVEL COST:	318 SEK
MEAN TRAVEL TIME:	40 MIN
VARIABILITY 20%	
50 MIN	
31 MIN	
37 MIN	
45 MIN	
47 MIN	

OPTION B	
TRAVEL COST:	212 SEK
MEAN TRAVEL TIME:	60 MIN
VARIABILITY 50%	
116 MIN	
36 MIN	
86 MIN	
60 MIN	
44 MIN	

Attributes weight

11) Please assign the weight percentage you have used in the choice sets for each attribute (all 3 weights must value 100%).
   - Cost: ………..
   - Travel time mean: ………..
   - Variability: ………..

Background

12) Which of the following concepts fits better with your idea of travel time reliability in freight transport?
   - □ Percentage of on-time deliveries
   - □ Average time of delays
   - □ Range within the 98th (or 95th) percentile of arrival times
   - □ Standard deviation of arrival times distribution

13) What part of the supply chain are you involved in?

□ Shipper

□ Carrier

□ Retailer

□ Other: …….

14) What industry your business is in?

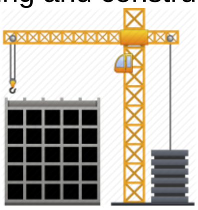
□ Automotive

□ Commercial services

□ Food and beverages

□ Textile

□ Building and construction



□ Electronics

- ◻ Manufacturing

- ◻ Pharmaceutical and healthcare

- ◻ Transport and storage

- ◻ Other: …….

Thank you for your time!

Appendix II – Interview

Interview shipper

Travel time variability cause uncertainty in companies involved in the supply chain, generating extra costs. Our thesis focus on understanding the concept of reliability and getting the value of reliability for road freight transport. We need your help answering the following questions to get the approach of the companies:

Introduction

1) Name: ……….

   Position in the company: ………………………………………………………………………………………………..

   Years working for the company: ………………………………………………………………………………………..

2) Please tell us what industry your business is in by checking one box:

   □ Automotive □ Building and construction

   □ Commercial services □ Electronics

   □ Food and beverage □ Manufacturing

   □ Pharmaceutical and healthcare □ Textile

   □ Transport and storage

   □ Other. Please specify: ……………………………..

3) Please list 3 top commodities that you typically ship with truck movements involved:

   Commodity 1: ……..

   Commodity 2: ……..

   Commodity 3: ……..

4) What is approximately the size of the shipments per customer?

   □ 0 - 3 tons □ 3 - 14 tons □ 14 - 24 tons □ 24 - 40 tons □ +40 tons

5) Please indicate the geographies that you serve by checking the applicable boxes:

   □ Serve urban locations □ Serve suburban locations

   □ Truck movements involve border crossings □ Serve rural locations

6) Please indicate who is in charge of the transport:

   □ Own transport fleet

   □ Third party logistics

      □ Postnord

      □ Schenker

□ DHL

□ Other. Please specify: ………………………

7) How many shipments are leaving your distribution centre every day?

□ 1 - 5 □ 6 - 20 □ 21 - 50 □ + 50

8) Which of the following concepts fits better with your idea of travel time reliability in freight transport? Please choose one option.

□ Percentage of on-time deliveries

□ Average time of delays

□ Range within the 98^{th} (or 95^{th}) percentile of arrival times

□ Travel time distribution and standard deviation

□ Other. Please specify: ……………

Deliveries information

1) Who is fixing time delivery requirements?

□ You as a shipper

□ Carrier

□ Receiver

1.1. How do you plan a journey's departure time?
1.2. Is it part of the contract agreement with logistics services provider or is it an informal agreement?

□ Yes □ No

2) How are time delivery requirements defined?

□ Consistent delivery between certain hours on a given day (e.g., 2-4 pm daily)

□ Consistent delivery within a stipulated delivery appointment

□ Consistent delivery on a specified day

□ Consistent delivery within a multi-day delivery window

□ Delivery requirements not specified

□ Other. Please specify ………………………

3) What percentage of delays does the company have?

□ 0 - 5% □ 6 - 10% □ 11 - 20% □ + 20%

4) Who is responsible for delays?

Carrier: %

Shipper: %

5) Do you stipulate penalties for missing the specified delivery requirements to your transport company?

□ Yes □ No

6) Do your customers stipulate penalties for missing the specified delivery requirements?

□ Yes □ No

7) What measures does the company take to assure that deliveries arrive on time?

Project evaluation

1) Do you think it would be useful to get access to the bus lane in ring roads? What would be the benefit?

2) How much would you be willing to pay for getting access to the bus lane in ring roads?

3) Do you see any inconveniences or do you propose any improvement?

Additional questions if shipper has own transport fleet

1) Considering that a journey is the route comprised since the truck leaves the distribution centre until it arrives here again, what is the average travel distance of journeys?

□ 0 - 30 km □ 30 - 100 km □ 101 - 300 km □ + 300 km

2) Describe your company's transport fleet:

2.1 Property:
□ Own □ Leased

2.2 Type of vehicles:
□ Light trucks □ Medium trucks □ Heavy trucks

3) How do you plan how long the journey will last?

4) Please rate these variables as a source of travel time variability (being 1 least significant and 5 most significant)?

	1	2	3	4	5
Vehicle breakdowns					
Weather					
Drivers unable to find locations					
Delays at loading / outbound facility					
Consistent travel times for road freight moves					
Availability of real-time traffic information					
Accidents					
Road works					
Paperwork and language barriers at receiving facilities					

Thank you. Let us know and provide your contact information if you want a copy of the report when it is completed or if we can contact you for additional information.

Interview carrier

Travel time variability cause uncertainty in companies involved in the supply chain, generating extra costs. Our thesis focus on understanding the concept of reliability and getting the value of reliability for road freight transport. We need your help answering the following questions to get the approach of the companies:

Introduction

1) Name: ………………………………………………………………………………………………………..........

Position in the company: ………………………………………………………………………………………….

Years working for the company: ……………………………………………………………………………….

2) Please tell us about the businesses that you serve (select all that apply):

□ Automotive □ Building and construction

□ Commercial services □ Electronics

□ Food and beverage □ Manufacturing

□ Pharmaceutical and healthcare □ Textile

□ Transport and storage

□ Other. Please specify: …………………………….

3) Please list 3 top typical payload per truck movement:

Commodity 1: …….

Commodity 2: …….

Commodity 3: …….

4) What is approximately the size of the shipments per customer?

□ 0 - 3 tons □ 3 - 14 tons □ 14 - 24 tons □ 24 - 40 tons □ +40 tons

5) Please indicate the geographies that you serve by checking the applicable boxes:

□ Serve urban locations □ Serve suburban locations

□ Truck movements involve border crossings □ Serve rural locations

6) Considering that a journey is the route comprised since the truck leaves the distribution centre until it arrives here again, how many journeys does the company make every day?

□ 1 - 5 □ 6 - 20 □ 21 - 50 □ + 50

7) What is the average travel distance of journeys?

□ 0 - 30 km □ 30 - 100 km □ 101 - 300 km □ + 300 km

8) Describe your company's transport fleet:

8.1 Property:

□ Own □ Leased

8.2 Type of vehicles:

□ Light trucks □ Medium trucks □ Heavy trucks

9) Which of the following concepts fits better with your idea of travel time reliability in freight transport? Please choose one option.

□ Percentage of on-time deliveries

□ Average time of delays

□ Range within the 98th (or 95th) percentile of arrival times

□ Travel time distribution and standard deviation

□ Other. Please specify: ……………

Deliveries information

1) Who is fixing time delivery requirements?

□ Customer □ Carrier □ Shipper

1.1. Is it part of the contract agreement or is it an informal agreement?

□ Yes □ No

2) How are time delivery requirements for on-time truck performance defined?

□ Consistent delivery between certain hours on a given day (e.g., 2-4 pm daily)

□ Consistent delivery within a stipulated delivery appointment

□ Consistent delivery on a specified day

□ Consistent delivery within a multi-day delivery window

□ Delivery requirements not specified

□ Other. Please specify: ………………………

3) How do you plan how long the journey will last?

4) Please rate these variables as a source of travel time variability (being 1 least significant and 5 most significant)?

	1	2	3	4	5
Vehicle breakdowns					
Weather					
Drivers unable to find locations					
Delays at loading / outbound facility					
Consistent travel times for road freight moves					
Availability of real-time traffic information					
Accidents					
Road works					
Paperwork and language barriers at receiving facilities					

5) How do you plan a journey's departure time?

6) What percentage of delays does the company have?

□ 0 - 5%　　□ 6 - 10%　　□ 11 - 20%　　□ + 20%

7) When do inconsistent travel times reach a point where the situation triggers an operational response (select one):

□ Under 1 hour additional travel time per day

□ 1 to 2 hours additional travel time per day

□ 3 to 4 hours additional travel time per day

□ More than 4 hours additional travel time per day

8) Do your customers stipulate penalties for missing the specified delivery requirements?

□ Yes　　□ No

9) Please briefly describe operational responses that you use to respond to congestion/unpredictable travel times (check all that apply):

□ Route re-planning　　□ Stop serving route

□ Using tolled routes　　□ Add more trucks to route

□ Use of driver teams　　□ Use an alternative mode (e.g., rail)

□ Other. Please describe: ………………..

Project evaluation

1) Do you think it would be useful to get access to the bus lane in ring roads? What would be the benefit?

2) How much would you be willing to pay for getting access to the bus lane in ring roads?

3) Do you see any inconveniences or do you propose any improvement?

Thank you. Let us know and provide your contact information if you want a copy of the report when it is completed or if we can contact you for additional information.

Interview retailer

Travel time variability cause uncertainty in companies involved in the supply chain, generating extra costs. Our thesis focus on understanding the concept of reliability and getting the value of reliability for road freight transport. We need your help answering the following questions to get the approach of the companies:

Introduction

1) Name: …….......

   Position in the company: ………………………………………………………………………………………………

   Years working for the company: ………………………………………………………………………………………

2) Please tell us about the businesses that you serve (select all that apply):

   □ Automotive
   □ Building and construction
   □ Commercial services
   □ Electronics
   □ Food and beverage
   □ Manufacturing
   □ Pharmaceutical and healthcare
   □ Textile
   □ Transport and storage
   □ Other. Please specify: …………………………….

3) Please list 3 top commodities that you typically receive with truck movements involved:

   Commodity 1: …….

   Commodity 2: …….

   Commodity 3: …….

4) What is approximately the size of the shipments?

   □ 0 - 3 tons □ 3 - 14 tons □ 14 - 24 tons □ 24 - 40 tons □ +40 tons

5) Please indicate the geographies where you are served by checking the applicable boxes:

   □ Served in urban locations
   □ Served in suburban locations
   □ Served in rural locations

6) How many shipments do you receive every day?

   □ 1 - 5 □ 6 - 20 □ 21 - 50 □ + 50

7) Which of the following concepts is it more important for you to consider a shipper/carrier reliable?

□ Percentage of on-time deliveries

□ Average time of delays

□ Accurate tracking

□ Other. Please specify: ……………

Deliveries information

1) Who is fixing time delivery requirements?

□ You as a receiver □ Carrier □ Shipper

1.1. Is it part of the contract agreement with logistics services provider or is it an informal agreement?

□ Yes □ No

2) How are time delivery requirements for on-time truck performance defined?

□ Consistent delivery between certain hours on a given day (e.g., 2-4 pm daily)

□ Consistent delivery within a stipulated delivery appointment

□ Consistent delivery on a specified day

□ Consistent delivery within a multi-day delivery window

□ Delivery requirements not specified

□ Other. Please specify: ………………………

3) What percentage of deliveries that you receive are delayed?

□ 0 - 5% □ 6 - 10% □ 11 - 20% □ + 20%

4) How a delay affects the company's supply chain in short term?

5) How a delay affects the company's supply chain in medium/long term?

□ Hire more workers

□ Decrease in level service

□ Difficulties to control inventory level

□ Others. Please specify: ……………

6) What short-term measures do you apply just in case there is a delayed delivery?

□ Safety stock

□ Safety margin in arrival times

□ Stipulate penalties to the carrier or shipper

□ Others. Please specify: ……………

7) What permanent measures do you apply just in case there are recurrent delayed deliveries?

□ Stipulate higher penalties to the carrier or shipper

□ Ordering the goods earlier

□ Forecast the arrivals with a pattern

□ Safety stock planning

□ Safety margin in arrival times

□ Stop working with the shipper and find another one better

□ Stop working with the carrier and find another one better

□ Others. Please specify:…………………….

8) Do you stipulate penalties for missing the specified time delivery requirements?

□ Yes □ No

Project evaluation

1) Do you think it would be useful to get access to the bus lane in ring roads (for carriers)?

2) Would you be willing to pay for getting more reliability?

3) Do you see any inconveniences or do you propose any improvement?

Thank you. Let us know and provide your contact information if you want a copy of the report when it is completed or if we can contact you for additional information.