Calculation of Transport Cost for Freight Carriers on the Last Mile

Conducting a Case Study in the Municipality of Delft to Validate and Improve Usage of the Last-Mile Scan Calculation Model

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Yours sincerely,
Glenn Schonewille
EXECUTIVE SUMMARY

Urban freight distribution problems vary in nature and can be characterized as economically, environmentally or socially grounded. Urban freight distribution operates in urban areas where space is in short supply. These residency areas are the homes of many people. Since most vehicles still drive on conventional energy sources, greenhouse gas emission is a big problem in cities. Safety and noise issues regarding old vehicles operating in urban areas also have a negative impact on liveability of cities. The social need to sustain urban freight distribution and to develop and improve the urban freight distribution system in high-density urban areas is large. The concept of sustainable developments can be divided in three principles, which include economic growth, social equity and environmental protection.

The context of urban freight distribution is rather complex. This complexity is created by the multi-actor context of urban freight distribution and the fact that stakeholders do not always carry (social) cost and benefits both. Cargo owners and distributors are at the centre of the system and possess a high degree of power to influence the UFD system and therefore cannot be left out of the process. Overall, they have a neutral attitude towards sustaining urban freight distribution (which is the main goal of the problem owner, the municipality of Delft). Their attitude is neutral since they cannot earn money directly in operating in a sustainable manner. This makes it difficult to implement solutions, create sense of urgency to activate involved stakeholders to make a change.

‘Maatwerk Distributie’ (MD) has developed a Last Mile Scan (LMS). This is a calculation model that is developed to calculate and predict cost structures of last mile trips in urban areas. The main purpose of development is to gather information for both the municipality of Delft as well as participants of the LMS, which are freight carriers. The research objective is: to identify the needs of stakeholders involved in the urban freight distribution system of Delft and to conduct a validation study on the LMS calculation model to be able to provide recommendations to the municipality of Delft on how to improve usage and extent lifespan the LMS model in order to sustain UFD in Delft.

This thesis seeks to answer the main research question: How can data and information collected by the LMS be of extended usage to the municipality of Delft to serve the purpose of improving urban freight distribution taking into account all stakeholder interests such as economic inefficiencies, (greenhouse) emissions, noise nuisance, air quality, safety and congestion issues?

The conceptual framework developed by Sargent describes the process of how to get from one entity to another (R. G. Sargent, 2005). This conceptual framework is an approach that could be applied and help in building valid and credible simulation model. This framework is used as guidance in the validation process of the LMS model. In order to ensure the LMS is validated properly the four phases of the validation process of the framework are conducted. These phases are conceptual model validation, operational validation, computerized model verification and data validity. In addition, a sensitivity analysis is conducted. Sensitivity analysis can support validation of a model.

![Figure 1 - Simplified version of the modelling process (Sargent, 2001)](image-url)
The LMS model uses different variables and constants to estimate and give an indication of cost of a specific shipping. The black box and the CRD are conceptual models developed to conduct conceptual model validation. The relations between variables used by the model are logic. Although only the direction of the relation is evaluated at this stage, the LMS model seems to be fairly reasonable, but simplified representation of the real situation.

Total distance of a trip is calculated using an API tool developed by Google. This application ensures a high accuracy of distances since it uses precise coordinates to calculate covered distances. The formula used for calculating distance per stop is plausible because distance per stop can be calculated by multiplying the number of stops times an average distance per stop. Total time is dependent on driving and unloading time. Driving time is dependent on average velocity of a vehicle and total distance covered. The general dimension of velocity is kilometre per hour; velocity = distance / time; time = distance / velocity. This relation is correct. Unloading time is dependent on the amount of small and large packages delivered multiplied by a constant ‘average unloading time’ per package/pallet. Unloading time can be estimated by using a constant average time for unloading small/large packages because every unit takes time to deliver. Total costs are calculated and dependent on total time multiplied by cost per hour and total distance multiplied by cost per kilometre. This is a plausible method. The formulas to calculate distance, time and cost of a last mile trip and relations between variables used to conduct these calculations are plausible.

The benchmark methodology and strict rules that Research Company Panteia practise ensures data collection is done properly and is significantly reliable. Input data on assumptions like velocities of vehicles and cost per minute and kilometre seems correct. Data collected throughout field research is less reliable. It is difficult to state that these assumptions correspond with real world values, because background information on scope of the field research is not available and unknown. Constants are still assumptions and not valid as truth-values.

Operational validity is impossible due to a lack of real data, which makes it impossible to crosscheck output of the LMS model with real data from the field. Freight carriers themselves do not know the cost of the last mile. This validation step cannot be conducted.

In the sensitivity analysis, all output variables are higher in case of scenarios where constants are higher. This means that all hypotheses are correct and that the LMS model gives the expected results in light of sensitivity of changing different assumptions. This argument strengthens validity of the model because, the model generates realistic and logic outputs when varying input variables and constants.

Overall, concluded from the validation process the LMS model is a reasonable representation of the problem entity and conceptualization and computerized model verification phases have been conducted properly. Data validity is not valid (yet) and should be improved on certain assumptions and the scope of the field research that supports these assumptions can be more extensive. Field research methods are basic and the actual size of the research is too small to gather a significant and crucial amount of reliable information and data. Operational validity is impossible due to a lack of real data and lack of knowledge of freight carriers on the exact cost of their last mile trip. Therefore, the LMS model cannot be labelled as valid because not all validation phases are successfully completed.

The majority of trips, around 75%, cover a smaller distance then 10 kilometres. This means that the most last-mile trips do not cover a large distance. The average time of all trips is 100 minutes. This is relatively long since the average distance covered in 100 minutes is only 8,59 kilometres. The cost of all trips is distributed evenly between 0 and 100 euro. The centre of gravity lies between 10 and 35 euro. The average cost of all trips is 36,56 euro. All scatterplots of output variables cost, time and distance show expected relationships and results. The structure of the LMS model is linear based. All formulas between variables used in the LMS model are linear. Outcomes of graphs of the relationships between distance, time and cost show linear featured as well. These types of relationships are in line with expectations and therefore strengthen validity of the LMS model slightly.
Interesting output variables that are not directly calculated by the LMS model yet, but can be created by applying a simple mutation of output variables of the data sample. These mutated variables can be seen as criteria or key performance indicators to see how different freight carriers are performing. KPIs that are explored in this paragraph are cost per unit; cost per minute; cost per kilometre; cost per m³.

The trend line of total cost of PostNL is a significant steeper linear relationship as the trend line of total cost LMS. This implies that as shipping load increases (packages + pallets) alternative shipping method PostNL is more expensive in comparison to a shipment conducted by a freight carrier internal. The intersection is interesting and lies at a shipping load of 5 units (packages + pallets). In the majority of cases (data points) a shipping load of 5 or smaller (relatively smaller shipments) are cheaper to be shipped by an alternative shipping method (PostNL). In majority of cases, larger loading ratios (relatively larger shipments) benefit to be executed by a freight carrier internally.

Distributors can be classified based on all parameters in the LMS model or parameters not yet present but easily created by a simple mutation. The possibilities are endless since all attributes and KPI’s can be used as inputs and/or evaluation fields both. The right setting for the municipality is probably a combination of economic and environmental parameters. A conclusion drawn from the cluster analysis is that clusters with a large shipping load score well on environmental aspects (defined environmental key performance indicators). In addition, these groups of carriers also score well on economic aspects (defined specific economic key performance indicators) concluded from the cluster analysis on economic aspects. This strengthens the conclusion that smaller shipments perform less good in general (both in economic and environmental terms) and can better use an alternative shipping method. The practical usability of the cluster analysis is three-folded. The analysis gathers detailed knowledge on available data derived by the LMS model. This information can be used to develop custom policy for specific freight carriers that are performing undersize. The results can contribute in mediating cooperation between involved freight carriers because cluster analysis provides them with specific knowledge on their performance on economic and environmental indicators.

The main goal of the municipality of Delft is to increase awareness among distributors and to mediate between (smaller) freight carriers and a larger and cleaner central distributor. This approach can contribute in achieving a sustainable urban freight distribution system. The focus of the LMS model is too narrow, since it addresses one group of stakeholders only. The rate of success or the potential improvement that can be achieved by cooperating is relatively low since other stakeholders do not see the benefit of the LMS model.

Distributors think in means of an entire supply chain from origin towards destination. This perspective is geographically larger and can have one or more last-mile regions in it. The LMS calculation model has a last-mile perspective. Another shortcoming was data availability during the development phase. Development of the LMS without accurate data or field research with a significant level of detail or size is difficult and can result in a too simplified model. During development, arbitrary decisions on assumptions and how to structure the LMS model had to be made. These decisions have not always resulted in finding the right level of accuracy of output variables. The deterministic nature of the model can be seen as a shortcoming of the model. In a real world, every trip differs from another. Another debatable characteristic is the linearity of the model. The model does not take into account the theory of economies of scale. Shipments above a certain amount are therefore biased.

The first recommendation is that data availability and the amount of data collected can be increased significantly by making it compulsory for freight carriers to participate in the LMS. This can be done to introduce a system that freight carriers need to have a certificate to operate in the urban area of Delft. All stakeholders receive a certificate if they provide the municipality with information by participating and filling out the last mile scan. The LMS model should be improved and extended on the following aspects: improve the usability of the LMS, include stochastic inputs (further research is needed), include environmental aspects, extent output variables (KPIs) with specific defined cost
parameters, extent output variables with total cost of an alternative shipping method and include benchmark results.

The usability of the LMS is an important factor that ensures collected data is gathered more. The interface needs to be user friendly and attractive to increase the amount of freight carriers completing the scan. The interface should be improved significantly. This can be realized by development of an application that can be used on smartphones and simultaneously develop a new website. This can result in higher degree of usability and an increased benefit to freight carriers.

The deterministic nature of the model can be upgraded by using stochastic input variables instead of deterministic set values in order to move towards a better representation of reality. This can be reached by replacing assumptions and constants into stochastic input variables. Future research needs to be conducted to explore stochastic distributions of used assumptions from the LMS model.

Applying footprints to carriers by including environmental aspects. This provides the municipality of Delft with information on performance of individual freight carriers on aspects other than economical. Information on vehicle types should be extended by year of built since this is an important factor that is needed to estimate environmental performance. Footprints should be created as output variables in the LMS model. These footprints are exhaust per stop and exhaust per unit. General total emission parameters that needs to be included are: CO, NOx, NO2, PM10 and PM2.5.

Finally, the outcome of the LMS model needs to be extended significantly by including more detailed key performance indicators. Conducting a few simple mutations can compute specific cost KPIs. This information is crucial for both freight carriers as the municipality of Delft since total cost, time and distance does not give them enough insight on level of performance. Specific cost output variables are cost per minute, cost per unite, cost per kilometre and cost per cubic.

The alternative shipping method (conducted by PostNL) should be defined as output variable. The cost of this alternative needs to be visible to freight carriers so they can compare outcome of the LMS model (estimation cost of last mile trip) with an alternative shipping method directly to create a sense of urgency. Finally, all these KPIs should be compared using a benchmark methodology to provide freight carriers not only with information on individual performance but also give them knowledge on performance relatively to similar freight carriers. All changes are implemented in the improved and extended LMS model are presented below.

![Figure 2 - Conceptual framework renewed LMS model](image-url)
### List of Abbreviations

<table>
<thead>
<tr>
<th>AT</th>
<th>Additional Transfer</th>
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<tr>
<td>API</td>
<td>Application Programming Interface</td>
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<tr>
<td>BC</td>
<td>Behaviour of Carriers</td>
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<tr>
<td>BCI</td>
<td>Buck Consultants International</td>
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<tr>
<td>BRS</td>
<td>Behaviour of retailers and/or shippers</td>
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<td>BSS</td>
<td>Binnenstadservice.nl</td>
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<td>CBA</td>
<td>Cost Benefit Analysis</td>
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<td>CD</td>
<td>Common Delivery</td>
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<td>CRD</td>
<td>Causal Relation Diagram</td>
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<td>CE</td>
<td>Circulation Economy</td>
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<tr>
<td>DC</td>
<td>Distribution Centre</td>
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<tr>
<td>EVO</td>
<td>Ondernemersorganisatie voor Logistiek en Transport</td>
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<td>GNP</td>
<td>Gross National Product</td>
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<td>FTL</td>
<td>Full Truck Load</td>
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<td>JIT</td>
<td>Just In Time</td>
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<td>LM</td>
<td>Last Mile</td>
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<td>LML</td>
<td>Last Mile Logistics</td>
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<td>LMS</td>
<td>Last-Mile Scan</td>
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<tr>
<td>LSI</td>
<td>Logistics Service Intermediary</td>
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<tr>
<td>LSP</td>
<td>Logistics Service Provider</td>
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<tr>
<td>LTL</td>
<td>Less than Truck Load</td>
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<tr>
<td>MolatE</td>
<td>Ministry of Infrastructure and the Environment</td>
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<td>MM</td>
<td>Material management</td>
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<tr>
<td>MAS</td>
<td>Multi-actor system</td>
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<td>MD</td>
<td>Maatwerk Distributie</td>
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<td>PD</td>
<td>Physical Distribution</td>
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<tr>
<td>PMV</td>
<td>Programmed Model Verification</td>
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<td>PPP</td>
<td>Public-Private Partnerships</td>
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<td>RO</td>
<td>Research Objective</td>
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<td>RQ</td>
<td>Research Question</td>
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<td>SA</td>
<td>Sensitivity Analysis</td>
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<td>SCBA</td>
<td>Social Cost and Benefit Analysis</td>
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<tr>
<td>SLR</td>
<td>Structured Literature Review</td>
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<tr>
<td>SQ</td>
<td>Sub Question</td>
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<tr>
<td>SUFT</td>
<td>Sustainable Urban Freight Transport</td>
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<td>TPL</td>
<td>Third Party Logistics</td>
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<tr>
<td>TLR</td>
<td>Traditional Literature Review</td>
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<tr>
<td>TLN</td>
<td>Transport en Logistiek Nederland</td>
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<tr>
<td>RSLR</td>
<td>Rapid Structure Literature Review</td>
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<tr>
<td>UCC</td>
<td>Urban Consolidation Centre</td>
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<tr>
<td>UFD</td>
<td>Urban Freight Distribution</td>
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<td>UFDS</td>
<td>Urban Freight Distribution System</td>
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<tr>
<td>TPM</td>
<td>Technology, Policy and Management</td>
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<tr>
<td>TU</td>
<td>Technical University</td>
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<td>TUD</td>
<td>Technical University Delft</td>
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1. CHAPTER 1  INTRODUCTION

1.1. Background

In the field of urban freight distribution there is a lot of on-going research in the last few decades. In every corner scientist, environmentalists, government bodies, inhabitants, (logistic) companies start to sense the urgency that something has to change regarding the way actors deal with urban freight distribution issues. In the Netherlands, this awareness resulted in several initiatives whereby environmental and economic aspects are intertwined to develop sustainable solutions and improve cooperation between stakeholders in the field of urban freight distribution.

The main developments and trends that have been going on in the last century need to be closer studied to provide insight on issues in the field of urban freight distribution (UFD). The main trends that have the biggest influence on how urban freight distribution is organized are worldwide population growth, urbanization of cities and the flourishing e-commerce sector. Next to these main trends there are some interesting developments such as the circulation economy, dynamic inventory management concepts (JIT) and smart cities.

Worldwide population is growing rapidly the last centuries. In 2004 the world population was 6.41 billion persons. In 2012 the total population grew to 7.05 billion persons. This is an enormous growth of 1.2% per year (The World Bank, 2013).

The last decades there is a worldwide trend of urbanization. From 1960 until 1995 upper middle-income range countries become almost fully urbanized. Nowadays, between 60-90% of the total world population is living in cities (Henderson, 2003). Consequently, cities are overcrowded and space is lacking and will even get scarcer.

Various researchers have sought to understand factors that affect e-commerce or e-business. Based on the current state of this research, only little is known about the aggregate level of national economies relatively to business to consumer e-commerce growth (Ho, Kauffman, & Liang, 2007). Kauffmann et al. 2007 explored aggregate-level drivers of e-commerce growth across countries. One of the most important drivers and good indicator to e-commerce growth is the number of Internet users in a country. This amount is worldwide growing on average between 11 and 28 percentage over the years, 2000, 2001 and 2002 (Ho et al., 2007).

Additionally, to these main trends that directly influence the size and way urban freight distribution is shaped a number of innovative concepts emerged recently. Further elaboration on innovative concepts is conducted in paragraph 2.1.2.
1.2. Problem definition

In this section problems regarding urban freight distribution are briefly introduced and explained. Factors that underlie these problems on different aspects are explored. Furthermore, the multi-actor system (MAS) of UFD and the last-mile is introduced. Finally, a brief introduction on the last-mile scan (LMS) is given.

Urban freight distribution is the delivery of freight in an urban area. From a supply-chain perspective it is the last section of the chain, in literature better known as the last mile. The final section of the supply chain is rather inefficient in economic, environmental and social terms. At the core of these inefficiencies underlining factors play an essential role. Meant by economic inefficiencies is the inefficient last-mile. Environmental terms are factors such as; air quality, noise nuisance and greenhouse and other emissions. Meant by social terms are; safety issues, congestion, liveability of cities and so on (Anderson, Allen, & Browne, 2005).

Furthermore, the context of urban freight distribution is complex due to the multi-actor context, all with their own needs and interests. This multi-actor environment increases complexity and complicates the search for compatible solutions. The challenge is to explore and find common ground where shared problems can be identified and solutions can be developed in conjunction. Before this can be challenged stakeholders need to communicate, cooperate and share information. Multi-actor theory developed by Prof. dr. J.A. de Bruijn and Prof. dr. E.F. ten Heuvelhof is discussed in chapter 3.

In the Netherlands urban freight distribution is a present subject. A number of innovative concepts regarding city logistics have been developed and tested in different regions across the country. An example of a promising concept is called ‘Binnenstadservice’ active in Nijmegen. After subsidizing was cut they continued their operations. Although they never reached the intended scale they continued on a reasonable (smaller) scale and are now just one of the many concepts a like (Coremans, 2015). Other regions and cities in the Netherlands like the city of Delft are showing a progressive attitude towards city logistics. This year the municipality of Delft and PostNL collaborated and launched a new concept called ‘Stadslogistiek Delft’ (city logistics Delft). This initiative is aiming to enhance the logistic services in the region of Delft to improve the liveability of the city. The concepts described all aim to consolidate flows of goods at the border of a city and distribute them in (smaller) electric vehicles into the city.

Furthermore, the municipality of Delft invested in a project called ‘Maatwerk Distributie’ (MD). MD is created to develop a calculation model called the ‘Last-Mile Scan’ (LMS), to calculate and predict monetary cost for freight carriers on the last mile. This model provides information on cost and potential cost reduction for every individual freight carrier (Maatwerk Distributie, n.d.). This model could significantly improve transparency among stakeholders and provide them of (still unknown) information on cost structures of the last mile. The deterministic calculation model can potentially build a bridge that would bring stakeholders together to realize full collaboration potential.

The LMS has not been analysed properly yet. There is a need that the model is systematically analysed and validated. The LMS has shortcomings on different aspects that need to be identified and improved. Furthermore, the LMS could be extended on different potential areas by including environmental aspects such as emissions ratios. In addition, the applicability of the calculation model could be analysed and possibly improved. Additionally, valuable data derived from the LMS could be used to explore relationships between cost of UFD and commercial tariffs. Data could also be used to identify and classify distributors in categories based on chosen KPIs.
The problem definition of the problem owner ‘municipality of Delft’ (Coremans, 2015)(Brandligt, 2014):

"Due to the expected growth of urban freight in the urban area of Delft and the social and environmental burden of UFD on the region, the municipality has developed a calculation model, the LMS, to gather data to increase knowledge regarding UFD. Knowledge on the performance and functioning of the LMS is still insufficient, as well as insight into the types of distributors that are active in the urban area. The Last Mile Scan could contribute in improving participation and cooperation among stakeholders involved, which is crucial to improve proper functioning of the entire UFD system."

1.3. Scope of the Research

1.3.1. Geographic Scope

The geographic scope of this thesis focuses on the Netherlands and more specific the region of Haaglanden. This region can be best described is a conglomerate of the cities Delft, Rijswijk, Leidschendam-Voorburg, Pijnacker-Nootdorp, Den Haag and Leiden. The reason for this scope is mainly determined by the focus of the workgroup ‘Maatwerk Distributie’ during the development of the calculation model, the Last-Mile Scan (LMS). Conclusions drawn from this thesis cannot be generalized directly though some suggestions can point to certain directions and can provide knowledge that applies for other urban areas.

1.3.2. Perspective from a Supply Chain View

The focus chosen from a supply chain perspective needs to be elaborated closer. The general supply chain perspective that holds for most transportation companies see their operations from the warehouse to final deliveries. Focus of this thesis is delineated further and concentrates on the final section of the supply chain that is known in scientific literature as city logistics, urban freight distribution or the last-mile.

The reason for this focus is two folded. Primarily, this section of the supply chain is the least efficient in economic terms. Furthermore, the last mile has a huge burden for both the environment and from a societal point of view. Improving the system has potentially the largest impact on as many stakeholders involved. Secondly, the research field and study casus of this thesis is the LMS calculation model. This model calculates and tries to monetize and provide insight on cost structures of distribution companies active in urban areas in the conglomerate of Haaglanden, more specific urban areas (cities) in this region.

1.3.3. Type of Goods Flows Scope

This study will focus on flows of goods in urban areas as mentioned in the previous paragraph. In these high-density areas different types of freight flows can be distinguished. The general method of distinction that is applied in this thesis is derived from the work of van Binsbergen and Visser, 2001. Urban freight flows can be characterized by nature of goods (consumer goods, mail, parcels, express delivery, building materials and waste), means of transport (road), size of shipments (relatively small) and number of stops (relatively many) (Van Binsbergen & Visser, 2001). This thesis does not focus on building materials and waste since consolidation of these flows of goods can be rather difficult due to their bulky characteristics. Focus is on consumer goods that have multiple destinations as shops, supermarkets, offices, HoReCa, hospitality industry and homes.

1.3.4. Sustainability Perspective

Finally, elaboration on the chosen sustainability perspective needs to be explained. Meant by this perspective is taking into account economic efficiency but at the same time environmental and societal objectives. The reason for choosing this starting point is tree folded. Firstly, the problem owner and client of this research is the municipality of Delft. The highest goal of this regional government body is to increase the liveability of their citizens (see also Appendix B). Their objective is
how they can reach the largest societal potential value for their residents. This value is best reached by choosing a sustainable approach. Secondly, the increased interest from theory (scientific research) and practice in moving towards consolidation of urban freight distribution reflects the urgency to further sustain urban freight distribution systems. Finally, the general tendency of sustainable processes and systems worldwide in combination with trends that are driving demand of urban freight distribution to higher levels result in the necessity of solving urban freight distribution problems from a sustainable perspective.

1.4. Research objective

In this section the research objective is introduced. The objective is derived from the problem definition. The objective that is formulated is three folded. Focus of the first section is on the context demands and needs of involved stakeholders in urban freight distribution. Second part of de objective is focused on conducting a validation study on the LMS and on identification of shortcomings, improvements and extensions of the LMS. These results are used in the final part in order to sketch an ideal LMS model and to advice the municipality on how to improve usage and results.

Based on the problem statement the following general research objective is formulated:

**RO**

To identify the needs of stakeholders involved in the urban freight distribution system of Delft and to conduct a validation study on the LMS calculation model to be able to provide recommendations to the municipality of Delft on how to improve usage and extent lifespan the LMS model in order to sustain UFD in Delft.

The general research objective can be broken into small logical parts to form specific objectives. The specific objectives tell what is researched and for what purpose.

**RO 1.1**

To explore the UFD context to identify needs of stakeholders involved, to assess cost and benefits of the urban freight distribution system and to define key performance indicators.

**RO 1.2**

To conduct a validation study to analyse the credibility of the LMS and to conduct data and cluster analyses to improve usage of the LMS model.

**RO 1.3**

To identify possible shortcomings, potential improvements and logical extensions of the LMS and formulate how the ideal LMS model should look.

The goal of the final objective is how the municipality of Delft can understand and solve urban freight distribution problems by improving usage of collected data. In addition, the ideal LMS model can extent the lifespan of the scan. The general research objective led to the main research question, which is treated in paragraph 1.5.
1.5. Research question

Based on the research objectives of previous paragraph the main research question is formulated. The main research question is answered by answering a set of sub-question presented in the second section of this paragraph.

Main Research Question (RQ)

*How can data and information collected by the LMS be of extended usage to the municipality of Delft to serve the purpose of improving urban freight distribution taking into account all stakeholder interests such as economic inefficiencies, (greenhouse) emissions, noise nuisance, air quality, safety and congestion issues?*

To answer the main question a number of sub questions have been formulated. The sub questions have been split up in three phases. The first phase focuses on scientific literature to analyse the urban freight distribution context and conducting an actor analysis to map all stakeholders involved. Research objective 1.1 is treated in phase I.

**Phase I**

**Theoretical framework**

<table>
<thead>
<tr>
<th>Chapter 2</th>
<th>Exploring the context of urban freight distribution</th>
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<tbody>
<tr>
<td>(SQ I-1)</td>
<td><em>What is the context of urban freight distribution and what problems and solutions are relevant?</em></td>
</tr>
<tr>
<td>Chapter 3</td>
<td>Multi-Actor Context</td>
</tr>
<tr>
<td>(SQ I-2)</td>
<td><em>What stakeholders are involved in urban freight distribution systems?</em></td>
</tr>
</tbody>
</table>

Phase II elaborates on the LMS to identify shortcomings of the model by conducting an extensive validation process. Furthermore, potential improvements and possible extensions are explored. Functionalities of the LMS with regard to needs of the UFD context, derived from actor analysis, are evaluated. Finally, this phase is concluded by analysing data collected by Maatwerk Distributie to explore interesting relations between output variables and to analyse performance of clusters (a cluster is a group of freight carriers with similar characteristics).

**Phase II**

**Validation of the Last-Mile Scan**

<table>
<thead>
<tr>
<th>Chapter 4</th>
<th>Validation process of the LMS</th>
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<tbody>
<tr>
<td>(SQ II-1)</td>
<td><em>Is the LMS a valid model?</em></td>
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<tr>
<td>Chapter 5</td>
<td>Data analysis</td>
</tr>
<tr>
<td>(SQ II-2)</td>
<td><em>How is data collected and in what conclusions can be drawn from the data sample?</em></td>
</tr>
<tr>
<td>Chapter 6</td>
<td>Cluster analysis</td>
</tr>
<tr>
<td>(SQ II-3)</td>
<td><em>How can a cluster analysis be conducted to see performance levels of different types of freight carriers on formulated key performance indicators?</em></td>
</tr>
<tr>
<td>Chapter 7</td>
<td>Shortcomings of the LMS</td>
</tr>
<tr>
<td>(SQ II-4)</td>
<td><em>What are shortcomings and potential improvements of the LMS and does the model fit UFD context needs?</em></td>
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</tbody>
</table>
The third and final phase is dedicated to provide the municipality of Delft with recommendations in the overall process, extended usage of the LMS model and how to further sustain urban freight distribution. Furthermore, some overall conclusions are drawn and a reflection on the entire process is conducted. The chapters and corresponding sub questions are presented below.

**Phase III Conclusion, Recommendation and reflection**

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Conclusion</th>
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</thead>
<tbody>
<tr>
<td>8</td>
<td>Conclusion</td>
</tr>
<tr>
<td>(SQ III-1)</td>
<td>What conclusions can be drawn from this research?</td>
</tr>
<tr>
<td>9</td>
<td>Recommendation</td>
</tr>
<tr>
<td>(SQ III-2)</td>
<td>What are the recommendations for the Municipality of Delft?</td>
</tr>
<tr>
<td>10</td>
<td>Reflection</td>
</tr>
<tr>
<td>(SQ III-3)</td>
<td>What lessons are learned during the process of writing this thesis?</td>
</tr>
</tbody>
</table>

Figure 3 gives a schematic overview of how to get from research objectives using different types of analysis or methodologies towards the desired results.
1.6. Research methodology and structure

In this section the research methodology is introduced. The structure of the thesis is divided in a number of phases where every phase different methodologies are applied. An elaboration on each phase is treated separately below.

1.6.1. Research methodology

The methodological embedding of this thesis is theory of sociotechnical systems (Bauer & Herder, 2009). A sociotechnical system has two natures or perspectives that are important. These systems are complex physical-technical systems and networks of interdependent actors. The two perspectives seem to lie directly opposed but are at the same time quite similar on multiple aspects. Theory on system perspectives and actor perspectives is explored in 2009 by de Bruijn and Herder (de Bruijn & Herder, 2009). The system perspective or complex physical technical systems can be analysed and designed by using the Delft system approach developed by Hans P.M. Veeke, Jaap A. Ottjes and Gabriel Lodewijks (Veeke, Ottjes, & Lodewijks, 2008). The actor perspective or networks interdependent actors can be analysed by using multi-actor theory developed by de Bruijn and Heuvelhof (de Bruijn, J.A. & Heuvelhof, 2008). The urban freight distribution system is a sociotechnical system that has characteristics of both physical-technical system and a network of interdependent actors. This combination results in a complex multi-actor sociotechnical context.

Phase I: Theoretical framework

The first phase is dedicated to exploring literature research to build a theoretical framework that can be used as a basis for subsequent phases. Phase I is divided in two chapters. In chapter two, an analysis to explore the context of city logistics/urban freight distribution is conducted. The methodology that is applied is an extensive literature research. The identification of present general problems, solutions and policy instruments regarding urban freight distribution is conducted. In addition, factors that are at the core of these problems are investigated and challenges explored. To deepen the research, interviews with experts with different backgrounds is conducted. In chapter three theories on the multi-actor context is explored. Furthermore, suitable actor analysis techniques are examined. Finally, a cost benefit analysis is conducted to identify cost and benefits of the urban freight distribution system of involved stakeholders. The CBA provides information on key performance indicators of the system.

The theoretical framework of phase I is used throughout the entire thesis. Background knowledge on different topics regarding city logistics are used on evaluation of context needs, purpose of development and how well the LMS model can be of benefit in solving urban freight distribution problems. Furthermore, the theory on multi-actor environments and stakeholder analysis methodology introduced in chapter three functions to increase knowledge of the system. Selected validation methodologies are applied in chapter four on the validation process of the LMS.

Phase II: The Last Mile Scan

The first part of phase II is an exploration of relevant validation methodologies available in existing literature. Thereafter, elaborations on the LMS model itself and the functioning of the scan is conducted. Various techniques and methodologies are used to analyse the model. For example, system analysis and causal relation diagrams. The aim of chapter four is to explore the LMS, how it is developed, what it calculates and what assumptions are used. Furthermore, data, parameters, formulas, input/output, results (scans), development problems and limitations are analysed. In this chapter a suitable validation methodology is applied. Frameworks that are applied is the validation model of Sargent and sensitivity analysis extensively described by Kleijnen.

In chapter five data analysis techniques are applied. The research methodology data analysis is applied in chapter five. In chapter six a cluster analysis is applied. The data set derived by the LMS model is statistically analysed. Therefore, the software package SPSS is used to conduct cluster analysis and other statistical analysis. Chapter seven is an evaluation and comparison of context of city logistics and functionalities of the model. In addition, common sense and qualitative analysis are applied to conclude if the LMS model fits needs of urban freight distribution problems and cover key performance indicators of involved stakeholders. Questions such as: ‘is the LMS model a helpful
solution to solve problems identified in phase I?’ and ‘does the LMS model enhance to increase transparency and cooperation among involved stakeholders and does it fit their needs?’ are answered in this section.

**Phase III: Conclusions and recommendations**
The final phase provides the municipality of Delft with recommendations that can be used as guidance to improve urban freight distribution in the region and to increase and extent the lifetime usage of the LMS model. Furthermore, a reflection on the process of this thesis is presented. This phase ends with conclusions drawn from this research.

### 1.6.2. STRUCTURE OF THESIS

This thesis proposes to validate the last-mile scan model (LMS), to explore relationships between tariffs and costs of urban freight distribution and how to better use outcome of the LMS by conducting cluster analysis. The final phase ends with conclusions, recommendations and a reflection. The structure of this research is shown in Figure 2. In this overview the structure is visualized to show how different phases relate to each other.

<table>
<thead>
<tr>
<th>Phase I - Theoretical Framework</th>
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<tbody>
<tr>
<td>C.2 - Context of urban freight distribution</td>
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<table>
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<tr>
<th>Outcome Phase I</th>
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<tr>
<td>Key performance indicators (KPIs) UFD system</td>
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<tr>
<th>Phase II - The Last-Mile Scan</th>
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<tr>
<td>C.4 - Validation of the LMS</td>
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<table>
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<tr>
<th>Outcome Phase II</th>
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<tbody>
<tr>
<td>Validation process results</td>
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<table>
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<tr>
<th>Phase III - Conclusions, recommendations and reflection</th>
</tr>
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<tr>
<td>C.8 - Conclusion</td>
</tr>
</tbody>
</table>

*Figure 4 – Structure of Thesis*
PHASE I

THEORETICAL FRAMEWORK

In this phase the context of UFD is explored through execution of an extensive literature review. The result of this literature research ends with the identification of some knowledge gaps. Thereafter, an actor analysis on all stakeholders involved in urban freight distribution is fulfilled. The structure of phase I is given in Figure 5.

<table>
<thead>
<tr>
<th>Phase I - Theoretical Framework</th>
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<tr>
<td>C.2 - Context of urban freight distribution</td>
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</table>

**Outcome**

| Key performance indicators (KPIs) UFD system | Knowledge on actors in UFD and their needs, cost and benefits |

Figure 5 - Structure of phase I

Chapter 2 Exploring the context of urban freight distribution

This chapter explores the context of urban freight distribution. It is important to see what trends drive demand for urban freight distribution, the type and nature of problems that are concerned. Furthermore, the last mile problem is introduced. Research on available solutions are executed and their corresponding pros and cons. Thereafter, available UFD models and measures for regulations are explored that can contribute to further sustain urban freight distribution systems. The relevance of this chapter is to explore what scientific research is available and what contribution this thesis can provide to the research field of urban freight distribution.

(SQ I-1) **What is the context of urban freight distribution and what problems and solutions are relevant?**

Chapter 3 Multi-actor context

This section provides the theoretical framework on multi-actor context. Furthermore, an extensive actor analysis is executed to see what stakeholders are involved. This chapter is concluded with a full list of important actors, and corresponding needs, interest and drivers. The relevance of this chapter is to see what impact different solutions can have on different actors and what parties should be involved to increase proper functioning of the system towards a better performing urban freight system.

(SQ I-2) **What stakeholders are involved in urban freight distribution systems?**
2. **CHAPTER 2** **EXPLORING THE CONTEXT OF URBAN FREIGHT DISTRIBUTION**

### 2.1. Literature research

In this chapter a literature research on, urban freight distribution, sustainable urban freight distribution, the last mile problem, problems and solutions regarding urban freight distribution are conducted. Furthermore, some available UFD models and approaches are introduced. The benefit of this section is to discover what scientific theory is developed and available for use. Thereafter it is possible to identify knowledge gaps and to position the research field of the thesis in the literature.

The structure of chapter 2 is as follows; first the geographic area is delineated and an explanation on urban freight distribution (UFD) is given. Thereafter, trends and developments in the field of UFD are explored. Next, the field of sustainable urban freight distribution is threatened. Subsequently, the last mile problem is introduced. Then, an overview of all problems and solutions regarding urban freight distribution in cities are listed. This section ends with research on available models and measurements that can be implemented by regulating parties such as government bodies to influence and regulate urban freight distribution systems.

#### 2.1.1. URBAN FREIGHT DISTRIBUTION

In scientific literature various definitions on urban freight distribution can be found. According to DaBlanc UFD can be defined as: ‘a large number of different types of freight flows that cross an urban environment’. Flows can consist out of consumer goods, waste products, building materials, postal mail and others. The term other is not further defined (Dablanc, 2007).

Muñuzuri et al. define urban logistics as: ‘movements of goods that are affected by particularities associated to urban traffic and morphology’ (Muñuzuri, Larrañeta, Onieva, & Cortés, 2005) (Department of the Environment Transport and the Regions, 1999).

These definitions do not differ a lot, merely that the definition of DaBlanc is more specific. Ambrosini & Routhier (2004) point out that the starting points or perspective is important in defining urban freight distribution. What these researchers say is that countries with low-density urban areas only focus on commercial vehicles while countries with high-density urban areas consider a broader scope by including trips by individuals from shop to home and waste transport (Ambrosini & Routhier, 2004).

Allen et al. define urban freight distribution as: ‘The delivery of consumer goods (not only by retail, but also by other sectors such as manufacturing) in city and suburban areas, including the reverse flow of used goods in terms of clean waste’ (Allen, Anderson, Browne, & Jones, 2000).

The geographic area and study of this Thesis is the region of Delft. From a Dutch perspective, containing urban areas with a high-density, it seems wise to use a wide scope in terms of the definition of urban freight distribution. A combination of the two definitions of DaBlanc and Allen et al. is used here. This means that when speaking about urban freight distribution the delivery of all freight flows crossing an urban environment including reverse flows of used goods in terms of clean waste are considered.

Urban freight distribution differs from freight distribution in general, because it has considerable small geographic boundaries like a single city. Freight that crosses an urban environment is considered as urban freight distribution. The Netherlands is characterized worldwide as one of the most urbanized countries in the world.
2.1.2. Trends driving demand of urban freight distribution

The (future) demand of freight distributed in a region is an important indicator that gives an idea of the urgency to properly organize the system. The amount urban freight distribution is driven by a number of forces and influenced by current trends and developments. This paragraph elaborates on these trends. Literature research shows that the main trends can be categorized in demographic developments, innovation & technology and higher standards demanded by consumers.

The trends identified and verified through literature research are: [1] growing population, [2] urbanization, [3] global e-commerce growth and [4] dynamic inventory management concepts. In addition, there are some general developments that might have an impact on the way people and parties think on how to arrange urban freight distribution. The main development is the overall awareness of recycling, reuse and overall reduction. This is nicely captured in the rather new concept of the emerging circulation economy.

Trend 1: Growing worldwide population
The first trend, worldwide population growth, is increasing gradually the last fifty years. In 1961, the world population was around 3 billion. Now, in the year of 2013 the world population grew over 7 billion persons (The World Bank, 2013). See Figure 7 for more details about the course of growth. This is an enormous growth of 1.2% per year (The World Bank, 2013). Figure 6 shows growth rates of the Netherlands and the world.

![Figure 6 - Worldwide population growth factor (The World Bank, 2013)](image)

![Figure 7 - World population in billions (The World Bank, 2013)](image)

Trend 2: Urbanization
Last half a century there is a worldwide trend of urbanization happening. From 1960 until 2013, upper middle-income range countries become almost fully urbanized. Now between 40 to 90% of the total worldwide populations live in cities (Henderson, 2003)(The World Bank, 2013). As is shown in Figure 8 the difference between worldwide urbanization and for example urbanization in the Netherlands is huge. First world countries generally have higher urbanization percentage compared to second and third world countries (The World Bank, 2013).
Consequently, cities are becoming overcrowded and relatively small historic centres having enormous problems in processing the amount of freight since infrastructure structures of these city centres cannot be reorganized due to lack of space and law and regulation that protects old historic buildings. Congestion, reduced liveability and higher emissions are a direct consequence of the lack of space in urban areas.

![Figure 8 - Chart of percentage of people living in urban areas (The World Bank, 2013)](chart)

**Trend 3: Global e-commerce growth**

The third and more recent trend is the emerging e-commerce sector. The global e-commerce growth is a fact that cannot be denied (Ho et al., 2007). The aggregate level of e-commerce is a research field that is not extensively developed, yet. Previous research is mainly focused on individual, firm or country level. Little is known about the aggregate level of e-commerce. Ho et al. tried to define and identify factors that drive the growth of e-commerce. Potential drivers are: GDP per capita, geographic and demographic characteristics, urbanization, information infrastructure, cost to shop on the internet, adequacy of economic and financial resources, cosmopolitanism, education and human capital (Ho et al., 2007).

Economic growth, refers to GDP per capita is an important driver of e-commerce growth. According to Ho et al. economic growth can be either indigenous or exogenous. The influence of exogenous economic growth in a neighbour country can for example positively influence the e-commerce growth of their neighbours. Overall, global e-commerce growth leads to higher demand of freight, mainly in high-density regions, which are generally urban areas.

**Trend 4: Dynamic inventory management concepts**

Information technology and other dynamic inventory management concepts have contributed to higher perform abilities of freight carriers. These higher standards have been translated, due to fierce competition among distributors towards higher standards demanded by consumers. The concept of ‘just in time’ (JIT) has led to lean manufacturing and a continuously increase in complexity and decrease in stock amounts. Lower stock amounts result in a cost advantage for operators (Macário, Galelo, & Martins, 2008)(Macário et al., 2008).

**General development: Circulation economy**

Scholars in China first proposed the circulation economy (CE) concept in 1998. The concept was formally accepted four years later by the central government of China and was from then on an accepted strategy. The aim of this strategy is to achieve a sustainable balance between the burden on the environment, rapid economic growth and usage of raw materials (Yuan, Z., Bi, J., Moriguichi, 2006). According to Yuan et al. there is not a commonly defined definition available yet. They define CE as: ‘the circular (closed) flow of materials and the use of raw materials and energy through multiple phases’. The three “R”s principles apply to CE, which are reduction, reuse and recycling. The main goal of the concept is to achieve an efficient economy while being less polluting.
2.1.3. **Urban Freight Distribution Problems**

In this paragraph a literature research on problems in the field of urban freight distribution are explored. These problems are characterized to be economic, environmental or social of nature.

**Lack of space in urban areas**

Urban freight distribution flows occupy around one fourth of the street traffic of an average city (facts derived from surveys conducted by the Laboratoire d’Economie des Transports (Lyon, France) with the support of the French national research program on *Goods in Cities*). The amount of urban space that is demanded related to urban freight distribution is even greater. On top of these flows, loading and unloading spots, storage, conditioning and packing capacity is needed (Dablanc, 2007).

**Greenhouse gas emissions**

The amount of greenhouse gas emissions is a problem in urban areas. Most vehicles operating in urban areas are conventional vehicles that still drive on petrol. Livability of an urban area is negatively affected by pollution. Environmental standards are too low to ensure maximum allowed emission polluted within urban boundaries (Muñuzuri et al., 2005).

**Economic inefficiency**

Economic inefficiency can occur since freight carriers are operating with low loading rates due to lack of critical mass or JIT concepts. Consolidating freight from both supply and demand perspective can increase economic efficiency. The not-at-home problem can be resolved partially as well.

**Congestion**

As mentioned, lack of space and low loading rates decreases freight carriers operating efficiencies. This leads to a higher amount of vehicles on the road than necessary. Moreover, historic city centres are small and not designed for large amounts of traffic. The existing infrastructure has limited capacity. These factors all together result in congested roads (Muñuzuri et al., 2005).

**Inefficient bundling**

Inefficient bundling from a city perspective is mainly caused due to a lack of cooperation and consultation between receiver and carrier (Verlinde, Macharis, & Witlox, 2012). Transportation flows could be enlarged when actors improve cooperation. Consolidation increases loading rates and decreases the total amount of vehicles operating in an urban area.

**Safety and noise**

Safety and noise issues regarding old vehicles operating in urban areas have a negative impact on liveability of cities. Smaller clean and quiet electric vehicles can reduce the amount of noise and accidents.

**Lack of critical mass in rural areas**

Another problem is the lack of critical mass. These areas do not generate freight flows that are large enough to arrange efficient freight distribution. Distribution in these areas is expensive and inefficient since carriers operate with low loading rates (Gevaers, 2011).

**Case: Municipality of Delft**

In case of the municipality of Delft several of foregoing problems occur. Delft is an old town with a historic city centre that is rather small of size. Lack of space and congestion are definitely problems that apply since distribution with large trucks is difficult and therefore have a larger impact on citizens due to their relatively high disturbance compared to urban areas with more space. Greenhouse emissions are definitely a problem since old conventional vehicles have a negative impact on the liveability of the municipality. Also in Delft, the economic efficiency is not fully utilized due to a large number of independent operators who do not communicate or collaborate to create win-win opportunities. Due to this lack of cooperation and communication between receiver and carrier, receiver and receiver and carrier and carrier potential efficient bundling is not yet achieved. Furthermore, the truck fleet that is active in the urban area of Haaglanden could be improved. In 2015 there are still many old vehicles active that have a large negative impact on the environment and cause nuisance and safety issues (Maatwerk Distributie, 2015). Moving towards smaller clean and quiet vehicles should be further emphasized.
2.1.4. **Sustainable Urban Freight Distribution**

Sustainable urban freight distribution (SUFD) is a concept that has developed strongly in the past years. In a literature review conducted by (Behrends, Lindholm, & Woxenius, 2008) a structured overview is provided on the origin of sustainable development. In their review, the key concepts and principles of sustainable development are introduced and a set of indicators that describe SUFD is developed.

Key concepts of sustainable development are two folded. Sustainable development has to meet needs of present generation without abiding to have the ability of future generations to meet their needs (Brundtland, 1987)(Behrends et al., 2008)(Goldman & Gorham, 2006).

This definition of sustainable development can be divided in three principles, which include economic growth, social equity and environmental protection (Brundtland, 1987) (Wolff, 2004). Social equity will meet needs of present generations while the dimension of environmental protection is safeguarded to meet needs of present generations and ensures the ability of future generations to meet their needs. Figure 9 gives an overview of the three dimensions of sustainability in their intersections (Johann Dréo, 2006)

![Figure 9 - Three dimensions of sustainability and their intersections (Johann Dréo, 2006)](image)

Lautso defined the principle of social equity in sub-objectives intra- and inter-generational equity and stability of social and cultural systems (Behrends et al., 2008). Economic growth, as a principle of sustainable development can be specified in a sub-objective: ‘maximizing the flow of income while simultaneously maintaining a sufficient stock of assets and/or capital that yields these benefits’. Environmental protection can be specified by three sub-objectives. The specification is drawn from the work of (Holmberga, 2000) who has defined four system conditions that provide a framework for ecological sustainability. These conditions are: ‘no systematic increase in concentration of substances extracted from the Earth’s crust’, ‘no systematic increase in concentration of matter that is produced within the ecosphere (produced by society)’, ‘no systematic physical deterioration of the ecosphere’s ability to utilize waste’ and ‘resources are used fairly and efficiently to meet basic human needs worldwide’. The last condition is also captured in the principles of social equity and economic growth.
Now the principles of sustainable development have been defined further elaboration on principles of sustainable urban freight transport are explored. Figure 10 gives a schematic overview of principles of sustainable urban transport systems (Behrends et al., 2008).

![Figure 10 - Principles of sustainable urban transport systems (Behrends et al., 2008)](image)

Under the umbrella of social equity, the principles of human health and equity fall. These principles can be operationalized by: limit noise nuisance, provide safety, the right on accessibility and quality of urban environments. A healthy economy, where economic growth is present can also be defined as a competitive economy. This can be further specified in accessibility and cost-effective transportation of persons and goods. Finally, environmental protection can be formulated as the healthiness of the ecosystem. More specific, by limiting the amount of emissions, waste, resource- and land use.

In this paragraph, it is substantiated that principles of sustainable urban freight transport are similar to problems of urban freight distribution threatened in paragraph 2.1.3.

**Indicator set of Sustainable Urban Freight Distribution**

Principles of sustainable urban freight distribution are known and threated above. The next logical step is trying to capture these principles by a set of indicators. What indicators influence the principles of SUFD? Behrends et al. (2008) have developed an indicator set to describe sustainable urban freight distribution from a carbon dioxide emission point of view. Carbon dioxide is not the only emission that matters, other greenhouse emissions need to be included as well to analyse the degree of sustainability of an urban freight distribution system. The mathematical equation that indicates the amount of carbon dioxide emission is presented in Appendix A (Behrends et al., 2008). In general, the formula describes the amount of carbon dioxide released. Indicators that drive and determine the amount of carbon dioxide released are transport intensity, traffic intensity and the degree of technical capabilities of an urban freight distribution system. These indicators can be further operationalized. This is shown in Figure 11.
Figure 11 - Indicator matrix for distribution of consumer goods (Behrends et al., 2008)

The indicator matrix gives an overview of all elements that influence parts of the equation that determine the level of sustainability of a transportation system. These indicators can be interpreted as instruments that have an impact on criteria that are economic, environmental or social of nature. Stakeholders that are participating in urban freight distribution have their own set of measures that influence the total level of sustainability. The set of impacts (or criteria) are derived from the indicator matrix shown in Figure 11. These criteria are accessibility, accidents, land use, air pollution, greenhouse gas emission, energy use, waste and noise. The criteria are taken into account in further analysis and used to assess benefit of the LMS model towards sustainable urban freight distribution.

2.1.5. THE LAST MILE PROBLEM

In this paragraph, the last mile is explored and a definition of the last mile is provided. Furthermore, general problems regarding the final section of the supply chain are introduced.

From a supply chain perspective, the last section of the supply chain is in literature known as the last mile. This section of the supply chain is for most freight considered problematic. As mentioned in previous paragraph on UFD problems, operating in urban areas is difficult due to a number of factors. Figure 12 gives an overview of a basic supply chain and the relative position of the last mile in the chain.
The last mile challenge has risen in the last ten years since an explosion in consumer deliveries such as delivery in grocery, office supply, packages and pharmaceutical products (Boyer, KK. & Prud’homme, AM., 2009). The last mile is regarded as more expensive, less efficient and more polluting compared to the entire logistic chain. A few problems identified in the research of Gevaers on the last mile are explored hereafter. A frequently occurring issue of the last mile delivery is the not-at-home problem. This issue results in high delivery failure and an increase in empty trip rates. This has negative impacts on cost efficiency and environmental performance (Gevaers, 2011).

The delivery of final products to the door of a consumer is logistically challenging due to a number of factors and is, as mentioned before, potentially very expensive. Costs for a single delivery of grocery vary between 10 and 20 dollar per order (Boyer, Frohlich, & Hult, 2005). The empirical data from (Boyer, KK. & Prud’homme, AM., 2009) could provide a method for estimating the cost of a delivering order. The parameters yield a total cost of 11,21 dollars per order.

Key factors that affect route efficiency are customer density and delivery window length. Consumer density is negatively correlated with costs of delivery. High-density areas are less expensive. The delivery window length is negatively correlated with costs of delivery. Longer delivery windows correspond with lower delivery costs. A key aspect of the relation between density, window length and route efficiency is balancing the demands of supplier and customer.

Customer delivery types can be categorized in three different groups. The customers could live in central cities (urban), suburban areas (semi-urban) or outside of metropolitan areas (rural)(Boyler, KK. & Prud’homme, AM., 2009). This thesis is focused on the urban region of Delft that is with regard to the categorization of Boyler at al. the first group, central cities (urban).

2.1.6. Urban Freight Distribution Solutions

In the past twenty years a various amount of sustainable urban freight distribution solutions has been introduced and tested in practice. Besides practical test cases, a lot of scientific literature is published on urban freight distribution. In the next section UFD solutions are explored and compared on multiple approaches; physical versus behavioural solutions, private versus public versus private-public partnership, carrier perspective versus receiver perspective (demand versus supply driven) and centralized versus decentralized (Allen et al. 2000). In general, improvements on urban freight distribution can be initiated by two distinguished groups of stakeholders who have the power and capability to change the system. These two groups are government bodies and private businesses. Change therefore can either be governmental driven (top-down, centralized) or company driven (bottom-up, decentralized) (Anderson et al., 2005).
Physical versus behavioural solutions

Solutions that can potentially improve urban freight distribution and can contribute to a more sustainable system differ in nature. According to Verlinde (2012) solutions can be divided in physical and behavioural solutions (Verlinde et al., 2012). These solutions can be vertically or horizontally integrated. This idea is captured in Figure 13.

![Figure 13 - Physical versus behavioural UFD solutions (Verlinde et al., 2012)](image)

**Traditional Urban Consolidation Centre**

An example of a physical orientated solution is the traditional urban consolidation centre (UCC). A UCC is a distribution centre specially built to consolidate freight on the border of an urban area. Freight, which is normally distributed by carriers themselves, is now brought to the UCC. From here, the operator of the UCC consolidates and distributes freight into an urban area. By consolidating freight on the border of a city, several (social) benefits can be achieved. The size of these benefits is dependent on the efficiency of the UCC and characteristics of vehicles used by the UCC and other freight carriers.

Studies on cases in France show positive result on vehicle kilometres and road occupancy (less vehicles are needed to ship the same amount of freight due to higher efficacy) (Verlinde et al., 2012). An UCC can positively contribute to impact on congestion, emission, shopping climate and safety. These, especially social benefits also have a counter side. The use of UCCs has a negative impact on economic aspects due to additional shipment cost and large sunk cost (construction of the distribution centre). These negative aspects are mainly the concerns of carriers since their main objective is profit while the positive effects of an UCC are social of nature and mainly the concerns of government bodies and residents. The inconsistency of cost and benefits of involved stakeholders become visible in the UCC example.

Consolidation or bundling can take place in different forms. Van Binsbergen and Visser, (2001) suggested a typology of bundling concepts. They distinguish four types of concepts (Van Binsbergen & Visser, 2001):

- Bundling in time;
- Bundling in activities;
- Bundling in routing;
- Bundling in depots

Practise has shown that bundling in time, activities and routing causes no strong increase in efficiency. Bundling in depots is the most promising bundling concept to improve overall urban distribution.
Most UCC are public-private partnerships (PPP) because government bodies have subsidized them. The majority of cases in practise have shown us that these PPPs are not profitable and cannot survive without subsidy (Verlinde et al., 2012). Most initiatives disappear shortly after the end of a procurement period. Another notable fact (that seems problematic) is that retailers do not see the benefit of consolidation. Benefits for retailers are a favourable shopping climate, which positively contributes to profit potential since people are keener to go shopping and spent money.

**Alternative additional transhipment**

A different physical solution and less costly than the traditional UCC is alternative additional transhipment. An example is consolidation of urban freight flows without setting up a UCC. This means the same function is performed except that there is no initial investment needed to construct a distribution centre. This solution tends to use existing infrastructure, for example private owned distribution centres at the outside of an urban area, to consolidate freight. Besides lower investment needs another advantage compared to traditional UCCs the solution itself is market orientated. The existing distribution centre is in the majority of the cases privately owned and operated. This increases to probability of survival (Verlinde et al., 2012).

Crainic et al. (2009) presented their logistic view on different forms of consolidation from a multi-echelon perspective and have distinguished three levels of consolidation. These levels are called: none-level, single-level and two-level (Crainic, Ricciardi, & Storchi, 2009). None-level is consolidation without a physical consolidation centre, the same as explained in previous paragraph. Single-level is consolidation through a traditional UCC. Two-level form of consolidation is the latest concept. Consolidation takes place at two physical locations. The first-level UCC is used and often located on the edge of an urban area and there is a second UCC, which are satellite platforms or mini-hubs were freight is consolidated and transhipped into vehicles suited for utilization in dense city zones. This concept is only applied in medium and large cities.

**Behavioural change**

Another solution, which is behavioural oriented and focused on retailers, carriers or both, is consolidation from a retailer/carryer perspective. An example from a retailers’ perspective is that retailers in certain region cooperate more intensively with each other. Often, every retailer places an order individually (at the moment they receive an order from their consumers or when restock of their stores is needed). This demand is driven by consumer needs. Changes on their behaviour by increasing cooperation among retailers to synchronize orders can contribute in optimizing freight flows (Verlinde et al., 2012).

Another behavioural solution is to change the awareness and point of view on the urgency to increase sustainability of UFD. Both retailers and carriers can increase their priority list and put a greater weight on sustainable distribution instead on economic motives. Carriers and retailers are stakeholders that are generally economic driven.

A great example of a traditional UCC but innovative initiative focused on a receiver perspective is binnenstadservice.nl (BSS). This company is operational in Nijmegen and tries to change the behaviour of retailers by increasing the awareness of clean distribution in urban areas. BSS is focused on retailers since they have the power to choose their own carriers (most of the time). They can also oblige their carriers to participate in the initiative of BSS. The success of BSS is dependent on the size of the freight flows in a certain region. They need a critical mass to be profitable. They have been operational for a couple of years now and recently subsidy stopped (Rooijen & Quak, 2010). It is interesting to see how this develops in the future and if they can exist without funds and be profitable.

**Private versus public versus public-private partnership**

The organizational structure of different initiatives can generally be divided in private owned/operated and public-private partnerships. An example of a PPP is a traditional UCC subsidized by a government body. The UCC is generally operated by a private party but cannot exist without procurement. The initiative of BSS, mentioned in previous paragraph, is also a PPP that changed into a privately owned organizational structure after a couple of years. A private operator like PostNL that
owns a distribution centre on the border Delft is a typical example of a private operator that can contribute by consolidating freight.

**Carrier perspective versus receiver perspective (demand versus supply driven)**

Another way to look at solutions is from which perspective they originate. There is a difference in solutions that are demand driven versus supply driven. Demand driven solutions generally approach problems from a receiver perspective by which is meant from a retailer/consumer view. Supply driven solutions are approaches from a carrier perspective. The supply of stock can be planned on a regular base dependent on sale figures (experience).

**Centralized versus decentralized**

The difference of this contradiction is the top down (centralized) or bottom up (decentralized) approach. Often, private parties are the initiators of decentralized oriented solutions. Different parties can initiate (innovative) solutions at the same time and often have a lower abstraction level and smaller scale regarding to centralized solutions. This is better known as the bottom up approach. The market itself (in general private parties) generates and implements innovations. Centralized solutions or top down approaches and are mostly initiated by regulated and governmental bodies.

### 2.1.7. UFD REGULATION MEASURES

This paragraph provides an overview of available urban freight distribution measurements. The measurements are analysed from a governance perspective because they have the means to regulate urban freight distribution. General governance measurements are time-window access, road pricing, creating sub-networks for freight vehicles, incentives to optimize transport efficiency and permits (for use of loading zones or type of vehicles) (Russo & Comi, 2010).

Time-windows are a measurement that forbids freight vehicles to enter a city centre at certain periods of the day. In general, the restriction or limited access periods are during rush hours in the morning and late afternoon. Sometimes night-time delivery is stimulated to reduce congestion during daytime. A drawback of this stimulant is these deliveries can increase noise levels during the night where lower noise levels are allowed. The main goal of time windows is to avoid interference with car traffic during peak hours and avoid interference with pedestrian traffic (Russo & Comi, 2010).

Road pricing is another measure that can regulate the amount and types of freight vehicles entering an urban area. Minimizing the amount of freight can be achieved by pricing entrees of city centres for all involved stakeholders. Another way is to prohibit only certain types of vehicles. For example, freight vehicles above a certain size, weight, age. In addition, non-e-vehicles could be prohibited.

Another measure is to create incentives for freight carriers and other involved stakeholders to increase transport efficiency by improving loading rates. Installing a minimum load factor of freight vehicles entering an urban area is a method to realize higher load factors. There are some problems regarding this measurement. What is an appropriate threshold value? How to maintain higher loading factors? Research conducted in Denmark has shown that this is difficult to realize. How to define the size of the area where the minimum load factors apply?

Development of sub-networks for freight vehicles is a measurement that can be implemented by government bodies. Nevertheless, not all cities are suited for this type of measure. Existing infrastructure as special developed bus and taxi lanes can be deployed. The urban area of Delft does not seem suitable due to the relatively small historical centre.

Permits addressed to certain areas such as specific load an unloading zones can result in lower disturbance of commercial areas where consumers do their shopping. This measurement is suitable when city centres have a lack of space.

The European program COST 321 (Cost321, 1998) conducted research on specific consolidation-oriented measures and identified thirteen measures distinguished over four categories. These categories are divided in the establishment of additional transfer (AT) points near an urban area. The second category is development or promotion of common delivery (CD) points. The last two
categories are related to change and/or influence behavior of carriers (BC) and behavior of retailers and/or shippers (BRS). The thirteen measures are presented in Table 1.

Table 1 - Consolidation-oriented measures

<table>
<thead>
<tr>
<th>Additional transfer points (AT)</th>
<th>Common delivery points (CD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Goods distribution centers (AT)</td>
<td>- Shared use of storage space by retailers (CD)</td>
</tr>
<tr>
<td>- Regional rail network in combination with urban Distribution Center (AT)</td>
<td>- Promotion of storage facilities in inner urban areas (CD)</td>
</tr>
<tr>
<td>- Optimization of distribution systems including transport centers (AT)</td>
<td>- Consolidation by means of ‘urban’ containers (CD)</td>
</tr>
<tr>
<td>- Extension of transshipment facilities (AT)</td>
<td>- Development of lock chambers common to a group of receivers (CD)</td>
</tr>
<tr>
<td>- To revive railway or fluvial central urban sites as urban distribution centers (AT)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Behavior of carriers (BC)</th>
<th>Behavior of retailers and/or shippers (BRS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Truck ownership licenses for urban distribution (BC)</td>
<td>- Outsourcing of freight transport (BRS)</td>
</tr>
<tr>
<td>- Road pricing in cities (BC)</td>
<td>- Transport coordination and cooperation of retailers (BRS)</td>
</tr>
</tbody>
</table>

2.1.8. SOCIAL COSTS AND BENEFITS OF UFD

In this paragraph the urban freight distribution system (UFDS) and the potential of urban consolidation is analysed from a social point of view. The most suitable method that could be used to evaluate the UFDS from a social point of view is to conduct a brief social cost benefit analysis (SCBA). Techniques derived from a CBA are used briefly. The entire system is not quantified as in an extensive CBA, only a global and qualitative approach is conducted to show that cost and benefits of the system and urban consolidation are not equally divided among stakeholders. Cost and benefits can be interpreted as key performance indicators (KPI). Quantitative appreciation of cost and benefits provides information on performance of individual stakeholders or the UFDS as a whole. In a later stage, KPIs derived from the last-mile scan calculation model or calculated by a few simple mutations are compared and matched to identify KPIs below. Performance of clusters (groups of similar freight carriers) can be compared with each other on formulated KPIs.

Potential effects
The potential effects of urban consolidation and other policies are presented below. These components derive from literature and by conducting a CBA (Duin, Quak, & Munuzuri, 2007).

- Greenhouse emission (CO2, NO etc.);
- Exhaust of fossil fuels;
- City maintenance costs;
- Vehicle kilometres on roads in urban area;
- Noise nuisance;
- Congestion;
- Low loading rates;
- Safety issues due to large trucks;
- Cost for (un)loading tariffs;
- Purchase of electric vehicles;
- Time window restrictions;
- Longer lead-times supply of goods;
- Income from (un)loading tariffs;
- Obligation to electric vehicles;
- Benefits from obligation to small vehicles;
- Benefits from time window restrictions;
- Benefits from JIT deliveries at home;
- Quality improvement of shopping area;
- Flexibility of delivery;
- Stock reduction at site;
• Fleet optimization;
• Time profit;
• Bundling opportunities;
• Separation of supply and return flows;

The potential effects do not count for every stakeholder. Some potential benefits, for example time window restriction, are in favour of residents of municipality since the policy reduces the amount of vehicles operating in an urban area. At the same time, the cost of this policy is worn by the distributors and cargo owners and maybe even buyers since prices might go up due to tight scheduling demands.

This list of potential cost and benefits can be allocated to different stakeholder groups. These groups are extensively analysed in a later stage, in paragraph 3.1. For now, these groups can be categorized in: shippers/cargo owners, distributors/carriers, planners and regulators and residents. Roughly, these groups can be distinguished on their main interest, which is commercial (shippers and distributors) or non-commercial (residents and planners and regulators). Some benefits or cost could not be assigned to a stakeholder group specifically but are societal cost.

Table 2 - Social cost and benefits for stakeholders of UFD

<table>
<thead>
<tr>
<th>Shippers/cargo owners</th>
<th>Residents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time profit (+)</td>
<td>Quality improvement of shopping area (+)</td>
</tr>
<tr>
<td>Stock reduction at site (+)</td>
<td>JIT deliveries at home (+)</td>
</tr>
<tr>
<td>Flexibility of delivery (+)</td>
<td>Time window restrictions (+)</td>
</tr>
<tr>
<td>Time window restrictions (-)</td>
<td>Obligation to small vehicles (+)</td>
</tr>
<tr>
<td>Purchase of electric vehicles (-)</td>
<td>Obligation to electric vehicles (+)</td>
</tr>
<tr>
<td>Cost for (un)loading tariffs (-)</td>
<td>Longer lead-times supply of goods (-)</td>
</tr>
<tr>
<td>Congestion (-)</td>
<td>Safety issues due to large trucks (-)</td>
</tr>
<tr>
<td>Low loading rates (-)</td>
<td>Congestion (-)</td>
</tr>
<tr>
<td></td>
<td>Noise nuisance (-)</td>
</tr>
<tr>
<td></td>
<td>Vehicle kilometres on roads in urban area (-)</td>
</tr>
<tr>
<td></td>
<td>Greenhouse emission (CO2, NO etc.) (-)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Distributors/carriers</th>
<th>Planners and regulators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separation of supply and return flows (+)</td>
<td>Income from (un)loading tariffs (+)</td>
</tr>
<tr>
<td>Bundling opportunities (+)</td>
<td>City maintenance costs (+)</td>
</tr>
<tr>
<td>Fleet optimization (+)</td>
<td></td>
</tr>
<tr>
<td>Time window restrictions (-)</td>
<td></td>
</tr>
<tr>
<td>Purchase of electric vehicles (-)</td>
<td></td>
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<tr>
<td>Cost for (un)loading tariffs (-)</td>
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<tr>
<td>Congestion (-)</td>
<td></td>
</tr>
<tr>
<td>Low loading rates (-)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Societal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle kilometres on roads in urban area (-)</td>
</tr>
<tr>
<td>Greenhouse emission (CO2, NO etc.) (-)</td>
</tr>
<tr>
<td>Exhaust of fossil fuels (-)</td>
</tr>
</tbody>
</table>

Further elaboration on KPI’s is conducted in phase II. There, KPI’s calculated by the LMS model are discussed. In chapter 6 a comparison between above social cost and benefit effects and KPIs derived from the model is conducted. This is conducted through a comparison of the UFD context (social cost and benefit of involved stakeholders) and the LMS model (available, calculated and missing KPIs).
2.2. Summary and conclusion

In this paragraph a concise summary and conclusion of chapter 2 on the exploration of the context of urban freight distribution is provided. Substantively, urban freight distribution and drivers of UFD are summarized. Furthermore, problems, solutions and the social need to move towards a more sustainable system are discussed. Finally, available regulation measures are given and the sub-question is answered. This section ends with some final remarks.

This chapter started with the following sub question:

(SQ I-1) What is the context of urban freight distribution and what problems and solutions are relevant?

The goal of this chapter was to explore the context of urban freight distribution. This exploration is executed by conducting a literature research. The following conclusions can be drawn from the literature research.

Urban freight distribution is defined in literature in many different ways. The definition that is used in this thesis is a combination of two definitions which are: 'The delivery of consumer goods (not only by retail, but also by other sectors such as manufacturing) in city and suburban areas, including the reverse flow of used goods in terms of clean waste' (Allen et al., 2000) and 'a large number of different types of freight flows that cross an urban environment'. Flows can consist out of consumer goods, waste products, building materials, postal mail and others. The term other is not further defined (Dablanc, 2007). The geographic area focus of this study is the high-density region of Haaglanden.

In total four trends can be defined that drive (future) demand of freight distribution in a region. The trends identified and verified through literature research are: growing population, urbanization, global e-commerce growth and dynamic inventory management concepts. These trends push and increase the demand of urban freight.

Urban freight distribution problems differ in nature and can be characterized as economic, environmental or socially grounded. Urban freight distribution operates in urban areas were space is in short supply. These residency areas are the homes of many people. Considering the fact that most vehicles still drive on conventional energy sources this result in greenhouse gas emission problems in cities. Safety and noise issues regarding old vehicles operating in urban areas also have a negative impact on liveability of cities.

In addition, urban freight distribution is rather inefficient because of low loading rates due to a lack of critical mass, the not-at-home problem and many stops due to small deliveries. Urban freight distribution takes place in high-density urban areas and small historical city centres congestion and slow driving traffic is a large problem for all distributors. Furthermore, inefficient bundling from a city perspective occurs and is mainly caused due to the lack of cooperation and consultation between receiver and carrier (Verlinde et al., 2012).

The social need to sustain urban freight distribution and to develop and improve the urban freight distribution system in high-density urban areas is large. The concept of sustainable development seeks to meet needs of present and future generations without abiding the fact that future generations are not able to meet their needs. The concept of sustainable developments can be divided in three principles, which include economic growth, social equity and environmental protection (Brundtland, 1987) (Wolff, 2004)

Solutions can be physical or behaviour of nature. A type of a physical solution is the traditional UCC. Another example is consolidation of freight without setting up an UCC. This type uses existing (mostly private owned) distribution centres to increase efficiency by enlarging freight flows. Another solution,
which is behavioural oriented and focused on retailers, carriers or both, is consolidation from a retailer/carrier perspective by increasing cooperation.

These solutions can vary in perspective, form and ownership. Variations in perspective are carrier versus receiver perspective (demand versus supply driven). Solutions or concepts can be privately owned, publicly owned or private-publicly owned. The type of ownership often results in different approaches, which can be top down (centralized or bottom up (decentralized).

General governance measurements derived from literature are time-window access, road pricing, creating sub-networks for freight vehicles, incentives to optimize transport efficiency and permits (for us of loading zones or type of vehicles)(Russo & Comi, 2010).

**Remark**
The context of urban freight distribution is complex. It holds various problems of different kinds of nature. Moreover, available solutions (theoretical and practical) are not proven to solve the entire problem or only favour some involved stakeholders. Both problems as available solutions are not entirely clear and differ for every stakeholder due to differences in points of view. This complexity is further increased by the multi-actor context of urban freight distribution and that stakeholders do not always carry both (social) cost and benefits. In addition, implemented measures by the municipality of Delft disrupt market functioning, which can result in higher cost for distributors or other involved stakeholders and eventually leads to a higher product prices for end consumers.
3. **CHAPTER 3  MULTI-ACTOR CONTEXT**

The next chapter starts with theory on multi-actor systems that is developed by de Bruijn and Heuvelhof (de Bruijn, J.A. & Heuvelhof, 2008). The aim of this section is to analyse in depth which stakeholders are involved in urban freight distribution. An elaboration on stakeholders’ interests, objectives, problem perceptions, formal and informal dependencies and common issues/grounds is conducted. Furthermore, mapping out the interdependencies between actors by making inventories of resources and the subjective involvement of actors with the problem. The analysis uses a 6-step framework developed by several professors of the faculty TPM at the TU Delft (Enserink et al., 2010). Theory developed by de Bruijn and ten Heuvelhof on multi-actor systems is embedded background information and lies at the centre of urban freight distribution systems. Theory on multi-actor systems are not threatened here but can be consulted in Appendix B.

### 3.1. **Stakeholder analysis**

The classic definition of a ‘stakeholder’ is that an actor/group that is affected or affects by the behaviour of the studied entity (Freeman, 1984). This means all stakeholders that are affected by urban freight distribution, in all means possible, are included in the analysis. An actor is defined as a social entity, person or organization that is able to act on or influence on a decision (Enserink et al., 2010). The procedure that is used to conduct the stakeholder analysis is the basic six-step framework (Enserink et al., 2010). In this section, the actor analysis is executed. The six-step theory on actor analysis is used as guidance and is further elaborated in Appendix B.

#### 3.1.1. **Step 1 – Problem Formulation**

The first step in the procedure is formulation of the problem as a point of departure. In chapter 2 an elaboration on problems regarding UFD is given. The perception of the problem owner, the municipality of Delft, is used as a starting point in combination with the problem exploration conducted in chapter 1.

The last mile of the supply chain is considered as economic inefficient, environmental damaging and a heavy social burden on an urban area. In this actor analysis, urban freight distribution in Delft is studied and the final section of the supply chain is (the last mile) is the entity. Everything that is geographically outside the urban area is outside the delineation. Problem owner is the municipality of Delft. From their perception, the importance of an efficient and sustainable UFD system is large. This means the system should be sustainable but simultaneously economically efficient, while taking into account the needs of as many involved stakeholders. The problem definition given in paragraph 1.2 is:

“Due to the expected growth of urban freight in the urban area of Delft and the social and environmental burden of UFD on the region, the municipality has developed a calculation model, the LMS, to gather data to increase knowledge regarding UFD. Knowledge on the performance and functioning of the LMS is still insufficient, as well as insight into the types of distributors that are active in the urban area. The Last Mile Scan could contribute in improving participation and cooperation among stakeholders involved, which is crucial to improve proper functioning of the entire UFD system.”

#### 3.1.2. **Step 2 – Stakeholders and Characteristics**

In this paragraph, an inventory of all actors involved in urban freight distribution is carried out. Conducting a brainstorm session where all stakeholders that either are influenced by or can influence the system are included.
Categorization based on type

First, a categorization of key stakeholders based on types is explored. Categorization is based on functionalities that the type of stakeholder performs. Four categories are introduced and discussed. The categorization is displayed in Figure 14 and provides an overview of the key stakeholders in urban freight distribution. The arrows between stakeholders suggest that they all have a certain (in)formal relationships and dependency upon each other (M. a P. Taylor, 2006).

![Figure 14 - Key stakeholders in urban freight distribution (M. a P. Taylor, 2006)](image)

**Shippers (or cargo owners)**

The first type of stakeholders introduced is the group of shippers. This might be confusing since shippers and freight carriers’ sound similar. Therefore, when talking about shippers the terminology of ‘cargo owners’ is used. The stakeholders in this category all legally own the transported cargo. The cargo owners can be retailers, wholesalers or manufacturers and are called consignor.

In case of a retailer, the cargo is generally bought of a wholesaler or manufacturer in large amounts. Shipping of cargo takes place after the cargo has been bought by and paid for. At time of shipping, a retailer often already owns the cargo. A Retailer can be either a physical or an online web store. The word retailer has been derived from the French word “retail” which means to sell in small rather than in gross quantities. Retailers are the chain between producer and consumer and they are often positioned at the end of the supply-chain (Puranik, 2015).

Another type of cargo owner is the wholesaler. A wholesaler does not produce goods themselves. They often buy goods (as a whole) at local markets and export these goods to foreign markets (Akerman, 2010). Wholesalers build and finance their own distribution network in foreign markets. Once the network is in place, they face a fixed cost to maintain their distribution network. Product characteristics influence the height of these costs. Complex products need higher standards of network characteristics and drive distribution network costs up. Producers, such as manufacturers can use the distribution networks of wholesalers instead of developing their own network. Wholesalers can spread fixed costs of their distribution network over more than one good compared to manufacturers that only ship a certain (often smaller) amount of goods to foreign markets. Economies of scale are the reason why wholesalers can offer good prices and are able to exist. A wholesaler can be the intermediary between manufacturer and freight carrier or manufacturer and retailer.

The last type of cargo owner is a manufacturer. A manufacturer produces goods, mostly from raw materials or semi-processed goods, to a final product. The whole products are often sold in large amounts to retailers and wholesalers. Furthermore, the manufacturers can also cooperate with distributors to distribute their products. Sometimes, large manufacturers own their own distribution networks. In these cases, they can organize the entire supply chain internally and they are therefore less dependent on other parties.
Residents
The second group of stakeholders discussed are residents. These stakeholders can be consumers or advocacy groups using their power to influence the public opinion and policy in behalf of residents of a certain region.

Consumers can be either residents living in the urban area or be visitors living somewhere else. Either way, these stakeholders are humans exposed to negative externalities caused by urban freight distribution. These externalities can be of environmental or social nature.

Advocacy groups are a type of stakeholder that tries to influence the general public opinion or urban freight transport policies. These groups either can hold an environmental idealism or are established by the transpiration sector to advocate in behalf of transportation companies to ensure the policy environment and new policies do not affect these stakeholders negatively. An example of an advocacy groups from the transportation sector are enterprise association EVO and association “Transport en Logistiek Nederland” (TLN).

Freight carriers (or distributors)
This type of key stakeholders is the freight carrier or more commonly known, the distributor. These distributors can be a transporter or carrier, freight forwarder or third-party logistics (TPL).

The transporters or carriers are hired by cargo owners to take care of transportation between origin and destination, for example between factory (manufacturer) and store (retailer). The transporters do not own cargo though they have a certain responsibility during transportation. Transporters are legally held responsible for damaged cargo or delivery. This group of distributors is the largest one.

The second type of distributor is a ‘freight forwarders’. This group takes care of a shipment on behalf of the buyer, the seller or even the carrier. Freight forwarders consolidate many small orders into larger shipments to advantage of higher load ratios. Freight forwarders are also known as forwarder or forwarder agent. International freight forwarders have specific knowledge and expertise in preparing and processing customs and other documentation (Wikipedia, 2015). Most of the time freight forwarders hold the same legal liabilities as a transporter/carryer.

The third type of distributors are ‘third-party logistic’ (TPL or 3PL) companies. These parties perform similar tasks as freight forwarders. However, the difference between freight forwarders and 3PL’s is that 3PL offers a full service package. Freight forwarders are specialized and focused on costs and logistics of transportation while 3PL’s offers overall service. Freight forwarders move cargo from origin to destination while 3PL’s move, store and process inventory and provide traditional forwarder services.

Compensation to an overall service can result in a less cost-effective solution for cargo owners. They need to find a balance between the ease of using a ‘third-party logistic’ company who handles the entire logistic process versus a higher cost of the service. Figure 15 provides a schematic overview of the key stakeholders, their services and how they relate to the level of service integration.

Figure 15 – Schematic overview of some key stakeholders, services and relations (Norall, 2013)
**Planners and regulators**

The last category of key stakeholders is the group of planners and regulators. In this category, different levels of governmental bodies are listed. These levels can be distinguished on national, state and city level. Furthermore, urban planners also fall under the umbrella of planners and regulators.

The first type of regulators is the national government body. This is the highest level of body that can influence urban areas by their plans and laws and regulations. In the Netherlands, this is the ‘Ministry of Infrastructure and the Environment’ (MolatE).

One level lower, the government state bodies are located. In the Netherlands there are twelve state bodies, every province has his own body. These bodies form the administrative layer between the national government and municipalities. They perform activities that are too small for central governments due to highly detailed and local knowledge demands but are on the other end too large for municipality bodies. They function as the communication channel between national government and municipalities.

The third and final types of regulator are the city bodies, also known as the municipalities. These regulators are the lowest layer of governmental bodies. Their focus lays on improving liveability of the municipality for their habitats. The last decade the number of municipalities is gradually decreasing. In 2015 the Netherlands still consist of 393 municipalities in total (Wikipedia, 2015). The municipality of Delft is one of them and is the problem owner.

**Case: Municipality of Delft**

In this thesis, focus is on these four key stakeholders. The municipality of Delft acts as a planner and regulator. Habitants of Delft act as the consumers. Cargo owners are parties that want to transport their cargo into the urban area of Delft. Distributors are parties that actually move cargo and can be cargo owners themselves, carrier, freight forwarder or 3PL. These four groups of stakeholders are considered in further analysis. All types per category are taken into account. If category level is sufficient, it is used instead.

Various approaches can be helpful to generate a full list of relevant involved stakeholders. The following approaches are useful: the imperative approach, the positional approach, the reputational approach, the social participation approach, the opinion leadership method, the demographic approach and the problem diagram and causal map. Not all approaches are relevant or can be of benefit. Approaches that have benefit are applied in next paragraphs.

The imperative approach tries to capture all relevant stakeholders that feel strongly about a certain policy, issue or solution. Most of these key stakeholders are already present. A stakeholder that comes to mind is the ‘road user’ that might be influenced by new regulations and policies. Some of these road users fall under the umbrella of residents and consumers, some do not.

The social participation approach is applied to identify all relevant stakeholders that participate in activities relating to the problem, policy and solution. Various associations that are important to include in the analysis are EVO, which is an entrepreneurial association that represents the interests of logistic oriented companies, and association ‘Transport en Logistiek Nederland’ (TLN) that represents interests of transportation companies in the Netherlands. Further appliance of approaches does not seem to be relevant or have benefit. The full list is generated and used in future steps provided in Table 3.
The overview of stakeholders in urban freight distribution in general can be further specified in case of Delft. The overview of stakeholders involved in UFD in the municipality of Delft is given in Table 4.

Table 3 - Overview of stakeholders in urban freight distribution in general

<table>
<thead>
<tr>
<th>Cargo owners</th>
<th>Residents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>Habitats</td>
</tr>
<tr>
<td>Wholesaler</td>
<td>Advocacy groups</td>
</tr>
<tr>
<td>Retailer</td>
<td>Road user</td>
</tr>
<tr>
<td>Distributors</td>
<td>Planners and regulators</td>
</tr>
<tr>
<td>Carrier</td>
<td>Government bodies (national/regional)</td>
</tr>
<tr>
<td>Freight forwarder</td>
<td></td>
</tr>
<tr>
<td>Third party logistic (TPL/3PL)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
</tr>
<tr>
<td>EVO</td>
<td></td>
</tr>
<tr>
<td>TLN</td>
<td></td>
</tr>
</tbody>
</table>

Table 4 - Overview of stakeholders in urban freight distribution municipality of Delft

<table>
<thead>
<tr>
<th>Cargo owners</th>
<th>Residents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturers with delivery in municipality</td>
<td>Habitats of municipality of Delft</td>
</tr>
<tr>
<td>of Delft</td>
<td>Road users urban area of Haaglanden</td>
</tr>
<tr>
<td>Wholesalers shipping to municipality of Delft</td>
<td></td>
</tr>
<tr>
<td>Retail in municipality of Delft</td>
<td></td>
</tr>
<tr>
<td>Distributors</td>
<td>Planners and regulators</td>
</tr>
<tr>
<td>Own carrier (Albert Hein, etc.)</td>
<td>Ministry of Infrastructure and Environment</td>
</tr>
<tr>
<td>Fast forwarder (PostNL, UPS, DHL, TNT express)</td>
<td>State of South-Holland</td>
</tr>
<tr>
<td>Solo proprietorship</td>
<td>Municipality of Delft</td>
</tr>
<tr>
<td>Other</td>
<td></td>
</tr>
<tr>
<td>EVO</td>
<td></td>
</tr>
<tr>
<td>TLN</td>
<td></td>
</tr>
<tr>
<td>Environmental group</td>
<td></td>
</tr>
</tbody>
</table>

3.1.3. **STAKEHOLDERS INTERESTS, OBJECTIVES AND PERCEPTIONS**

In this paragraph, the problem formulation of all involved stakeholders is systematically drafted by looking at their interest, objectives and problem perception. The outcome of this analysis is an overview of interest, objectives and perception of all key stakeholders and can be consulted in Appendix B Table 44.

To summarize distributors and cargo owners mainly hold the same interests since these groups of stakeholders operate from a commercial perspective. In contrary, habitats, government bodies and environmental groups mainly have interest in clean, safe and an attractive municipality that can be realized by sustaining the UFD system. Furthermore, road users do not like obstacles when driving. This means low prices and no congestion. Last, EVO/TLN has interest in well-maintained traffic networks and a good sector image to the outside world. Again, more details on the full analysis can be consulted in Appendix B in Table 44.

3.1.4. **STEP 4 – INTERDEPENDENCIES**

In this paragraph the interdependencies or network of power is from the perspective of the problem owner, the municipality of Delft is explored. The following three aspects determine the dependency: resource dependency of the problem owner towards critical actors, the extent to which those resources are replaceable and the degree to which interest and objectives are in line (problem owner and stakeholder have similar interest). These aspects are treated in the next section.
Table 5 gives an inventory of important resources of involved key stakeholders. These resources are unique and give a stakeholder a certain degree of power.

Table 5 - Inventory of important resources

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Important resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer/wholesaler/retailer</td>
<td>A strategic position in the network. Manufacturers, wholesalers and retailers have the power and access to other actors involved to force a breakthrough by initiating and improving cooperation and information sharing.</td>
</tr>
<tr>
<td>Habitats</td>
<td>The power to demand a clean, safe and attractive municipality and urban area. The community has enough citizens and therefor manpower to form a coalition and claim social and environmental improvements. Furthermore, they have the legitimacy to say something since they have to carry the burden of UFD.</td>
</tr>
<tr>
<td>Distributor</td>
<td>These parties mainly carrying out the work they have been hired for. Although it won’t be listed anywhere on their agenda they have the power to change vehicle characteristics and lower the social and environmental burden. The also poses a certain degree of knowledge and skill.</td>
</tr>
<tr>
<td>Ministry of Infrastructure and Environment</td>
<td>Authority of implementing new legislation on relevant policies (such as vehicle restrictions, time windows, obligation to use a central distributor with specific requirements) to improve sustainable urban freight systems in urban areas.</td>
</tr>
<tr>
<td>EVO/TLN</td>
<td>Network connections and formal relations among the entire transportation sector. Authoritarian position towards all transpiration companies involved in the urban freight distribution system.</td>
</tr>
<tr>
<td>Environmental group</td>
<td>Knowledge and expertise regarding environmental protection and pollution reduction.</td>
</tr>
</tbody>
</table>

Table 6 - Resource dependency

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Important resource</th>
<th>Replaceable?</th>
<th>Dependency</th>
<th>Critical actor?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer/wholesaler/retailer</td>
<td>Strategic position in network and organization</td>
<td>No</td>
<td>High dependency</td>
<td>Yes</td>
</tr>
<tr>
<td>Habitats</td>
<td>Manpower and legitimacy</td>
<td>Yes</td>
<td>Limited dependency</td>
<td>No</td>
</tr>
<tr>
<td>Distributor</td>
<td>Average strategic position in network and knowledge &amp; skill</td>
<td>No</td>
<td>High dependency</td>
<td>Yes</td>
</tr>
<tr>
<td>Ministry of Infrastructure and Environment</td>
<td>Authority and formal power</td>
<td>No</td>
<td>Medium dependency</td>
<td>Yes/No</td>
</tr>
<tr>
<td>EVO/TLN</td>
<td>Network connections, information, formal connections and some form of authorization</td>
<td>No</td>
<td>Medium dependency</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Environmental group</td>
<td>Knowledge and expertise</td>
<td>Yes</td>
<td>Limited dependency</td>
<td>No</td>
</tr>
</tbody>
</table>

Table 7 - Overview of critical and non-critical actors

<table>
<thead>
<tr>
<th>Similar interests and objectives</th>
<th>Critical actors</th>
<th>Non-critical actors</th>
<th>Conflicting interests and objectives</th>
<th>Critical actors</th>
<th>Non-dedicated actors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer/wholesaler/retailer</td>
<td>Habits</td>
<td>Ministry of Infrastructure and Environment</td>
<td>EVO/TLN</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Not all stakeholders have been threatened because not all hold critical or important resources. The actor ‘road users’ does not hold resources that are of any importance to the municipality of Delft. This actor is not included in further analysis. The resources are further elaborated on to what extent a resource is replaceable, the degree of resource dependency and concluded with the final remark of critical versus non-critical. Table 6 presents an overview. The degree of resource dependency is evaluated with aid of Table 7. Resources that can be replaced are rated limited/medium dependent. Opposite, resources that are harder to replace are rated medium/high dependent.

Based on the analysis the stakeholders’ manufacturer/wholesaler/retailers (cargo owners) and distributors (carriers) are critical actors. All other parties have resources where the municipality of Delft is limited to medium dependent on. These resources are either non-critical or can be replaced. Both the cargo owners as well as the carriers hold strategic positions in the urban freight distribution system what makes them critical actors that need to be involved in the process of moving towards a sustainable urban freight distribution system.
Another angle of approach is to analyse the degree of dedication of involved stakeholders. The degree of dedication is based on the interest of actors towards the problem and their willingness to use their resources. Mapping these actor interdependencies and their degree of dedication provides information to what extent involvement of actors can be expected and when they will, is involvement be positive or negative. Mapping interdependency tables (both general and from the perspective of the Municipality of Delft) are displayed in Table 8 and Table 9.

**Table 8 – General interdependencies table**

<table>
<thead>
<tr>
<th>Limited options to replace</th>
<th>Limited importance</th>
<th>Great importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can easily be replaced</td>
<td>Medium dependency</td>
<td>High dependency</td>
</tr>
</tbody>
</table>

**Table 9 – Interdependencies table from the perspective of the Municipality of Delft**

<table>
<thead>
<tr>
<th>Limited options to replace</th>
<th>Limited importance</th>
<th>Great importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can easily be replaced</td>
<td>Environmental group</td>
<td></td>
</tr>
</tbody>
</table>

The information from Table 8 can also be visualized in a so-called ‘stakeholder map’ or ‘power versus interest matrix’. These visualizations hold as advantage easier communication of information and providing a good overview of the relations and important patterns. An empty power versus interest matrix is given in Figure 16. The x-axis classifies stakeholders on their degree of interest or willingness to participate. The y-axis classifies stakeholders to their degree of power to influence the process and the proposed solutions. The pluses and minuses are used to indicate if an actor supports or opposes the main interests and objective of the problem owner.

![Figure 16 - Power versus interest grid (Bryson, 2004)](image-url)
The power versus interest grid retrieved from (Bryson, 2004) in case of urban freight distribution in Delft is applied below. The six key stakeholders are mapped and visualized on the grid in Figure 17.

![Image of power versus interest grid]

Figure 17 - Power versus interest grid of the urban freight distribution system from the perspective of the municipality of Delft

The conclusion that can be drawn from the power versus interest grid is that the ‘key players’ (high level of interest and high level of power) both have an opposite objective and interest towards the problem of the municipality of Delft (both 2* minuses). The problem formulation is in that sense too far away from the purely economic motives of the cargo owners and the freight carriers. These key stakeholders do not recognize the need to move towards a more sustainable urban freight distribution system. This is disturbing since these stakeholders are critical to improve the system and overcome urban freight problems.

Furthermore, the group of ‘context setters’ (low level of interest and high level of power), in this case the habitats hold corresponding objectives and interest towards the problem statement and need to be satisfied by the municipality of Delft. They do have power to influence the process but they only participate in case developments turn badly to their interest.

The environmental group is categorized in quadrant known as the group of ‘crowd’ (low level of interest and low level of power). This type has minimal effect and seems to hold little interest in participating in the process. The awareness and power are not significant enough. As well as the habitats they hold a positive interest toward the initial problem statement.

The last quadrant, the group of ‘subjects’ (high level of interest and low level of power) need to be informed. Both the Ministry of Infrastructure and Environment and EVO/TLN fall in this category. They are both very interesting in all developments but do not have high power to influence the process directly. However, if certain developments tend to move in a minus direction they can move towards the quadrant of ‘key players’ and try to pull some strings to influence the development on their behave.

3.1.5. **Step 5 – Consequences**

Let us have another look at the problem formulation first before concluding what consequences the outcome of the actor analysis has on the problem. The problem formulation is:

“Due to the expected growth of urban freight in the urban area of Delft and the social and environmental burden of UFD on the region, the municipality has developed a calculation model, the LMS, to gather data to increase knowledge regarding UFD. Knowledge on the performance and functioning of the LMS is still insufficient, as well as insight into the types of distributors that are active in the urban area. The Last Mile Scan could contribute in improving participation and cooperation among stakeholders involved, which is crucial to improve proper functioning of the entire UFD system.”

Concluded from paragraph 3.1.3 that the involved stakeholders have different interests, objectives and problem perspectives. Furthermore, paragraph 3.1.4 shows that two groups of stakeholders, cargo owners and distributors, have a lot of power and are critical stakeholders since these groups need to be involved in the process to sustain the UFD system. In addition, these groups retain an adverse position towards the main objective and interest of the problem owner, the municipality of Delft. Therefore, **improving participation and cooperation among involved stakeholders that is crucial**
to improve proper functioning of the entire UFD system can become a rather difficult goal to accomplish. The section of the problem formulation that addresses in detail functioning of the LMS model and if the model contributes in sustaining the UFD system is not yet treated and is further elaborated in chapter 4.

## 3.2. Summary and conclusion

To finalize this chapter, the sub question of this chapter needs to be answered. To repeat the sub question:

**(SQ I-2) What stakeholders are involved in urban freight distribution systems?**

The context of urban freight distribution can be identified as a multi-actor context where different stakeholders have different interest and issues’ regarding the way the urban freight distribution system (UFDS) is organized. They vary in objectives, since some are economic driven while others are more social and environmental driven. Furthermore, not all stakeholders can influence the UFD system. In general, the theory developed de Bruijn and ten Heuvelhof on multi-actor context is used as starting point.

A six-step actor analysis framework is introduced and applied. Research on the multi-actor context and an extensive actor analysis is important because results provide a full picture of needs of participants of a system, in this case the urban freight distribution system. To understand a system, knowledge on what factors drive involved stakeholders and what issues they encounter is key. Solutions to increase sustainability of the system, as well as to improve the LMS model to have a good fit with needs of involved stakeholders, if not a renewed system will definitely fail.

Stakeholders identified in urban freight distribution can be distinguished in five categories. These groups are: cargo owners, distributors, residents, planners and regulators and interest associations and environmental groups. Each category consists of a number of stakeholders. Table 10 provides an overview of the case study of involved stakeholders in urban freight distribution in the municipality of Delft.

### Table 10 - Overview of stakeholders in urban freight distribution municipality of Delft

<table>
<thead>
<tr>
<th>Cargo owners</th>
<th>Residents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturers with delivery in municipality of Delft</td>
<td>Habitats of municipality of Delft</td>
</tr>
<tr>
<td>Wholesalers shipping to municipality of Delft</td>
<td>Road users urban area of Haaglanden</td>
</tr>
<tr>
<td>Retail in municipality of Delft</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Distributors</th>
<th>Planners and regulators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Own carrier (Albert Hein, etc.)</td>
<td>Ministry of Infrastructure and Environment</td>
</tr>
<tr>
<td>Fast forwarder (PostNL, UPS, DHL, TNT express)</td>
<td>State of South-Holland</td>
</tr>
<tr>
<td>Solo proprietorship</td>
<td>Municipality of Delft</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVO</td>
</tr>
<tr>
<td>TLN</td>
</tr>
<tr>
<td>Environmental group</td>
</tr>
</tbody>
</table>

An inventory of important resources, resource dependency, critical and non-critical actors and power versus interest is conducted for every stakeholder.

Cargo owners and distributors possess a high degree of power to influence the UFD system because they possess important resources due to their strategic position in the network. In general, these involved stakeholders have conflicting interest and objectives with the problem owner, municipality of Delft. They mainly seek to optimize profit while the municipality seeks to sustain the urban freight distribution system. These stakeholders are dedicated and have a high interest towards the researched entity.
Residents possess a high degree of power due to their manpower and legitimacy to demand a clean, safe and attractive urban area. This group is not directly a critical actor and the municipality is limited dependent on their resources. Residents have similar interest and objectives as the problem owner. The level of interest towards the UFD system is low but can increase if urban freight influences their living.

Planners and regulators, in this case, the Ministry of Infrastructure and Environment possess a medium degree of power because the municipality controls local decision-making. They do have the resources to implement new legislation or policies that can impact the system and are therefore a critical actor. Their interest towards the problem is high and is similar as the municipality of Delft since both actors seek to further sustain urban freight distribution.

Environmental groups are easy replaceable and are therefore a non-critical actor. The resource (knowledge and expertise) dependency of the municipality is limited. They have limited power to influence the UFD system. Residents have similar interest and objectives as the problem owner.

All these conflicting interest, different levels in degrees of power, bilateral dependencies and resource dependency makes it difficult to implement solutions, create awareness to the urge of change and activate stakeholders to contribute.
**Phase II**  
**Validation of the Last-Mile Scan**

In this phase, the last-mile scan (LMS) is introduced and validated extensively. This phase identifies a list of shortcomings, additions and possible extensions of the LMS model. Next, misfits of the model compared to needs of the urban freight distribution context are evaluated. Finally, data and cluster analysis are conducted to explore and explore collected data and improve usage of this valuable information.

<table>
<thead>
<tr>
<th>Phase II - The Last-Mile Scan</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.4 - Validation of the LMS</td>
</tr>
<tr>
<td>C.5 - Data analysis</td>
</tr>
<tr>
<td>C.6 - Cluster analysis</td>
</tr>
<tr>
<td>C.7 - Shortcomings of the LMS</td>
</tr>
</tbody>
</table>

**Outcome Phase II**

<table>
<thead>
<tr>
<th>Validation process results</th>
<th>Data analysis results</th>
<th>Cluster analysis results</th>
<th>An ideal LMS model</th>
</tr>
</thead>
</table>

*Figure 18 - Structure of phase II*

**Chapter 4**  
**Validation process of the LMS**

The validity of the model is explored. First part of this chapter elaborates on the original purpose of the scan (aim of developing). Subsequently, the functionalities of the scan are explored. Furthermore, the mathematical formulas, input parameters and data are threatened. Thereafter, the usability of the scan is critically evaluated. The research question that is answered at the ending of this chapter is:

(SQ II-1) *Is the LMS a valid model?*

**Chapter 5**  
**Data analysis**

In this chapter, data that has been collected by MD is used to analyse and explore relationships of variables. Relationships between variables (total) cost, (total) time and (total) distance of a trip are researched. Next, the link between prices and distribution ratios is analysed. First, the procedure of data collection is discussed. Subsequently, a case study is introduced and collected data analysed to explore relations between important key performance indicators.

(SQ II-2) *How is data collected and in what conclusions can be drawn from the data sample?*

**Chapter 6**  
**Cluster analysis**

In this chapter, a cluster analysis is applied. The methodology is introduced first. Thereafter, different types of distinction possibilities and key performance indicators are discussed. This chapter ends with some remarks on how different types of freight carriers perform.

(SQ II-3) *How can a cluster analysis be conducted to see performance levels of different types of freight carriers on formulated key performance indicators?*

**Chapter 7**  
**Shortcomings of the LMS**

This chapter emphasizes deeper on shortcomings, potential improvements and extensions of the LMS model. Weaknesses and strengths are identified. In addition, certain trade-offs that are made during the development process are discussed and evaluated. Thereafter, an evaluation of needs of the UFD context compared to key performance indicators is conducted. An evaluation on functionalities of the model and how these can support involved stakeholders is conducted. This section ends with an exploration of potential development directions and a possible ideal LMS model.

(SQ II-4) *What are shortcomings and potential improvements of the LMS and does the model fit UFD context needs?*
4. CHAPTER 4 VALIDATION PROCESS OF THE LMS

In the first paragraph, a brief literature research is conducted to explore available validation techniques and methodologies. Authors as Kleijnen and Sargent published a number of scientific articles on validation techniques and methodologies. First, the chosen validation framework is introduced. In addition, another validation methodology, sensitivity analysis is discussed. The extensive literature review on validation methodologies can be consulted in Appendix D.

4.1. Validation framework

Figure 19 displays the conceptual framework developed by Sargent that describes the process of how to get from one entity to another (R. G. Sargent, 2005). This conceptual framework is an approach that could be applied and help in building validated and credible simulation models. This framework is used as guidance in the validation process of the LMS.

To ensure the LMS is validated properly all phases of the validation process in the framework are applied. These phases are conceptual model validation, operational validation, computerized model verification and data validity.

Conceptual model validation

Conceptual model validation is defined by determining if the theories and assumptions underlying the conceptual model are correct. Furthermore, it validates if the conceptual model is a reasonable representation of the problem entity and if it serves the purpose and reason of development. Questions answered in this step of the validation process are:

- Are theories and assumptions correct?
- What formulas and assumptions are used?
- Is the model a reasonably representation of the problem entity?
- Does the model serve the purpose and reason of development?

Computerized model verification

Computerized model verification is defined as determining if the computer programming (the translation of assumptions and theories into computer language) and if the implementation is right.

Data validity

Data validation is the process of determining if input data that is used for model building, model evaluation and testing is adequate and correct.
Operational validation
Operational validation is the process of verifying the outcome of the computerized model has sufficient accuracy in relation to the intended purpose of development. Validation is reached through logic reasoning and expert consulting. Finally, the outcome of the model can be verified with real data (if available) and could be crosschecked with similar models.

Sensitivity analysis
Sensitivity analysis (SE) or what-if analysis is a validation technique that is applied often. The technique is especially suitable if there is no or only scarce data available (Fossett & Harrison, 1991). This type of study tries to analyse how the outcome of a model apportioned to sources of uncertainty in its inputs. Sensitivity analysis can support model validation. Parameters can be varied to see if outcomes of the model agree with prior knowledge. Furthermore, sensitivity analysis can give an indication in the importance of factors/parameters (Kleijen, 1999). There are different forms of sensitivity analysis. The simplest type is the one-way sensitivity analysis. This analysis changes one variable or parameter at the time to see the impact on the outcome of the model. This is called ‘main effect’ in ANOVA, Analysis of Variance (Kleijen, 1999)(M. Taylor, 2009). A more complex type of sensitive analysis is the multi-way sensitivity analysis. In some models it is important to examine the relationship of two or more parameters at the same time (M. Taylor, 2009).

4.2. Last-mile scan background information
In 2009 Connekt initiated a workgroup with various stakeholders from the transportation sector. In the workgroup associations like ‘Transport en Logistiek Nederland’ (TLN) and ‘Ondernemersorganisatie voor logistiek en transport’ (EVO) and various municipalities (Delft, Arnhem, Nijmegen, Utrecht, Amsterdam and Breda) participated. Derived from this workgroup the initiative ‘Maatwerk Distributie’ (MD) has been established. MD is procured and owned by the municipality of Delft. Dhr. B. Coremans, employee of the Municipality of Delft, is project manager of MD and developed the LMS in participation with companies Buck Consultants International (BCI) and Panteia.

The model is eventually called the ‘Last Mile Scan’.

The LMS is a tool and calculation model that attempts to simulate and predict individual cost for freight carriers on their last mile. The model tries to capture reality in such a way that complexity of the model is within hand able boundaries and the results of the model are interpretable and have sufficient level of accuracy and detail to remain usable. The model does not provide an aggregated overview of a particular area or region. It simple uses input variables (collected from individual freight carriers), input data (constants) and mathematical formulas to be able to give estimations on cost of a last mile trip of a carrier. The following steps are threatened subsequently.

- Conceptual model validation (paragraph 4.3)
- Computerized model verification (paragraph 4.4)
- Data validity (paragraph 4.5)
- Operational validation (paragraph 4.6)
- Sensitivity analysis (paragraph 4.7)
In the next paragraph the conceptual model validation is conducted. Recap from Appendix 0 on conceptual model validation, the method determines if theories and assumptions underlying the (conceptual) model are correct. Furthermore, it validates if the conceptual model is a reasonable representation of the problem entity and if it serves purpose and reason of development. All these matters are explored and analysed in this chapter. The questions are answered and summarized at the end of this section. In this paragraph the purpose of development is threatened and an elaboration on all functionalities of the LMS is analysed.

**Purpose of development**

In phase I, an extensive literature research on urban freight distribution is conducted. Urban freight distribution, and more particular the last mile of the supply chain, is economically inefficient, environmental damaging and a heavy social burden on the region. In addition, it is noticed that the amount of urban freight will increase in the near future due to a number of trends that have been identified. To recapitulate, these worldwide trends are population growth, a flourishing e-commerce sector, urbanization and innovative concepts like dynamic inventory management.

In general, these developments mean that sustaining the urban freight distribution system is not a natural matter of course but takes time and effort to realize. These efforts need to come from all involved stakeholders. Collaboration and information sharing among them is a crucial part and could contribute to ensure proper functioning of the UFd system and to achieve higher sustainability, more economic gains and other social and environmental benefits.

After ‘Maatwerk Distributie’ was established the workgroup concluded that a certain group of stakeholders, freight carriers, not always know or have a clear overview of their cost structure on the last mile. In phase I, on actor analysis, it is shown that the interests and objectives of freight carriers are mainly economic. In other words, they conduct economic driven. In general, stakeholders that make decisions on the basis of economic terms must have knowledge on current performance levels on the final section of the supply chain to be able to implement suitable policy. Surprisingly, this is not the case in practise (Maatwerk Distributie, 2015).

**Knowledge gap**

The lack of information on the cost structure of the last mile of the supply chain can be identified as a knowledge gap. The desired situation is a full understanding of the cost structure. From the perspective of the municipality of Delft this line of reasoning can be drawn a bit further. They do not only like to know more about transport cost but would like to have an indication on what carriers are operating in a sustainable and society responsible matter.

**Identify, facilitate and regulate**

The purpose for developing the LMS is threefold and formulated by MD as identify, facilitate and regulate. The first objective, identify, is about collecting data and information by making an inventory of all activities in an urban area. With activities is meant all shipments that take place in the region. The second objective, facilitating, is providing freight carriers information by giving them an indication on their cost structure. Collected information and knowledge can be used to mediate between freight carriers and other involved stakeholders such as central distributors or retailers active in the region. The final objective, regulate, can be achieved by usage of outcome of the model to develop local policy measures. This can only be applied if results are of sufficient accuracy and valid.

**The LMS model**

The LMS uses formulas, assumptions, indicators and tools to conduct calculations. Outcome of the model consist of dimensions’ distance, time and cost. These three dimensions are used throughout the entire model. The general result of the LMS is twofold. First, the LMS estimates transport cost of freight carriers on the last mile based on their characteristics, expressed in euros. Secondly, the LMS calculates the probability of saving. This probability is based on the outcome of the LMS (estimation of transport cost) compared to an alternative situation. The alternative is a central urban freight distributor with competitive tariffs. Information on the level of tariffs is received from PostNL.
In order to give freight carriers’ an estimation of their last mile cost characteristics of the shipment are needed. Characteristics, expressed in variables such as: vehicle type, origin, destination, number of stops, number of small packages, number of large packages, place of activity (‘in’ and/or ‘outside city centre’), active during peak hours and number of days active per week are needed and used as input variables. Besides, a number of assumptions are made to calculate cost of a last mile and to make assumptions on the probability of saving money. These assumptions are further elaborated in paragraph 4.5 on data validity.

The LMS is a deterministic calculation since similar input variables always result in exactly the same output. A definition of a deterministic model is: “mathematical model in which outcomes are precisely determined through known relationships among states and events, without any room for random variation. In such models, a given input will always produce the same output, such as in a known chemical reaction” (Businessdictionary, 2015). In contrary, there are stochastic models; these types of models have the capacity to handle uncertainty in input variables by using distributions as ‘random’ (stochastic) or ‘uncertainty’ (deterministic + noise) input variables. Chapter 5 elaborates on the reason to choose this type of model.

The LMS is available in different urban areas and cities in the region of Haaglanden. The municipalities that are included are Delft, Rijswijk, Leidschendam-Voorburg, Pijnacker-Nootdorp, Den Haag and Leiden. All these areas differ in spatial structure. These differences are translated into the model in variation of assumptions, input variables and constants. Every region is subdivided in different areas. All regions have a maximum of three areas. In the case of Delft, the region is divided in only two subareas. These are ‘Delft centre’ and ‘outside the centre’. In the case of Delft, the region has a total number of six access/exit roads. All these access/exit points have specific coordinates that are used by the model. Elaboration on the use of these coordinates is treated in a later stage of this chapter.

Figure 19 provides an overview of the city of Delft and all six access and exit roads. The access roads can be recognized as ‘green dots’ and the exit roads by ‘red squares’. The stars display the centres of both areas (centre and outside).
4.3. Conceptual model validation

In this paragraph the conceptual model is explained. Relations between input variables, constants (assumptions) and output variables are threatened. The conceptual model is analysed by appliance of the causal relation diagram (CRD) and the black box principle. The black box of the LMS is discussed first. Subsequently the causal relation diagram is introduced. The full CRD and description can be consulted in appendix E.

4.3.1. Black box and causal relation diagram

The black box visualizes a system and more specific input variables that are needed to calculate output variables. The calculations to get from input variables to output variables, which are the centre of the black box, are elaborated in the causal relation diagram and in paragraph 4.4 in the computerized model verification phase.

Black box

The LMS model is using input variables and constants to generate results (output variables). Input variables can be distinguished on type. The model uses time, location and delivery input variables (orange variables) that enter the black box. The information is gathered through conducting a scan with a participant (a freight carrier). The scan consists out of a number of questions filled out by a freight carrier active in one or more of the six regions. The results of the model are output variables that exit the black box at the bottom (green variables). To calculate output variables constants, data and formulas are needed. Constants (purple variables) enter the black box on the left side. Next paragraph discusses all input variables, constants and output variables. The black box of the LMS is shown in Figure 20.

Figure 21 – Black box of the LMS
Causal relation diagram

The relation between the CRD and the black box is simple; the causal relation diagram is the centre of the black box. It elaborates in detail on the relations between input variables, constants and output variables. In addition, the CRD uses system variables and formulas that are needed to calculate output variables. Output variables are discussed from start (input and constants) via calculations (formulas/system variables) to result (output variables). The constants are derived from expertise and traffic data. This is further analysed in paragraph 4.5 on data validity.

4.3.2. INPUT VARIABLES

In previous section the black box and the causal relation diagram are introduced. In this paragraph all input variables, constants and output variables are treated subsequently.

Time

Input variables regarding time are activity during peak hours and number of days active.

- Peak hours [1/0]
  This variable captures if a freight carrier is active during peak hours. The participant can be either active in peak hours [1] or active outside peak hours [0].
- Number of days active [1-7]
  This variable captures the number of days a carrier is active per week. This can vary between 1 till 7 days.

Location

Input variables regarding location are vehicle type, activity in city, route and activity in specific area of a city.

- Vehicle type [1-9]
  This variable captures all possible vehicle types. Nine vehicle types are distinguished. These types vary between smaller vans to larger trucks. In addition, trucks with a large trailer are included.
  Table 11 gives a full overview of type of vehicles.

<table>
<thead>
<tr>
<th>Number</th>
<th>Type of vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Van (GVW 1000 kg)</td>
</tr>
<tr>
<td>2</td>
<td>Van (GVW 1350 kg)</td>
</tr>
<tr>
<td>3</td>
<td>Van (GVW 1650 kg)</td>
</tr>
<tr>
<td>4</td>
<td>Truck (GVW &lt;4000 kg)</td>
</tr>
<tr>
<td>5</td>
<td>Truck (GVW &lt;12 ton)</td>
</tr>
<tr>
<td>6</td>
<td>Truck (GVW 12 - 16 ton)</td>
</tr>
<tr>
<td>7</td>
<td>Truck (GVW &gt;16 ton)</td>
</tr>
<tr>
<td>8</td>
<td>Truck + trailer</td>
</tr>
<tr>
<td>9</td>
<td>Tractor + trailer</td>
</tr>
</tbody>
</table>

- City [1-6]
  The LMS is active in six different cities. Table 12 gives an overview of these cities.

Table 12 - Overview of cities where LMS is active

<table>
<thead>
<tr>
<th>Number</th>
<th>Type of vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Delft</td>
</tr>
<tr>
<td>2</td>
<td>Rijswijk</td>
</tr>
<tr>
<td>3</td>
<td>Leidschendam-Voorburg</td>
</tr>
<tr>
<td>4</td>
<td>Pijnacker-Nootdorp</td>
</tr>
<tr>
<td>5</td>
<td>Den Haag</td>
</tr>
<tr>
<td>6</td>
<td>Leiden</td>
</tr>
</tbody>
</table>
• Route (access/origin and exit/destination) [1-6]
The LMS uses access and exit roads to calculate distances. The city of Delft uses a total number of six access and exit roads. Table 13 and Table 14 give an overview of the names of the access and exit roads and corresponding coordinates.

Table 13 - Overview of coordinates of access roads

<table>
<thead>
<tr>
<th>Coordinates</th>
<th>Access roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>51.997346 x 4.389551</td>
<td>A13 access road Delft South</td>
</tr>
<tr>
<td>52.011742 x 4.378154</td>
<td>A13 access road Delft Centre</td>
</tr>
<tr>
<td>52.026521 x 4.360689</td>
<td>A13 access road Delft North</td>
</tr>
<tr>
<td>51.983031 x 4.329146</td>
<td>A4 via 'Kruithuisweg' (N470)</td>
</tr>
<tr>
<td>52.019619 x 4.330763</td>
<td>A4 via 'Provincialeweg'</td>
</tr>
<tr>
<td>52.007614 x 4.387353</td>
<td>N473 via 'Delfgauwseweg'</td>
</tr>
</tbody>
</table>

Table 14 - Overview of coordinates of exit roads

<table>
<thead>
<tr>
<th>Coordinates</th>
<th>Exit roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>51.995705 4.389884</td>
<td>A13 exit road 'Delft South'</td>
</tr>
<tr>
<td>52.016621 4.334160</td>
<td>A4 via 'Provincialeweg'</td>
</tr>
<tr>
<td>52.010948 4.376283</td>
<td>A13 exit road 'Delft Centre'</td>
</tr>
<tr>
<td>51.982922 4.324160</td>
<td>A4 via 'Kruithuisweg' (N470)</td>
</tr>
<tr>
<td>52.026454 4.360792</td>
<td>A13 exit road 'Delft North'</td>
</tr>
<tr>
<td>52.007589 4.387462</td>
<td>N473 'Delfgauwseweg'</td>
</tr>
</tbody>
</table>

• Area [1,2 or both]
The final input variable regarding location is activity in specific area of a city. This means that every city is divided in 2 areas. A freight carrier can either be active in 1, 2 or in both areas.

Delivery
The scan asks freight carriers how many small and large packages they deliver and the amount of stops they are making during a shipment. The amount of packages and stops that can be chosen varies between 1 and 25. Input variables regarding delivery are given below.

• #small packages [1-25];
• #large packages [1-25];
• #stops [1-25];

4.3.3. Constants

The model needs more information, or data, to be able to execute necessary calculations. This data are mainly assumptions made during the development phase of the model and are collected throughout extensive field research conducted by an external research company Panteia. Additionally, students conducted field research by way of counting. All this research has been put together to generate accurate assumptions as constants. The constants enter the black box from the left side and are discussed below.

• dInOut [meters]
This constant represents the average distance to get from an access road to the centre of an area and from this centre to an exit road. The value of this constant is dependent on infrastructure characteristics of a region. The dimension is meters.

• dStops [meters]
The average distance per stop is calculated. The value of this constant is dependent on infrastructure characteristics of a region. The dimension is meters.
• **tStops [minutes]**
The model uses an average delivery time per stop. The value of this constant is dependent on infrastructure characteristics of a region. The dimension is minutes.

• **tSmallPackage [minutes]**
The model uses an average time to unload a small package. The value of this constant is set on two minutes per small package. The dimension is minutes.

• **tLargePackage [minutes]**
The model uses an average time to unload a large package. The value of this constant is set on six minutes per large package. The dimension is minutes.

• **vArea [km/hr]**
The velocity constant area represents average velocity of vehicles in a city centre. The dimension is kilometre per hour.

• **vOutsideArea [km/hr]**
The velocity constant outside area represents average velocity of vehicles outside the city centre. The dimension is kilometre per hour.

• **Kilometre cost ([€/km])**;
This constant represents average cost per kilometre. This is distracted and calculated from data collected by Panteia. The dimension is euro per kilometre.

• **Hourly cost ([€/km])**;
This variable represents average cost per hour. This is distracted and calculated from data collected by Panteia, the dimension is euro per kilometre.

Paragraph 4.5 on data validity further elaborates on these constants.

### 4.3.4. Output variables

The output variables are the outcome/results of the LMS model. These results are total cost, total distance and total time of an individual last mile trip of a freight carrier. In addition, the percentage of savings is calculated. This is the total cost of a last mile trip compared with an alternative shipping method. The alternative option is a shipping conducted by a central distributor that operates with competitive, commercial tariffs. In succession, all output variables and required input variables, constants and system variables are threatened below.

• **Total cost [€/trip]**
Output variable total cost is calculated and dependent on output variables total time and total distance, input variables vehicle type and constants kilometre cost and hourly cost.

• **Total distance [km/trip]**
Output variable total distance is calculated and dependent on system variables dBetweenArea, dRouteIn, dRouteOut and dStops. System variables dBetweenArea, dRouteIn and dRouteOut are calculated with aid of an Application Programming Interface (API) that is called Google Distance Matrix (GDM). This application uses input variables area and route (origin and destination). System variable dStops is calculated and dependent on input variable nStops and constant dStops.

• **Total time [minutes/trip]**
Output variable total time is calculated and dependent on input variable nStops and system variables driving time and (un)load time. System variable driving time is calculated and dependent on constants vArea, vOutsideArea and dInOut and on system variable dArea and dOutsideArea. System variable (un)load time is calculated and dependent on input variables nSmallPackages and nLargePackages and constants tSmallPackage, tLargePackage and general time.
• Percentage of savings [%]

Output variable percentage of savings is dependent and calculated on input variables nSmallPackages and nLargePackages and on constant pSmallPackage and pLargePackage and outcome variable total cost.

The formulas between input variables; system variables; constants and output variables are threatened in the next paragraph 4.4 on computerized model verification where all formulas are discussed. The causal relation diagram can provide more information on relationships and direction in general and can be consulted in Appendix E.

4.3.5. Remarks

In this section the LMS model is evaluated and compared with the problem entity. The question seeks to be answered is: Is the model a reasonably representation of the problem entity? Hereby meant is whether the LMS model is a justified translation of the reality. Is the model not too much simplified in order to execute calculations and is outcome of the model accurate, meaningful and useful?

The LMS tries to capture and estimate last mile trips of individual freight carriers. The problem entity is the ‘unknown cost of a last mile trip’ for both freight carriers and the municipality of Delft. The LMS model uses different variables and constants to estimate and give an indication of cost of a specific shipping.

The black box and the CRD are conceptual models of the LMS model. The relations between variables used by the model are logic. Although only the direction of the relation is evaluated at this stage the LMS model seems to be a simplified representation of the real situation. A simplification of the real world is insurmountable to be able to conduct calculations. In reality, last mile trips are individual cases with unique characteristics. Therefore, analysing these cases one by one is too difficult and time consuming. Assumptions on constants that represent average values need to be used. A simplification of reality is imperative. In some cases, these average constants are higher/lower in reality based on specific characteristics such as product demands (refrigerated transport), delivery time demands, and insurance and juristic related demands.

The outcome of the model can be meaningful for freight carriers because it gives them knowledge on performance indicators cost, time and distance on their last mile. Therefore, the outcome can be useful to improve and adjust operations. The usability of the model can be further increased if specific key performance indicators (KPIs) that provides both the municipality and freight carriers with greater knowledge on performance levels. Chapter 6 discusses these improvements. The accuracy and actual correctness of results and used formulas is not yet validated. Paragraph 4.4 on computerized model conducts this verification step.

The purpose of development the LMS model by MD was defined to identify, facilitate and regulate is partly achieved. The first and second objective, identify activities that take place in the urban area and facilitate involved stakeholders with information on cost structures, has been succeeded since the model provides both the municipality of Delft and freight carriers with an indication on the cost structure of the last mile. The final objective, regulate, is not yet met since it is still unknown if results are accurate and valid enough so they can be used as input to implement improved, tailor made policies.
4.4. Computerized model verification

Computerized model verification determines if computer programming, the translation of assumptions and theories (conceptual) into computer language (formulas) are right. In the next paragraph all formulas to calculate outcome variables: distance, time and cost are threatened.

4.4.1. Distance

First, the model calculates the total distance of a last mile trip. The total distance, $d_{\text{total}}$, is the cumulative of the distance from the access road (start of the last mile trip) till the exit road (end of the last mile trip). The total distance of a trip is calculated from the access road till the centre of an area; $d_{\text{route in}}$ plus the distance between areas; $d_{\text{between Area}}$ plus the distance between stops; $d_{\text{stops}}$ plus the distance from the final area till the exit road; $d_{\text{route out}}$. This calculation is captured in formula 1.

$$d_{\text{total}} = d_{\text{route in}} + d_{\text{between Area}} + d_{\text{stops}} + d_{\text{route out}} [\text{metres}]$$

(1)

where

$$d_{\text{route in}} = X_i \text{ to } X_j \text{ [metres]}$$

$$d_{\text{between Area}} = X_j \text{ to } X_k \text{ [metres]}$$

$$d_{\text{stops}} = d_{\text{stops Area}} + d_{\text{stops Outside Area}} \text{ [metres]}$$

$$d_{\text{route out}} = X_k \text{ to } X_l \text{ [metres]}$$

$X_i$ = access road

$X_j$ = middle city centre

$X_k$ = middle of outside centre

$X_l$ = exit road

Figure 22 shows a possible route of a freight carrier. The numbers identify different elements of the total distance calculation.

1. $d_{\text{route in}}$
2. $d_{\text{between Area}}$
3. $d_{\text{stops}}$
4. $d_{\text{route out}}$

Figure 22 - Overview of route that determines Total Distance
The distances $d_{routeIn}$, $d_{betweenArea}$ and $d_{routeOut}$ are calculated using the Application Program Interface (API) the Google distance matrix (Google, 2015). This is a tool developed by Google that calculates distances between coordinates. The information about access- and exit roads and activity in city centre or outside centre is collected when freight carriers participate in the LMS. Paragraph 4.4.4 elaborates the API in more detail.

If a participant is active in only one area, then the first and last area are the same and therefore the distance between areas is zero. If participant is active in more than one area the model calculates the order in which the areas are passed. Since the LMS only uses a maximum of three areas per city/region it can calculate the route when the first and the last area are known. Calculating the first and last area is based on the criterion shortest route of $d_{routeIn}$ and $d_{routeOut}$. The distance between areas is always the same since the LMS calculates the distance from the fixed centre. After the order is determined the total distance between areas can be calculated.

The distance between areas is the total distance between the middle of the areas. The order of the areas is determined according to the smallest path principle. When the route is known (the order of the areas), the Google Distance Matrix calculates the total distance between the areas. The distance $d_{betweenArea}$ visualized in Figure 22, #2. Formula 2 shows how this variable is calculated.

$$d_{betweenArea} = X_j \, \text{to} \, X_k \, [\text{metres}]$$

where

$X_j = \text{middle city centre}$

$X_k = \text{middle of outside centre}$

The total distance of stops is the sum of the distance of stops in the area and the distance of stops outside the area. Formula 3 captures this.

$$d_{stops} = d_{stopsArea} + d_{stopsOutsideArea} \, [\text{metres}]$$

where

$$d_{stopsArea} = (n_{stopsArea} - 1) \times d_{stop} \, [\text{metres}]$$

$$d_{stopsOutsideArea} = n_{stopsOutsideArea} \times d_{stop} \, [\text{metres}]$$

The distance of stops in an area is calculated by the number of stops in an area minus 1, (if there is only 1 stop the distance is calculated by driving to the centre of the area, so without extra distance for a stop) times the distance per stop. The distance per stop is different per region and is based on expertise and data of average distances per stop. In Delft the distance of a stop is 250 metres. The distance of stops outside an area is calculated by the number of stops in the area times the distance per stop. The distance of a stop for the outside area is the same. This is given in Formulas 4 and 5.

$$d_{stopsArea} = (n_{stopsArea} - 1) \times d_{stop} \, [\text{metres}]$$

$$d_{stopsOutsideArea} = n_{stopsOutsideArea} \times d_{stop} \, [\text{metres}]$$

where

$$d_{stop} = \text{LMS database} \, [250 \, \text{metres}]$$

$n_{stopsArea} = \text{number of stops in area} \, [#]$  

$n_{stopsOutsideArea} = \text{number of stops outside area} \, [#]$
4.4.2. **Time**

The total time is the sum of driving time and unloading time. The total time calculation is given in Formula 6.

\[ t_{total} = t_{driving} + t_{unloading} \text{ [minutes]} \]  

where

\[ t_{driving} = \frac{d_{outsideArea}}{v_{outsideArea}} + \sum \left( \frac{d_{area}}{v_{area}} \right) \text{ [minutes]} \]

\[ t_{unloading} = t_{general} + (t_{smallPackage} \cdot n_{smallPackage}) + (t_{largePackage} \cdot n_{largePackage}) \text{ [minutes]} \]

The driving time is calculated by dividing the distance in the outside area by the average velocity in the outside area plus the sum of the distance of the area divided by the average velocity in that area. This is shown in the Formula 7 below.

\[ t_{driving} = \frac{d_{outsideArea}}{v_{outsideArea}} + \sum \left( \frac{d_{area}}{v_{area}} \right) \text{ [minutes]} \]  

where

\[ d_{outsideArea} = d_{total} - \sum(d_{stopsArea} + d_{in=out}) \text{ [metres]} \]

\[ v_{outsideArea} = LMS \text{ database [30 km/hour]} \]

\[ d_{area} = d_{stopsArea} + d_{in=out} \text{ [metres]} \]

\[ v_{area} = LMS \text{ database [15 km/hour]} \]

The distance in the outside area is determined starting from the total distance minus the sum of the distance of the stops in the area plus the distance of the in=area. The average velocity in the outside area and the area is determined based on expertise and traffic data. The average velocity differs per area and is documented in the LMS database. The distance of an area is calculated by the distance of the \( d_{in=out} \) plus the distance of the stops in the area. Distance of stops; \( d_{stapsArea} \) is explained in Formula 3. \( d_{in=out} \) is a constant that is needed to calculate the distance to enter and exit an area. This constant varies per region and is set on 500 metres for Delft (2 times the distance of a stop).

The unloading time is calculated by the sum of the general time plus the time for unloading packages times the number of packages (either small or large).

\[ t_{unloading} = t_{general} + (t_{smallPackage} \cdot n_{smallPackage}) + (t_{largePackage} \cdot n_{largePackage}) \text{ [minutes]} \]  

where

\[ t_{general} = LMS \text{ database, varies per vehicle type [minutes]} \]

\[ t_{smallPackage} = LMS \text{ database [2 minutes]} \]

\[ n_{smallPackage} = \text{ number of small packages [#]} \]

\[ t_{largePackage} = LMS \text{ database [6 minutes]} \]

\[ n_{largePackage} = \text{ number of large packages [#]} \]

4.4.3. **Cost**

The total cost of the last mile is calculated by the total distance times the cost per kilometre plus the total time times the hourly cost. This is captured in the Formula shown below.

\[ c_{total} = d_{total} \cdot c_{km} + t_{total} \cdot c_{hour} \text{ [euro]} \]
where

\[ d_{\text{total}} = d_{\text{route in}} + d_{\text{between Area}} + d_{\text{stops}} + d_{\text{route out}} \text{[metres]} \]

\[ c_{\text{km}} = \text{LMS database, varies per vehicle type} \frac{\text{euro}}{\text{km}} \]

\[ t_{\text{total}} = t_{\text{driving}} + t_{\text{unloading}} \text{[minutes]} \]

\[ c_{\text{hour}} = \text{LMS database, varies per vehicle type} \frac{\text{euro}}{\text{hour}} \]

### 4.4.4. **GOOGLE DISTANCE MATRIX (GDM)**

As mentioned, distances of a last mile trip are calculated using a tool called Google Distance Matrix (GDM). GDM is an Application Programming Interface (API) developed by Google that is a computer program that can communicate with another program. APIs are the communication layer between different layers of abstraction. In case of the GDM it uses coordinates (longitude and latitude) of origins and destinations or in the LMS access and exit roads and middle of areas to calculate distances expressed in common language. Freight carriers provide the LMS with their origin and destinations, the access and exit roads. These access and exit roads all hold different coordinates that are known by the model. Thereafter, these coordinates are used by the API to calculate distances in kilometres between access and exit roads but also between areas and all other distances. As explained in previous paragraph these distances are part of the total distance calculation Formula 1.

### 4.4.5. **REMARKS**

**Distance**

Formula 1 shows how a total distance of a trip is calculated. Three of the four variables that are used in the Formula use an API tool developed by Google. This application ensures a high accuracy of distances because it uses precise coordinates to calculate covered distances. Formula 3, used for calculating distance per stop, is a plausible formula because distance per stop can be calculated by multiplying the number of stops times an average distance per stop. The accuracy and correctness of the average distance per stop still needs to be validated. This is analysed in next paragraph 4.5.

**Time**

Formula 6 provides information on how the total time of a trip is calculated. Total time is dependent on driving and unloading time. Total time of a last mile trip can be calculated by driving- plus stopping time (in the case of a last mile trip stopping time is unloading time). The structure of Formula 6 is plausible. Driving time is dependent on average velocity of a vehicle and total distance covered. This relation is correct because, the general dimension of velocity is kilometre per hour; velocity = distance / time; time = distance / velocity. Unloading time is dependent on the amount of small and large packages delivered multiplied by an average unloading time per package. This relation is plausible because every package takes time to deliver. Calculations of the total time can be realized by using an average time per small/large package. In addition, a general time is set for every delivery. This time (or penalty) is time that is spent on searching for a parking lot and parking the vehicle. The accuracy and correctness of constants used in this section, which are velocity in and outside an area, average unloading time per package and general time are analysed in paragraph 4.5.

**Cost**

Formula 9 shows how total costs are calculated. Total cost is dependent on total time multiplied by cost per hour and total distance multiplied by cost per kilometre. This seems a valid method to calculate total cost. The accuracy and correctness of cost per kilometre and cost per hour still needs to be validated. This is analysed in paragraph 4.5.

The formulas introduced in paragraph 4.4 to calculate distance, time and cost of a last mile trip and relations between variables used to conduct these calculations are plausible. The correctness of assumptions of constants of average distance per stop, vehicle velocity, average-unloading times for small and large packages and general time are not yet validated. This means that formula structures are valid but correctness of values of constants used in these formulas are not yet validated.
4.5. Data validity

Data validation is the process of determining if input data that is used for model building, model evaluation and testing is adequate and correct.

Cost structures of freight carriers on their last mile are commonly unknown by the carriers themselves. The cost of a single transportation is difficult to monetize due to many variables like overhead cost, amortization, and variation in truck driver salaries and in cost per vehicle. The model gives an indication of costs for a single transportation. In order to get to an estimation, assumptions have been made and real data needs to be available. Research on the following constants has been conducted: average velocity of vehicles, cost per vehicle type per hour and kilometre, time for a stop, unloading times (large and small packages) and average distance per stop. The correctness and accuracy of these constants are discussed in this paragraph.

4.5.1. Data collection for development

Benchmark methodology
Research company Panteia have collected input data that is used to execute calculations. They collect data from companies active in the transportation sector. Companies are generally not willing to share sensitive and confidential information with a third party. The reason why they are willing to share information is that Panteia is independent and provides all participating companies with information on performance levels with regard to their competitors. The working methodology of Panteia is explained briefly below.

Panteia collects data of similar transportation companies. The minimum amount of data that is needed to reach a certain level of significance and confidence is ten companies. The group of companies are homogenous. They are homogenous based on similar characteristics. These similarities can for example vary in company size, active in a subreddit, frequency of activity, geographic similarities and magnitude. Furthermore, to draw strong conclusions the underlying used sources need to be significant substantiated. The added value that Panteia can offer a participating company is providing them with information on direct competitors. This methodology is known as a benchmark. Information on performance indicators of competitors is valuable information to transportation companies. The incentive that data can only become available by sharing data with an objective and neutral research company is the reason why Panteia can conduct research with real data collected from the field (van den Engel, 2014).

Field research
The second method that is widely applied by MD to gather data is field research. Field research is conducted by NHTV (Breda University of Applied Science). NHTV employed students that went out on the streets to count loading times, unloading times and stopping times. The size and scope of this field research is unknown. The background data where values of constants are based on is not available. Therefore, the scope of the conducted field research cannot be consulted, which makes it impossible to make a statement about the validity of results of the field research. To elaborate on this a bit, the scope of the field research can be based on 1 or 2 counting days where a limited amount of data is collected. On the other hand, the field research can also be an extensive investigation that took many days to collect an enormous amount of data to ensure and increase the reliability of founded values of constants.

4.5.2. Validation of assumptions

In this paragraph all assumptions on constants are critically evaluated. The constants are distance in=out, average distance per stop, average time for a stop, unloading times (large and small packages), average velocity of vehicles and cost per vehicle type per hour and kilometre.

Distance in=out
Constant distance in=out varies between 250 and 1500 metre dependent on the region. In Delft the value of the constant is set on 500 metres. This is related to the size of a city and more specific the...
area. The historic city centre of Delft is relatively small compared to other cities. The distance in=out is related to the average distance per stop which is also dependent on the size of a city/area. Figure 23 visualizes how the distance in=out is structured. A freight carrier enters the centre of Delft from the west. The black arrow indicts the average distance covered to the middle of the centre. The red arrow shows the distance covered to exit the city centre. The total distance of entering and exiting the centre of area is ‘d_in=out’. The length of his distance is set on 500 metres which means the average distance represented by each arrow is 250 metres. The question here is: Is the distance of 250 metres correct and though valid? This is further elaborated in the next section on distance per stop since these constants are related due to their dependency on size of the area.

Figure 23 - Size of city centre of Delft

Distance per stop
Formula 1 threated in paragraph 4.4 uses an average distance per stop \( (d_{stop}) \). Since the model does not know the specific location of delivery it uses an average distance per stop to calculate the total distance for all stops. A distance of 250 metres is used for Delft. In other cities the value is higher because the cities and therefore areas are larger. In order to make a validate statement on the distance of 250 metre per stop a number of scenarios are simulated.

Situation 1: Little amount of stops
In this scenario the amount of stops is three. The location of stops is chosen randomly and the average distance per stop is calculated by dividing total distance by number of stops. This scenario is simulated four times. These situations are displayed below.

Figure 24 - Situation 1 (little amount of stops, 3 stops)

The total distances of the four situations are 1,54; 1,32; 0,71 and 0,89 kilometres as the crow flies. The average distance per stop of these 4 situations is \( (1,54 + 1,32 + 0,71 + 0,89) / 12 = 0,37 \) kilometres. This amount is 120 metres more than the average distance of 250 metres. Worth to mention is that these are kilometres as the crow flies. Real distances, using roads, are even larger.
Situation 2: Average amount of stops
In this scenario the amount of stops is 7. The location of stops is again chosen randomly and the average distance per stop is calculated by dividing total distance by number of stops.

Figure 25 - Situation 2 (average amount of stops, 7 stops)

The total distances of the four situations are 2.91; 1.78; 2.93 and 2.51 kilometres as the crow flies. The average distance per stop of these 4 situations is \((2.91 + 1.78 + 2.93 + 2.51) / 28 = 0.36\) kilometres. Again, this amount is larger than the average distance of 250 metres.

Situation 3: Large amount of stops
In this scenario the amount of stops is 15. The location of stops is chosen randomly, as in all cases, and the average distance per stop is calculated by dividing total distance by number of stops.

Figure 26 - Situation 3 (average amount of stops, 15 stops)

The total distances of the four situations are 3.91; 6.69; 5.77 and 4.12 kilometres as the crow flies. The average distance per stop of these 4 situations is \((3.91 + 6.69 + 5.77 + 4.12) / 60 = 0.34\) kilometres. Again, this amount is larger than the average distance of 250 metres.

The average distance per stop over the three situations is 0.37 + 0.36 + 0.34 divided by 3 is 0.36. This is 360 meter on average. Compared to the set distance of 250 meter this is greater by 110 meter. The
constants distance per stop and coherent distance in-out should be increased. Impacts on sensitivity of constants is analysed in paragraph 4.7 on sensitivity analysis.

**Time for a stop**
The time penalty used to calculate total time differs per region dependent on infrastructure characteristics. The average stopping time ($t_{\text{stop}}$) varies between 4 and 6 minutes. The centre of Delft constant is set on 5 minutes and the outside area is set on 4 minutes per stop. Information on stopping times is collected throughout field research. A group of students hired by MD recorded stopping times of a large number of freight carriers. This resulted in an average stopping time in the centre of Delft and outside the centre (Maatwerk Distributie, 2015).

To be able to see if set values are within valid boundaries a situation where a freight carrier is making a stop is reconstructed. A freight carrier needs to find a parking spot and park the vehicle. Finding a free parking spot can go quickly, within a minute, but could also take longer, 3 minutes. Parking the vehicle could take some time, especially when a vehicle needs to make a difficult manoeuvre by driving rearwards into a narrow and busy alley. Parking can take between 1 and 3 minutes. After parking the vehicle has been completed the process of unloading starts. Unloading times are discussed in the next paragraph. After the process of unloading is finished the vehicle needs to be sealed shut, this can take up to a minute. The average time for a stop of 4 and 5 minutes in the region of Delft, dependent on stopping in the centre or outside the centre, is reasonable since the reconstruction gives an average stopping time between 3 to 7 minutes depending on the ease of finding a parking lot, the ease of parking and the vehicle being sealed shut.

**Unloading times**
The unloading times can be distinguished on an average unloading time for small packages ($t_{\text{small Package}}$) and average unloading time for large pallets ($t_{\text{large Package}}$). The set value for unloading small packages on average is 2 minutes. The set value for unloading large pallets on average is 6 minutes. Distributors data is collected by NHTV (Breda University of Applied Science) that counted loading and unloading times. This data is again gathered throughout field research conducted by students.

Again, to be able to see if set values are within valid boundaries a scenario to unload a shipment is reconstructed. After the vehicle is parked the first step of a truck driver is to sort out what packages/pallets need to be unloaded. This can be arranged within a minute. The second step is to grab the shipment out of the vehicle. A small package can be grabbed quickly, for example within a minute. A large pallet is heavy and often needs to be handled by a machine. Therefore, it takes more time, varying between 2 and 4 minutes. The third and final step is to deliver the shipment. A small package is delivered within a minute. A larger pallet can take between 1 and 3 minutes. The total unloading time for a small package is $1+1+1 = 3$ minutes’ tops. It can also be realized in 2 minutes. The total unloading time for a large pallet is $1+4+3 = 8$ minutes, but it can also be realized in $1+2+1 = 4$ minutes. This means the total unloading time for a large pallet is between 4 and 8 minutes. The set amount of 2 and 6 minutes, dependent on packages or pallets, seems to be a reasonable and valid assumption.

**Average velocity of vehicles**
The average velocity of vehicles is determined on 15 km/hour in an urban area ($v_{\text{area}}$) and 30 km/hour outside an urban area ($v_{\text{outside Area}}$). In some areas the average velocity is higher due to different infrastructure characteristics. The average velocity in the outside area and the area is determined on the basis of expertise and traffic data collected by research company Panteia. Taking in consideration traffic lights and busy streets an average velocity of 15 km/hour in an urban area and 30 km/hour outside an urban area seems fair. The speed limit in both areas is 50 km/hour but can also be lower in city centre (30 km/hour).

Table 15 summarize all parameters discussed in this section. The impact of constants on outcome of the model is further analysed in paragraph 4.7 on sensitive analysis. The sensitivity of higher/lower values of constants is tested.
Table 15 - Parameters per city and area

<table>
<thead>
<tr>
<th>City</th>
<th>Area</th>
<th>dIn</th>
<th>dOut</th>
<th>tStop</th>
<th>tSmall</th>
<th>tLarge</th>
<th>vArea</th>
<th>vOutside</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delft</td>
<td>Centre</td>
<td>500</td>
<td>250</td>
<td>5</td>
<td>2</td>
<td>6</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Delft</td>
<td>Outside Centre</td>
<td>500</td>
<td>250</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Rijswijk</td>
<td>Shopping mall In de Boogaard</td>
<td>500</td>
<td>500</td>
<td>5</td>
<td>2</td>
<td>6</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Rijswijk</td>
<td>Old Rijswijk</td>
<td>250</td>
<td>250</td>
<td>5</td>
<td>2</td>
<td>6</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Rijswijk</td>
<td>Rijswijk outside these areas</td>
<td>500</td>
<td>500</td>
<td>5</td>
<td>2</td>
<td>6</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Leidschendam-Voorburg</td>
<td>Shopping mall Leidsenlage</td>
<td>500</td>
<td>250</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Leidschendam-Voorburg</td>
<td>Leidschendam centre</td>
<td>500</td>
<td>250</td>
<td>5</td>
<td>2</td>
<td>6</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Leidschendam-Voorburg</td>
<td>Shopping mall Julianabaan</td>
<td>500</td>
<td>250</td>
<td>5</td>
<td>2</td>
<td>6</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Leidschendam-Voorburg</td>
<td>Leidschendam-Voorburg outside</td>
<td>500</td>
<td>500</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Pijnacker-Nootdorp</td>
<td>Shopping mall Emerald</td>
<td>300</td>
<td>150</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Pijnacker-Nootdorp</td>
<td>Pijnacker centre</td>
<td>300</td>
<td>150</td>
<td>5</td>
<td>2</td>
<td>6</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Pijnacker-Nootdorp</td>
<td>Shopping mall De Parade</td>
<td>300</td>
<td>150</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Pijnacker-Nootdorp</td>
<td>Pijnacker-Nootdorp outside these areas</td>
<td>500</td>
<td>500</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Den Haag</td>
<td>Centre</td>
<td>1000</td>
<td>1000</td>
<td>6</td>
<td>2</td>
<td>6</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Den Haag</td>
<td>Den Haag outside centre</td>
<td>1500</td>
<td>1500</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Leiden</td>
<td>Centre</td>
<td>500</td>
<td>500</td>
<td>5</td>
<td>2</td>
<td>6</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Leiden</td>
<td>Leiden outside centre</td>
<td>750</td>
<td>750</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>

Cost per vehicle type

The costs per vehicle type are displayed in Table 16. These costs are categorized in total cost per kilometre and total cost per hour. Panteia has determined cost per kilometer and per hour. The costs per kilometre are calculated by dividing variable cost by the total amount of yearly kilometres. The costs per hour are calculated by the sum of fixed cost exclusive yearly wage plus yearly wage divided by total driver hours. Thereafter these numbers are multiplied by the inflation rate since the numbers are collected in the year 2012.

Table 16 - Cost per vehicle type

<table>
<thead>
<tr>
<th>Type of vehicle</th>
<th>Cost 2014</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Van (GVW 1000 kg)</td>
<td>€ 0,28</td>
<td>€ 24,65</td>
</tr>
<tr>
<td>Van (GVW 1350 kg)</td>
<td>€ 0,31</td>
<td>€ 25,02</td>
</tr>
<tr>
<td>Van (GVW 1650 kg)</td>
<td>€ 0,34</td>
<td>€ 25,29</td>
</tr>
<tr>
<td>Truck (GVW &lt;4000 kg)</td>
<td>€ 0,39</td>
<td>€ 28,51</td>
</tr>
<tr>
<td>Truck (GVW &lt;12 ton)</td>
<td>€ 0,35</td>
<td>€ 31,07</td>
</tr>
<tr>
<td>Truck (GVW 12 - 16 ton)</td>
<td>€ 0,44</td>
<td>€ 32,21</td>
</tr>
<tr>
<td>Truck (GVW &gt;16 ton)</td>
<td>€ 0,49</td>
<td>€ 32,70</td>
</tr>
<tr>
<td>Truck + trailer</td>
<td>€ 0,66</td>
<td>€ 36,32</td>
</tr>
<tr>
<td>Tractor + trailer</td>
<td>€ 0,62</td>
<td>€ 36,44</td>
</tr>
</tbody>
</table>
Research organization Panteia has collected data from transport companies of yearly mileage, number of yearly hours per driver, yearly fixed costs (exclusive wage), wage, variable costs and depreciation per vehicle type. This information is used to calculate the costs per vehicle type per kilometre and per hour and is shown in Table 17.

Table 17 – Background data for calculation of cost parameter per vehicle type

<table>
<thead>
<tr>
<th>Type vehicle</th>
<th>Yearly kilometrage</th>
<th>Total driver hours</th>
<th>Fixed cost excl. yearly wage</th>
<th>Yearly wage</th>
<th>Variable cost</th>
<th>Depreciation</th>
<th>Variable cost excl. depreciation</th>
<th>Total differential cost</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Van (GVW 1000 kg)</td>
<td>45000</td>
<td>2160</td>
<td>€ 14.232,00</td>
<td>€ 38.388,00</td>
<td>€ 11.752,50</td>
<td>€ 6.787,50</td>
<td>€ 50.140,50</td>
<td>€ 64.372,50</td>
<td></td>
</tr>
<tr>
<td>Van (GVW 1350 kg)</td>
<td>45000</td>
<td>2160</td>
<td>€ 14.954,00</td>
<td>€ 38.388,00</td>
<td>€ 13.325,00</td>
<td>€ 7.170,00</td>
<td>€ 51.713,00</td>
<td>€ 66.667,00</td>
<td></td>
</tr>
<tr>
<td>Van (GVW 1650 kg)</td>
<td>45000</td>
<td>2160</td>
<td>€ 15.555,50</td>
<td>€ 38.388,00</td>
<td>€ 14.682,50</td>
<td>€ 7.507,50</td>
<td>€ 53.070,50</td>
<td>€ 68.626,00</td>
<td></td>
</tr>
<tr>
<td>Truck (GVW &lt;4000 kg)</td>
<td>45000</td>
<td>2160</td>
<td>€ 17.941,00</td>
<td>€ 42.875,00</td>
<td>€ 16.589,00</td>
<td>€ 9.603,00</td>
<td>€ 59.459,00</td>
<td>€ 77.400,00</td>
<td></td>
</tr>
<tr>
<td>Truck (GVW &lt;12 ton)</td>
<td>78000</td>
<td>2585</td>
<td>€ 18.988,00</td>
<td>€ 60.033,00</td>
<td>€ 25.335,00</td>
<td>€ 18.465,00</td>
<td>€ 85.368,00</td>
<td>€ 104.356,00</td>
<td></td>
</tr>
<tr>
<td>Truck (GVW 12 - 16 ton)</td>
<td>78000</td>
<td>2585</td>
<td>€ 21.966,00</td>
<td>€ 60.033,00</td>
<td>€ 31.689,00</td>
<td>€ 22.094,00</td>
<td>€ 91.722,00</td>
<td>€ 113.688,00</td>
<td></td>
</tr>
<tr>
<td>Truck (GVW &gt;16 ton)</td>
<td>78000</td>
<td>2585</td>
<td>€ 23.232,00</td>
<td>€ 60.033,00</td>
<td>€ 35.919,00</td>
<td>€ 24.505,00</td>
<td>€ 95.952,00</td>
<td>€ 119.184,00</td>
<td></td>
</tr>
<tr>
<td>Truck + trailer</td>
<td>78000</td>
<td>2585</td>
<td>€ 32.454,00</td>
<td>€ 60.033,00</td>
<td>€ 47.581,00</td>
<td>€ 35.702,00</td>
<td>€ 107.614,00</td>
<td>€ 140.068,00</td>
<td></td>
</tr>
<tr>
<td>Tractor + trailer</td>
<td>78000</td>
<td>2585</td>
<td>€ 32.749,00</td>
<td>€ 60.033,00</td>
<td>€ 45.059,00</td>
<td>€ 34.567,00</td>
<td>€ 105.092,00</td>
<td>€ 137.841,00</td>
<td></td>
</tr>
</tbody>
</table>

4.5.3. Remarks

Based on the interview conducted with a senior researcher of Research Company Panteia information on how data is collected and applied is obtained. Panteia uses a benchmark methodology and works according a few rules of thumb; a minimum amount of participants (10 transport companies) need to be included when collecting data in order to guarantee conclusions have a significant level of reliability. Another important rule is that collected data needs to be up to date in order to ensure a right reflection of reality. The extensive methodology applied by Panteia and the strict rules that they practise ensures data collection is done properly and is significantly reliable. The input data provided by Panteia, assumptions like velocities of vehicles and cost per minute and kilometre per vehicle type are therefore valid.

Validation of data collected throughout field research is less reliable. It is difficult to state that these assumptions correspond with real world values, because background information on the scope of this field research is not available and unknown. A situation sketch on distance per stop proved that a larger distance per stop is more likely. The same applies for distance in=out. Assumptions about time for a stop and unloading times seems to be reasonable since reconstruction of the situation provides a range where set values fall within. To ensure set values are within confidence interval that is of reasonable significance more information on the background of the field research is needed. The advice is to increase the scope of the field research to ensure the amount of background data is large and constructed assumption are more likely to be reliable.
4.6. **Operational validation**

Operational validation is the process of verifying if outcome of the computerized model has sufficient accuracy in relation to the intended purpose of development. Operational validation is conducted throughout logic reasoning, cross validation (with similar calculation models) and expert interviews. Finally, results of the model are verified with real data, if available.

### 4.6.1. **Accuracy of outcome of the model**

The results of the model will collect data and information for distributors and policy makers on cost structure of the last-mile. The degree of accuracy of this information is an important benchmark to evaluate the usability. The results of the LMS are total distance; total time; total cost of a last mile trip and are given in two decimals. A two-digit outcome is precise and definitely of significance detail. This accuracy does not mean that outcome is correct (compared to the real world) and that this degree of detail is needed or meaningful. The objective of the model is to give estimation on the cost structure of the last-mile. The term ‘estimation’ or ‘indication’ already holds a notion of an approximation. Therefore, a two-digit outcome does not provide extra information or does not add any value because the degree of accuracy is lower anyway. It is questionable if results of the LMS model can be used for development of mandatory custom policies due to the fact that results are just an approximation of the real world. The municipality cannot proof performance levels in reality are exactly the same as outcome of the model.

### 4.6.2. **Cross validation**

Due to the lack of real data from the field it is not possible to verify outcome of the model with real numbers and measurements outside the case study. Operational validation can also be conducted by comparing the model with similar calculation models or numbers from scientific literature or other studies. In this section a cross validation is conducted with regard to a similar calculation model developed by PostNL and results of a research conducted by Roger Peters.

**Cross validation with calculation model of PostNL**

There is a model developed by PostNL that captures a current and future scenario and compares them on environmental performance, distance covered, cost difference and number of vehicle movements. In the future scenario distribution takes place by consolidation executed by a large distributor who operates with electric vehicles only. The current scenario is the existing situation as it is in practice. In this model a different methodology is applied since cumulative results are calculated and not individual trips as in the LMS model.

Cross validation is conducted on assumptions used in both models. Output of both models is not comparable because the models have different output variables. Assumptions that are used in both models are vehicle velocity in city centre and vehicle velocity at entrance and exit roads. Furthermore, some cost assumptions are compared. This cannot be conducted on every constant since methods that are used and structure of formulas differs.
Figure 27 – Table of assumptions of LMS and model developed by PostNL

<table>
<thead>
<tr>
<th>LMS</th>
<th>PostNL</th>
</tr>
</thead>
<tbody>
<tr>
<td>tStop [min]</td>
<td>5</td>
</tr>
<tr>
<td>tStopSmall [min]</td>
<td>not applicable</td>
</tr>
<tr>
<td>tStopLarge [min]</td>
<td>not applicable</td>
</tr>
<tr>
<td>tSmall [min]</td>
<td>2</td>
</tr>
<tr>
<td>tLarge [min]</td>
<td>6</td>
</tr>
<tr>
<td>Fixed time per trip [min]</td>
<td>not applicable</td>
</tr>
<tr>
<td>vArea [km/hr]</td>
<td>15</td>
</tr>
<tr>
<td>vOutsideArea [km/hr]</td>
<td>30</td>
</tr>
<tr>
<td>Cost per hour (euro/hr)</td>
<td>25/36*</td>
</tr>
<tr>
<td>Cost per km [euro/km]</td>
<td>0.28/0.66*</td>
</tr>
<tr>
<td>Fixed car cost per year [euro/yr]</td>
<td>not applicable</td>
</tr>
<tr>
<td>Fixed car cost per day [euro/day]</td>
<td>not applicable</td>
</tr>
<tr>
<td>Emission CO2 [g/km]</td>
<td>not applicable</td>
</tr>
<tr>
<td>Emission NOx /PM10 [g/km]</td>
<td>not applicable</td>
</tr>
</tbody>
</table>

* dependent on vehicle type

Since the models differ in structure formulas and assumptions used also differ and not everything can be compared. Therefore, it is difficult to state if comparable assumptions are used in the same way and therefore more valid if they are similar. Drawing straightforward conclusions is not possible and a conservative position is needed.

Both models use different constants and formulas to calculate the length and cost of a trip. The assumption for time for a stop is structured differently. The LMS uses a general stopping time plus time for unloading small packages and large pallets. In contrast the model developed by PostNL uses an unloading and stopping time for packages and pallets separately and fixed time per trip of 20 minutes. These different methodologies make it hard to compare. To make a valid statement a shipping is reconstructed and calculated by both models.

The first shipping (relatively small) consists of 5 small packages and 2 pallets divided over 5 stops. Calculated through the PostNL model the shipping takes: 0.05*5+5*5+2*5+2*15+20 = 85 minutes. The LMS model output gives a total time of 53 minutes. Another trip (relatively large) makes 15 stops and consist of 20 small packages and 1 large pallet gives as output in the model of PostNL: 0.05*20+5*20+1*1+15*1+20 = 137 minutes. The LMS output gives a total time of 137 minutes.

The first example shows a large difference between both models. The second example gives exactly the same output in both models. Drawing conclusions from this example is difficult since these models are structured significantly different. In general, the LMS model puts a heavy weight (penalty) on a shipping where only 1 package is delivered. In contrary a shipment of a large pallet contributes to a greater extent to the total time in the PostNL model.

**Cross validation with results of other research**

The research conducted by Roger Peters is used as reference to see if formulas used in that research have similar structures as the LMS model. The calculation model developed by Peters calculates total air quality & climate, trajectory velocity, intensity of the network, trip length and residence time in the city of Breda. It differs in output because the LMS model tries to give an indication in total time, distance and cost of an individual trip. A comparison on how output variables are structured is conducted, if possible. The formulas used in the research of Peters are displayed below.
Figure 28 - Formulas defined in thesis research of Roger Peters (Peters, 2013)

<table>
<thead>
<tr>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air quality &amp; climate</td>
</tr>
<tr>
<td>Trajectory velocity</td>
</tr>
<tr>
<td>Intensity</td>
</tr>
<tr>
<td>Total trip length</td>
</tr>
<tr>
<td>Residence time</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>General variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x ) = Total trip length</td>
</tr>
<tr>
<td>( o ) = occasional transporters</td>
</tr>
<tr>
<td>( c ) = chain transporters</td>
</tr>
<tr>
<td>( s ) = specialists</td>
</tr>
<tr>
<td>( N ) = Number of vehicles</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Specific variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Q ) = Quality of air or climate</td>
</tr>
<tr>
<td>( V_{avg} ) = Average velocity</td>
</tr>
<tr>
<td>( E ) = Emission rate per vehicle</td>
</tr>
<tr>
<td>( L ) = Total length of all trips</td>
</tr>
<tr>
<td>( I ) = Intensity</td>
</tr>
<tr>
<td>( t ) = Amount of trips (for trip length formula)</td>
</tr>
<tr>
<td>( t ) = time (for residence time formula)</td>
</tr>
<tr>
<td>( R ) = residence</td>
</tr>
<tr>
<td>( G ) = general (loading &amp; unloading &amp; handling) per vehicle</td>
</tr>
<tr>
<td>( D ) = driving in the city centre (distance/velocity) per vehicle</td>
</tr>
</tbody>
</table>

The formulas used by Peters are cumulative formulas that calculate total length, time, intensity, vehicle velocity and air quality. This differs from the LMS model. Average velocity of vehicles can be compared. The formula of air quality can be compared to the proposed option of how environmental aspects can be included in the LMS model (chapter 6). Intensity is not included in the LMS model at all. Total trip length is dependent on specific city characteristics of Breda and Delft and therefore hard to compare.

Air quality/footprints

The cumulative air quality is calculated by emission rate per vehicle multiplied by number of vehicles multiplied by total trip length. Air quality of a single trip can therefore be calculated through emissions rate multiplied by total trip length. The LMS model calculates the total trip length. The emission rate used in the research of Peters uses a distinction on the base of vehicle weight. Light, middle heavy and heavy traffic categories are distinguished. For all these categories different emission rates are defined on CO, NOx, NO2, PM10 and CO2. A similar distinction can be conducted on the LMS model to include environmental aspects. Paragraph 7.6.1 elaborates on how to extent the LMS model to include this environmental key performance indicator.

Vehicle velocity

Peters uses average vehicle velocities dependent on vehicle type. Again, the same classification is used as in calculation of air quality. The average vehicle velocities are 25 km/h (light vehicles), 22 km/h (middle heavy vehicles) and 17 km/h (heavy vehicles). The LMS model applies another method. Two vehicle velocities are used, not based on vehicle type, but on location. In city centre a velocity of 15 km/h is used and outside the city centre a velocity of 30 km/h. The average velocities used in the
model of Peters are in between the velocities used in the LMS. This strengthen the degree of validity of velocities used in both models.

**Intensity**
The intensity of the network is not calculated and used in the LMS model because the intensity of a network provides information on cumulative values. The LMS model only estimates individual last-mile trips.

**Total trip length**
Peters calculates total trip length by multiplying the amount of trips with an average trip length multiplied by 2 (in and out). Again, the LMS model calculates individual trip lengths not cumulative. Therefore, the method to calculate average trip length needs to be explored. The average trip length is calculated with aid of Google maps and is based on the allocation of all access and exit roads and the weighted distances to the city centre. The LMS model uses even a more sophisticated method because it uses an API that calculates distance of the access and exit roads (coordinates are known) to the centre of an area (coordinates are known). This tool is extremely precise. Both used methods are plausible. The method applied by the LMS model is better since it is more accurate. The location of the centre is chosen arbitrary and can therefore be debatable.

**Residence time**
The total residence time formula used by Peters is constructed from the total general time (loading, unloading and handling) plus the total driving time multiplied by the amount of vehicles. The LMS model does not calculate total times of the city of Delft but individual shipping times, therefore it is interesting to research what the average general and driving times are. The LMS model applies the same formula structure to calculate the total time of a trip, see Formula 6.

\[ t_{\text{total}} = t_{\text{driving}} + t_{\text{unloading}} \text{[minutes]} \]  

The mean of all scans is 98 minutes with a standard deviation of 125,98 as is shown in Table 18. The total time of different types of occasional transporters, specialist and chain transporters derived from the research of Peters are respectively 46, 80 and 124 minutes. These are total trip times of shipments in Breda. The cities of Delft and Breda are quite similar in size and distances. It seems that results from both models are within plausible boundaries.

**Table 18 – Descriptive statistics of variable Time (SPSS)**

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>273</td>
<td>00</td>
<td>971,00</td>
<td>98,0842</td>
<td>125,89064</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>273</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Since both formulas use the same structure it is admissible that the approach that is used is right. Contrary, it is not possible to say if the results are valid because it is not known what type of vehicle trips are used in the model of Peters and if the dataset of the LMS model consist from the same types of trips and size.

### 4.6.3. Experts consultation

According to different experts the outcome of the LMS model is valuable information that can be helpful for participants (in general freight carriers of distributors) to gather information on their cost structures. In total four experts have been consulted. These experts are active in the field of urban freight distribution in different aspects. Interviews are conducted with Dhr. W. Ploos van Amstel professor at the university of Amsterdam, Dhr. A. van den Engel senior researcher at Panteia, Dhr. K.W. Rademakers head of city logistics in Delft of PostNL and Dhr. S. Brandligt is councilmen of the municipality of Delft of employment, sustainable development and urban management. These...
experts have knowledge regarding urban freight distribution and are able to influence the system in a certain way. The full interviews are elaborated in Appendix F.

According to Dhr. W. Ploos van Amstel the LMS model could be a helpful tool to increase knowledge on UFD, but he made a remark that it needs to be improved and extended significantly before it could really be beneficial for multiple stakeholders. At the moment it is just an extensive directory of involved stakeholders in a certain urban area (Ploos van Amstel., 2015). The model also needs to capture and calculate more than cost structures only. This is an important variable but definitely not the only aspect that needs to be considered.

Senior researcher Dhr. A. van den Engel stated that input data (assumptions) and formulas that are used in the LMS are correct. The input data is gathered from the practical field from a sufficient amount of participants. The relations between variables and calculations that are executed are also logic and seem to be correct. The methodology how data is collected and assumptions calculated is treated in paragraph 4.5.1.

Dhr. K.W. Rademakers thinks the LMS model is a helpful tool from his point of view. He received a list of freight carriers that participated. This list is a potential target group for PostNL. Not all companies are willing to work together with PostNL in their new 'Stadslogistik Delft' distribution centre. Barriers of different nature stop them in transferring their cargo to PostNL. Barriers such as: economical, psychological, administrative, juristic and insurance grounded keeps them from working together with a central distributor. In practice, not even one company of the entire list of companies collected by MD was willing to change way of shipping goods. Dhr. Rademakers argued different reasons why companies are not willing to cooperate. These barriers are elaborated below.

Firstly, as the LMS model suggested some companies can benefit in terms of saving money in moving their shipments to an established distributor. When a company is a freight carrier and their core business is transportation, giving away their business is not an option, even if some of the shipments can be shipped cheaper so money can be saved. Another example is a barrier on juristic and insurance grounds. 'Who is responsible if shipments are not handled properly in terms of damage or within time constrains?' Is in that case PostNL responsible or the company that hired PostNL to handle the shipment, or even the consumer? This is a difficult question. Ensuring all shipments are insured properly costs money, which makes the alternative shipping method less attractive. Another issue is one of handling goods that need special treatment, such as fast moving consumer goods or goods that need to be transported by a refrigerator truck. Handling these types of goods is costlier and demands for special expertise and equipment.

Dhr. S. Brandligt has an ambitious viewpoint in further sustaining urban freight distribution in the municipality of Delft. He is willing to implement difficult policy measurements to increase sustainability of urban freight in Delft. An example he named that is to implement policy instruments like (stricter) time windows or a reward and charge payment system. His interest towards the LMS model is mainly on how to use the collected data and information more wisely in order to properly organize a reward and payment system. The information derived from the LMS model could be used to know what freight carriers are interesting targets groups to either reward or charge depending on their performance levels.

4.6.4. Remarks

Due to a lack of real data it is impossible to crosscheck output of the LMS model with real data from the field. Freight carriers themselves do not know the cost of the last mile. They see urban freight distribution from a larger, supply chain perspective instead of a smaller, last mile perspective. The larger perspective of distributors gives them a blind spot on performance levels on the last-mile.
4.7. Sensitivity analysis

In previous paragraph the absence of real data has been addressed. Making strong (operational) validation statements is therefore impossible. The validation process or analysis should at least perform a sensitivity analysis (SA) or what-if analysis (Kleijen, 1999). Kleijen defines this type of analysis as: ‘a systematic investigation of the reaction of the simulation responses to extreme values of the model’s input or to drastic changes in the model’s structure’.

4.7.1. Case: Average Shipment

To apply a SA a case study needs to be chosen. The region of Delft is used to vary constants, other constants from different region fall outside the scope of this analysis. Constants that are analysed are displayed in Table 19. Every constant has a set value. This set value is varied to see what influence extreme values have on output variables cost, time and distance and on percentage of saving.

Table 19 – Set value of constants

<table>
<thead>
<tr>
<th>City</th>
<th>Area</th>
<th>dInOut</th>
<th>dStops</th>
<th>tStops</th>
<th>tSmall</th>
<th>tLarge</th>
<th>vArea</th>
<th>vOutside</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delft</td>
<td>Centre</td>
<td>500</td>
<td>250</td>
<td>5</td>
<td>2</td>
<td>6</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Delft</td>
<td>Outside</td>
<td>500</td>
<td>250</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>

There are several techniques to conduct sensitivity analysis. Most practitioners change one factor at a time. Based on literature research this is the scientific way to conduct SA. Another method that provides information on interactions among factors is ANOVA, analysis of variance. In the following analysis, one factor at the time is changed. In

Table 20 all set values of constants are shown and changes applied to conduct SA are given. Modified values of constants can be higher or lower, but must be realistic. For example, increasing driving velocity of an outside area above 50 kilometres per hour is impossible because there is a speed limit of 50 km/hour.

For example: scenario A1+ constant dInOut is modified. In this scenario the constant is adjusted to a higher value. The distance is increased from 500 (set value) to 1000 (A1+). This is analysed for two possible trips. First, activity in city centre only is analysed (case 1). Thereafter, activity in both city centre and outside centre is examined (case 2).

Table 20 - Variation in constants of set values

<table>
<thead>
<tr>
<th>SA Scenario</th>
<th>City</th>
<th>Area</th>
<th>dInOut</th>
<th>dStops</th>
<th>tStops</th>
<th>tSmall</th>
<th>tLarge</th>
<th>vArea</th>
<th>vOutside</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>Delft</td>
<td>Centre</td>
<td>500</td>
<td>250</td>
<td>5</td>
<td>2</td>
<td>6</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Current</td>
<td>Delft</td>
<td>Outside</td>
<td>500</td>
<td>250</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Higher</td>
<td>Delft</td>
<td>Centre</td>
<td>1000 (A1+)</td>
<td>500 (B1+)</td>
<td>10 (C1+)</td>
<td>4 (D1+)</td>
<td>12 (E1-)</td>
<td>30 (F1+)</td>
<td>50 (G1+)</td>
</tr>
<tr>
<td>Higher</td>
<td>Delft</td>
<td>Outside</td>
<td>1000 (A2+)</td>
<td>500 (B2+)</td>
<td>8 (C2+)</td>
<td>4 (D2+)</td>
<td>12 (E2+)</td>
<td>50 (F2+)</td>
<td>50 (G2+)</td>
</tr>
<tr>
<td>Lower</td>
<td>Delft</td>
<td>Centre</td>
<td>100 (A1-)</td>
<td>50 (B1-)</td>
<td>2.5 (C1-)</td>
<td>1 (D1-)</td>
<td>3 (E1-)</td>
<td>8 (F1-)</td>
<td>15 (G1-)</td>
</tr>
<tr>
<td>Lower</td>
<td>Delft</td>
<td>Outside</td>
<td>100 (A2-)</td>
<td>50 (B2-)</td>
<td>2 (C2-)</td>
<td>1 (D2-)</td>
<td>3 (E2-)</td>
<td>15 (F2-)</td>
<td>15 (G2-)</td>
</tr>
</tbody>
</table>

Every possible scenario is numbered (A till G) as is shown in

Table 20. Next to a set of constants a set of input variables needs to be provided to be able to complete a scan. A general set of input variables is used and is shown in Table 21. The choice of input variables is decided on the base of the actual scans collected by MD. Frequent input variables are used to conduct the analysis. This way the SA is a realistic image of a real situation in the city of Delft. The set of input variables can be described as an average shipment with a vehicle of medium size and medium amount of stops. The amount of small packages is 10. The amount of large packages is 3 and the amount of stops is 5.
Table 21 – Average shipment, set of input variables

<table>
<thead>
<tr>
<th>Input variables</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>City</td>
<td>Delft</td>
</tr>
<tr>
<td>Vehicle type</td>
<td>Truck of 12-16 ton</td>
</tr>
<tr>
<td>Peak hour</td>
<td>Yes</td>
</tr>
<tr>
<td>Active in area</td>
<td>Both</td>
</tr>
<tr>
<td>Access road</td>
<td>A13 Delft South</td>
</tr>
<tr>
<td>Exit road</td>
<td>A13 Delft North</td>
</tr>
<tr>
<td># of small packages</td>
<td>10</td>
</tr>
<tr>
<td># of large packages</td>
<td>3</td>
</tr>
<tr>
<td># of stops</td>
<td>5</td>
</tr>
</tbody>
</table>

The sensitivity analysis generates a total of 2 scans/results (centre only case and centre and outside centre case). These 2 scans are compared on all possible scenarios (A till G). The scenarios are compared on output variables distance, time and cost and in addition on percentage of saving.

**Hypotheses average shipment**

H0+: Cost per trip is higher for all scenarios

H0-: Cost per trip is lower for all scenarios

**Results**

Figure 29 and Table 22 presents the results of scenario centre only.

Figure 29 – SA of an average shipment (centre only)
Table 22 - Results of SA analysis – Case: average shipment (centre only)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>From</th>
<th>To</th>
<th>Distance [km]</th>
<th>Time [min]</th>
<th>Cost [€]</th>
<th>Relatively</th>
</tr>
</thead>
<tbody>
<tr>
<td>H0</td>
<td>x</td>
<td>x</td>
<td>7.5</td>
<td>67</td>
<td>46.45</td>
<td>100%</td>
</tr>
<tr>
<td>A1+ dInOut</td>
<td>500</td>
<td>1000</td>
<td>7.5</td>
<td>68</td>
<td>47.14</td>
<td>101%</td>
</tr>
<tr>
<td>A1- dInOut</td>
<td>500</td>
<td>100</td>
<td>7.5</td>
<td>66</td>
<td>45.75</td>
<td>98%</td>
</tr>
<tr>
<td>B1+ dStops</td>
<td>250</td>
<td>500</td>
<td>8.5</td>
<td>72</td>
<td>49.91</td>
<td>107%</td>
</tr>
<tr>
<td>B1- dStops</td>
<td>250</td>
<td>50</td>
<td>6.7</td>
<td>63</td>
<td>43.67</td>
<td>94%</td>
</tr>
<tr>
<td>C1+ tStops</td>
<td>5</td>
<td>10</td>
<td>7.5</td>
<td>92</td>
<td>63.78</td>
<td>137%</td>
</tr>
<tr>
<td>C1- tStops</td>
<td>5</td>
<td>2.5</td>
<td>7.5</td>
<td>52</td>
<td>36.05</td>
<td>78%</td>
</tr>
<tr>
<td>D1+ tSmall</td>
<td>2</td>
<td>4</td>
<td>7.5</td>
<td>85</td>
<td>58.93</td>
<td>127%</td>
</tr>
<tr>
<td>D1- tSmall</td>
<td>2</td>
<td>1</td>
<td>7.5</td>
<td>58</td>
<td>40.21</td>
<td>87%</td>
</tr>
<tr>
<td>E1+ tLarge</td>
<td>6</td>
<td>12</td>
<td>7.5</td>
<td>85</td>
<td>58.93</td>
<td>127%</td>
</tr>
<tr>
<td>E1- tLarge</td>
<td>6</td>
<td>3</td>
<td>7.5</td>
<td>58</td>
<td>40.21</td>
<td>87%</td>
</tr>
<tr>
<td>F1+ vArea</td>
<td>15</td>
<td>30</td>
<td>7.5</td>
<td>63</td>
<td>43.67</td>
<td>94%</td>
</tr>
<tr>
<td>F1- vArea</td>
<td>15</td>
<td>8</td>
<td>7.5</td>
<td>73</td>
<td>50.61</td>
<td>109%</td>
</tr>
<tr>
<td>G1+ vOutside</td>
<td>30</td>
<td>50</td>
<td>7.5</td>
<td>67</td>
<td>46.45</td>
<td>100%</td>
</tr>
<tr>
<td>G1- vOutside</td>
<td>30</td>
<td>15</td>
<td>7.5</td>
<td>66</td>
<td>45.75</td>
<td>98%</td>
</tr>
</tbody>
</table>

Table 22 and Table 23 show the results from the SA of all scenarios active in centre only and active in both areas compared on output variables distance, time and cost of a last mile trip. The cost of a last mile trip is compared relatively per scenario. Time constants have a relatively large impact on total cost. Constants that are time related are time per stop; time for a small package and time for a large package.

![SA average shipment (centre and outside centre)](image)

![SA average shipment (centre and outside centre)](image)
Table 23 - Results of SA analysis – Case: average shipment (centre and outside centre)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>From</th>
<th>To</th>
<th>Distance [km]</th>
<th>Time [min]</th>
<th>Cost [€]</th>
<th>Relatively</th>
</tr>
</thead>
<tbody>
<tr>
<td>H0</td>
<td>1</td>
<td>x</td>
<td>8.5</td>
<td>125</td>
<td>86.66</td>
<td>100%</td>
</tr>
<tr>
<td>A2+ dInOut</td>
<td>500</td>
<td>1000</td>
<td>8.5</td>
<td>126</td>
<td>87.35</td>
<td>101%</td>
</tr>
<tr>
<td>A2- dInOut</td>
<td>500</td>
<td>100</td>
<td>8.5</td>
<td>66</td>
<td>85.96</td>
<td>99%</td>
</tr>
<tr>
<td>B2+ dStops</td>
<td>250</td>
<td>500</td>
<td>10.5</td>
<td>133</td>
<td>92.2</td>
<td>106%</td>
</tr>
<tr>
<td>B2- dStops</td>
<td>250</td>
<td>50</td>
<td>6.9</td>
<td>119</td>
<td>82.5</td>
<td>95%</td>
</tr>
<tr>
<td>C2+ tStops</td>
<td>4</td>
<td>8</td>
<td>8.5</td>
<td>170</td>
<td>117.85</td>
<td>136%</td>
</tr>
<tr>
<td>C2- tStops</td>
<td>4</td>
<td>2</td>
<td>8.5</td>
<td>100</td>
<td>69.32</td>
<td>80%</td>
</tr>
<tr>
<td>D2+ tSmall</td>
<td>2</td>
<td>4</td>
<td>8.5</td>
<td>161</td>
<td>111.61</td>
<td>129%</td>
</tr>
<tr>
<td>D2- tSmall</td>
<td>2</td>
<td>1</td>
<td>8.5</td>
<td>107</td>
<td>74.18</td>
<td>86%</td>
</tr>
<tr>
<td>E2- tLarge</td>
<td>6</td>
<td>3</td>
<td>8.5</td>
<td>107</td>
<td>74.18</td>
<td>86%</td>
</tr>
<tr>
<td>F2+ vArea</td>
<td>30</td>
<td>50</td>
<td>8.5</td>
<td>120</td>
<td>83.19</td>
<td>96%</td>
</tr>
<tr>
<td>F2- vArea</td>
<td>30</td>
<td>15</td>
<td>8.5</td>
<td>135</td>
<td>93.59</td>
<td>108%</td>
</tr>
<tr>
<td>G2+ vOutside</td>
<td>30</td>
<td>50</td>
<td>8.5</td>
<td>126</td>
<td>87.35</td>
<td>101%</td>
</tr>
<tr>
<td>G2- vOutside</td>
<td>30</td>
<td>15</td>
<td>8.5</td>
<td>123</td>
<td>85.27</td>
<td>98%</td>
</tr>
</tbody>
</table>

Time is relatively expensive compared to distance since distance components have a smaller impact on total cost. Taking in mind a truck driver wage it is imaginable why. The outcome of the model proves that for example traffic jams (which cost a lot of valuable time) are a huge waste of money. All freight carriers’ benefit from proper infrastructure without congestion.

The hypothesis needs to be evaluated. Recap, hypotheses formulated at the beginning of this paragraph are:

H0+: Cost per trip is higher for all scenarios
H0-: Cost per trip is lower for all scenarios

All output variables are higher in case of scenarios where constants are higher. This means that all hypotheses are correct and that the LMS model gives the expected results in light of sensitivity of changing different assumptions. Overall, it can be concluded that all constants and modified values give the expected output. This argument strengthens validity of the model because, the model generates realistic and logic outputs when varying input variables and constants.
4.7.2. **Case: Large shipments**

In previous paragraph a SA is conducted on average shipments. In this paragraph sensitivity of constants on a large shipment is explored. A set of input variables is given in Table 24. The set of input variables can be described as a large shipment, a vehicle of medium size and a low amount of stops. The amount of small packages is 20. The amount of large packages is 5 and the amount of stops is 3.

**Table 24 – Large shipment, set of input variables**

<table>
<thead>
<tr>
<th>Input</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>City</td>
<td>Delft</td>
</tr>
<tr>
<td>Vehicle type</td>
<td>Truck of 12-16</td>
</tr>
<tr>
<td>Peak hour</td>
<td>Yes</td>
</tr>
<tr>
<td>Active in area</td>
<td>Both</td>
</tr>
<tr>
<td>Access road</td>
<td>A13 Delft</td>
</tr>
<tr>
<td>Exit road</td>
<td>A4 via</td>
</tr>
<tr>
<td># of small</td>
<td>20</td>
</tr>
<tr>
<td># of large</td>
<td>5</td>
</tr>
<tr>
<td># of stops</td>
<td>3</td>
</tr>
</tbody>
</table>

Constants are varied similar as is in previous paragraph on average shipment. In Table 25 variation in constants is given.

**Table 25 - Variation in constants of set values**

<table>
<thead>
<tr>
<th>SA</th>
<th>City Area</th>
<th>dInOut</th>
<th>dStops</th>
<th>tStops</th>
<th>tSmall</th>
<th>tLarge</th>
<th>vArea</th>
<th>vOutside</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td>Delft Centre</td>
<td>500</td>
<td>250</td>
<td>5</td>
<td>2</td>
<td>6</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Current</td>
<td>Delft Outside</td>
<td>500</td>
<td>250</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Higher</td>
<td>Delft Centre</td>
<td>1000</td>
<td>500</td>
<td>10</td>
<td>4</td>
<td>12</td>
<td>30</td>
<td>50 (A1+)</td>
</tr>
<tr>
<td>Higher</td>
<td>Delft Outside</td>
<td>1000</td>
<td>500</td>
<td>8</td>
<td>4</td>
<td>12</td>
<td>50</td>
<td>50 (A2+)</td>
</tr>
<tr>
<td>Lower</td>
<td>Delft Centre</td>
<td>100</td>
<td>50</td>
<td>2,5</td>
<td>1</td>
<td>3</td>
<td>8</td>
<td>15 (B1-)</td>
</tr>
<tr>
<td>Lower</td>
<td>Delft Outside</td>
<td>100</td>
<td>50</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>15</td>
<td>15 (B2-)</td>
</tr>
</tbody>
</table>

**Hypotheses large shipment**

H0+: Cost per trip is higher for all scenarios
H0-: Cost per trip is lower for all scenarios

**Results**

Figure 31 and Table 26 present the results of scenario centre only. Figure 31 shows the results from the SA of all scenarios active in centre only compared on output variables distance, time and cost of a last mile trip. Again, the cost of a last mile trip is compared relatively per scenario. In case of a large shipment the same conclusions can be drawn. Time constants also have a relatively large impact on total cost compared to other constants. This is applicable for centre only as well as centre and outside centre trips.
**Figure 31 – SA of a large shipment (centre only)**

**Table 26 - Results of SA analysis – Case: large shipment (centre only)**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>From</th>
<th>To</th>
<th>Distance [km]</th>
<th>Time [min]</th>
<th>Cost [€]</th>
<th>Relatively to H0</th>
</tr>
</thead>
<tbody>
<tr>
<td>H0</td>
<td>x</td>
<td>x</td>
<td>11,7</td>
<td>89</td>
<td>60,77</td>
<td>100% 0%</td>
</tr>
<tr>
<td>A1+ dinOut</td>
<td>500</td>
<td>1000</td>
<td>11,7</td>
<td>90</td>
<td>61,46</td>
<td>101% 1%</td>
</tr>
<tr>
<td>A1- dinOut</td>
<td>500</td>
<td>100</td>
<td>11,7</td>
<td>88</td>
<td>60,09</td>
<td>99% -1%</td>
</tr>
<tr>
<td>B1+ dStops</td>
<td>250</td>
<td>500</td>
<td>12,2</td>
<td>92</td>
<td>62,82</td>
<td>103% 3%</td>
</tr>
<tr>
<td>B1- dStops</td>
<td>250</td>
<td>50</td>
<td>11,3</td>
<td>86</td>
<td>58,73</td>
<td>97% -3%</td>
</tr>
<tr>
<td>C1+ tStops</td>
<td>5</td>
<td>10</td>
<td>11,7</td>
<td>104</td>
<td>71,02</td>
<td>117% 17%</td>
</tr>
<tr>
<td>C1- tStops</td>
<td>5</td>
<td>2.5</td>
<td>11,7</td>
<td>80</td>
<td>54,63</td>
<td>90% -10%</td>
</tr>
<tr>
<td>D1+ tSmall</td>
<td>2</td>
<td>4</td>
<td>11,7</td>
<td>129</td>
<td>88,09</td>
<td>145% 45%</td>
</tr>
<tr>
<td>D1- tSmall</td>
<td>2</td>
<td>1</td>
<td>11,7</td>
<td>69</td>
<td>47,12</td>
<td>78% -22%</td>
</tr>
<tr>
<td>E1+ tLarge</td>
<td>6</td>
<td>12</td>
<td>11,7</td>
<td>119</td>
<td>81,26</td>
<td>134% 34%</td>
</tr>
<tr>
<td>E1- tLarge</td>
<td>6</td>
<td>3</td>
<td>11,7</td>
<td>74</td>
<td>50,53</td>
<td>83% -17%</td>
</tr>
<tr>
<td>F1+ vArea</td>
<td>15</td>
<td>30</td>
<td>11,7</td>
<td>86</td>
<td>58,73</td>
<td>97% -3%</td>
</tr>
<tr>
<td>F1- vArea</td>
<td>15</td>
<td>8</td>
<td>11,7</td>
<td>93</td>
<td>63,51</td>
<td>105% 5%</td>
</tr>
<tr>
<td>G1+ vOutside</td>
<td>30</td>
<td>50</td>
<td>11,7</td>
<td>89</td>
<td>60,77</td>
<td>100% 0%</td>
</tr>
<tr>
<td>G1- vOutside</td>
<td>30</td>
<td>15</td>
<td>11,7</td>
<td>88</td>
<td>60,09</td>
<td>99% -1%</td>
</tr>
</tbody>
</table>
The results of scenario centre and outside centre are presented in Figure 32 and in Table 27.

The hypothesis needs to be evaluated. Hypotheses formulated at the beginning of this paragraph are:

H0+: Cost per trip is higher for all scenarios  
H0-: Cost per trip is lower for all scenarios

Outcome of the analysis are in line with formulated hypotheses. Lower values of constants have resulted in lower outputs on cost per trip and higher values of constants have resulted in higher outputs on cost per trip.

Table 27 - Results of SA analysis – Case: large shipment (centre and outside centre)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>From</th>
<th>To</th>
<th>Distance</th>
<th>Time</th>
<th>Cost</th>
<th>Relatively</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[km]</td>
<td>[min]</td>
<td></td>
<td></td>
<td>[€]</td>
<td></td>
</tr>
<tr>
<td>H0</td>
<td>x</td>
<td>x</td>
<td>12.2</td>
<td>172</td>
<td>117.45</td>
<td>100%</td>
</tr>
<tr>
<td>A2- dInOut</td>
<td>500</td>
<td>1000</td>
<td>12.2</td>
<td>173</td>
<td>118.13</td>
<td>101%</td>
</tr>
<tr>
<td>B2- dStops</td>
<td>250</td>
<td>500</td>
<td>13.2</td>
<td>177</td>
<td>120.86</td>
<td>103%</td>
</tr>
<tr>
<td>C2- tStops</td>
<td>4</td>
<td>8</td>
<td>12.2</td>
<td>199</td>
<td>135.89</td>
<td>116%</td>
</tr>
<tr>
<td>D2- tSmall</td>
<td>2</td>
<td>4</td>
<td>12.2</td>
<td>252</td>
<td>172.08</td>
<td>147%</td>
</tr>
<tr>
<td>E2- vArea</td>
<td>30</td>
<td>50</td>
<td>12.2</td>
<td>169</td>
<td>115.4</td>
<td>98%</td>
</tr>
<tr>
<td>F2- vArea</td>
<td>30</td>
<td>45</td>
<td>12.2</td>
<td>179</td>
<td>122.23</td>
<td>104%</td>
</tr>
<tr>
<td>G2- vOutside</td>
<td>30</td>
<td>60</td>
<td>12.2</td>
<td>173</td>
<td>118.13</td>
<td>101%</td>
</tr>
</tbody>
</table>

Figure 32 – SA of large shipment (centre and outside centre)
In general, time related variables have a larger impact on output of the LMS model. Time related variables are time per stop, time to unload small packages and time to unload large pallets.

Differences of sensitivity between centre only and centre and outside centre are little because relative impacts of all scenarios are similar for both cases. Figure 36 visualizes both bar graphs. These graphs show similar heights on all scenarios concerning corresponding size of shipments for centre and outside centre cases.

The difference in sensitivity between ‘average’ versus ‘large shipments’ is higher. Heights of the bars (blue versus red) in the graph show the difference between ‘average’ versus ‘large shipments’. The characteristics of an average shipment with regard to a large shipment is that it has a smaller shipping load but does make more stops. Relative impact of constant ‘stops’ in case of an ‘average shipment’ on the outcome is higher compared to a ‘large shipment’ (5 versus 3 stops). Evaluation of number of small and large packages versus sensitivity on the output show similar results. An average shipment (10 small packages and 3 large pallets) versus a large shipment (20 small packages and 5 large pallets) show corresponding relative impact on output variables. The relative impact of large shipments is for both cases (centre and outside centre) higher compared to an average shipment. The conclusion of this comparison is in line with expected hypothesis.

Validation on assumptions and constants has been conducted in paragraph 4.5.2. Time for a stop and unloading times are not perfectly accurate. Conducted field research could have resulted in values of assumptions that do not correspond with values in practise. Unfortunately, the sensitivity analyses show that especially these variables have a relatively large impact on output variables of the LMS model.

4.7.3. Sensitivity analyses of tariffs

The result of percentage of saving is influenced by the tariff handled by a commercial distributor; in the case of Delft this is PostNL. The provided tariffs of a commercial distributor of small and large packages is analysed with a lower tariff only and are compared with outcome of the LMS model, the total cost of a trip.

An alternative shipping method is that carriers deliver their shipment on the outside of the city at the city distributions centre of a commercial distributor. The tariffs that are used to calculate cost of a last mile trip, using a commercial distributor, are competitive tariffs and determined by PostNL. Since PostNL is a commercial company the handled tariff includes a profit margin for PostNL. Handling shipping for cost price will definitely be lower.

Company PostNL has an existing DC at the Staalweg. This (still temporary) DC is provided to PostNL by the municipality of Delft. The building is owned by the municipality and was not in use at the time. PostNL has invested heavily in electric vehicles. Therefore, they only operate with e-vehicles in the urban area of Delft. The municipality noticed these investments and were willing to stimulate
sustainable initiatives, they decided to provide PostNL with a free and existing (by than empty) building that would be perfectly suitable as distribution centre. The location is perfect due to the close distance towards the city centre and great accessibility from the highway. Since the beginning of February 2015 PostNL is operating from the city logistic DC at the Staalweg with e-vehicles only.

The LMS model uses set tariffs for small packages of €3,95 and €9,00 for large pallets. In the SA a lower tariff of €3,25 and €7,00 is used. These lower tariffs can either be reduced by PostNL or subsidized by the municipality of Delft to stimulate electric freight transportation. In order to analyse the impact on percentage of saving for freight carriers active in the region of Delft a SA is conducted. The SA on tariffs explores impact of adapting lower tariffs by PostNL and to see what market share they could gain potentially. Variations on tariffs are given in Table 28.

Table 28 - Variation in tariffs in euros of commercial distributor

<table>
<thead>
<tr>
<th>Tariff small package</th>
<th>Tariff large package</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,95</td>
<td>9</td>
</tr>
<tr>
<td>3,25 (reduced/subsidized)</td>
<td>7 (reduced/subsidized)</td>
</tr>
</tbody>
</table>

For the analysis the same basic set of input variables of an average shipment is used. The set of input variables is presented again below.

Table 29 – Average shipment set of input variables

<table>
<thead>
<tr>
<th>Input variables</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>City</td>
<td>Delft</td>
</tr>
<tr>
<td>Vehicle type</td>
<td>Truck of 12-16 ton</td>
</tr>
<tr>
<td>Peak hour</td>
<td>Yes</td>
</tr>
<tr>
<td>Active in area</td>
<td>Both</td>
</tr>
<tr>
<td>Access road</td>
<td>A13 Delft South</td>
</tr>
<tr>
<td>Exit road</td>
<td>A13 Delft North</td>
</tr>
<tr>
<td># of small packages</td>
<td>10</td>
</tr>
<tr>
<td># of large packages</td>
<td>3</td>
</tr>
<tr>
<td># of stops</td>
<td>5</td>
</tr>
</tbody>
</table>

Results

Table 30 and Table 31 provide the results of the SA on tariffs. Worth noticing is that carriers active in and outside the city centre (Table 31) which are covering larger distances between stops, score higher on the percentage of saving. This means that the according to the output of the model it can be more beneficial for these carriers to choose an alternative shipping method.

Figure 34 and Table 30 present the results of the SA on tariffs of freight carriers active in the city centre. In general, outcome of the LMS model (outcome LMS) is compared with an alternative shipping method (current PostNL) and with an alternative shipping method with a reduced tariff (reduced PostNL). In all scenarios the current PostNL is a more expensive alternative compared to outcome LMS and of course reduced PostNL. Interesting to see is that reduced PostNL is in some scenarios a less costly alternative then outcome LMS. This is applicable for scenarios C1+ tStops, D1+ tSmall and E1+ tLarge which are related to time variables, more specific stopping time, time for small packages and time for large pallets. In these scenario time variables are increased compared to the set value of the constant.
Furthermore, worth noticing is that the cost of a trip active in both areas compared on outcome LMS current cost PostNL and reduced cost PostNL scenarios score better than scenarios in centre only. The results are shown in Figure 35. Purely on the base of these outcomes of the LMS model, all freight carriers active in both areas with similar trip characteristics (average shipment set of input variables), can benefit and save money when using an alternative shipping method (reduced tariff scenario).

![Figure 34 - SA cost PostNL versus cost LMS (centre)](image)

**Figure 34 - SA cost PostNL versus cost LMS (centre)**

**Table 30 – Results SA PostNL tariff versus cost LMS (active in city centre)**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>From</th>
<th>To</th>
<th>Active in area</th>
<th>Cost</th>
<th>Current</th>
<th>Reduced</th>
<th>Cost</th>
<th>Current</th>
<th>Reduced</th>
</tr>
</thead>
<tbody>
<tr>
<td>H0</td>
<td>x</td>
<td>x</td>
<td>Centre</td>
<td>€46,45</td>
<td>€66,50</td>
<td>€53,50</td>
<td>-30%</td>
<td>-13%</td>
<td></td>
</tr>
<tr>
<td>A1+ dInOut</td>
<td>500</td>
<td>1000</td>
<td>Centre</td>
<td>€47,14</td>
<td>€66,50</td>
<td>€53,50</td>
<td>-29%</td>
<td>-12%</td>
<td></td>
</tr>
<tr>
<td>A1- dInOut</td>
<td>500</td>
<td>100</td>
<td>Centre</td>
<td>€45,75</td>
<td>€66,50</td>
<td>€53,50</td>
<td>-31%</td>
<td>-14%</td>
<td></td>
</tr>
<tr>
<td>B1+ dStops</td>
<td>250</td>
<td>500</td>
<td>Centre</td>
<td>€49,91</td>
<td>€66,50</td>
<td>€53,50</td>
<td>-25%</td>
<td>-7%</td>
<td></td>
</tr>
<tr>
<td>B1- dStops</td>
<td>250</td>
<td>50</td>
<td>Centre</td>
<td>€43,67</td>
<td>€66,50</td>
<td>€53,50</td>
<td>-34%</td>
<td>-18%</td>
<td></td>
</tr>
<tr>
<td>C1+ tStops</td>
<td>5</td>
<td>10</td>
<td>Centre</td>
<td>€63,78</td>
<td>€66,50</td>
<td>€53,50</td>
<td>-4%</td>
<td>19%</td>
<td></td>
</tr>
<tr>
<td>C1- tStops</td>
<td>5</td>
<td>2.5</td>
<td>Centre</td>
<td>€36,05</td>
<td>€66,50</td>
<td>€53,50</td>
<td>-46%</td>
<td>-33%</td>
<td></td>
</tr>
<tr>
<td>D1+ tSmall</td>
<td>2</td>
<td>4</td>
<td>Centre</td>
<td>€58,93</td>
<td>€66,50</td>
<td>€53,50</td>
<td>-11%</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>D1- tSmall</td>
<td>2</td>
<td>1</td>
<td>Centre</td>
<td>€40,21</td>
<td>€66,50</td>
<td>€53,50</td>
<td>-40%</td>
<td>-25%</td>
<td></td>
</tr>
<tr>
<td>E1+ tLarge</td>
<td>6</td>
<td>12</td>
<td>Centre</td>
<td>€58,93</td>
<td>€66,50</td>
<td>€53,50</td>
<td>-11%</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>E1- tLarge</td>
<td>6</td>
<td>3</td>
<td>Centre</td>
<td>€40,21</td>
<td>€66,50</td>
<td>€53,50</td>
<td>-40%</td>
<td>-25%</td>
<td></td>
</tr>
<tr>
<td>F1+ vArea</td>
<td>15</td>
<td>30</td>
<td>Centre</td>
<td>€43,67</td>
<td>€66,50</td>
<td>€53,50</td>
<td>-34%</td>
<td>-18%</td>
<td></td>
</tr>
<tr>
<td>F1- vArea</td>
<td>15</td>
<td>8</td>
<td>Centre</td>
<td>€50,61</td>
<td>€66,50</td>
<td>€53,50</td>
<td>-24%</td>
<td>-5%</td>
<td></td>
</tr>
<tr>
<td>G1+ vOutside</td>
<td>30</td>
<td>50</td>
<td>Centre</td>
<td>€46,45</td>
<td>€66,50</td>
<td>€53,50</td>
<td>-30%</td>
<td>-13%</td>
<td></td>
</tr>
<tr>
<td>G1- vOutside</td>
<td>30</td>
<td>15</td>
<td>Centre</td>
<td>€45,75</td>
<td>€66,50</td>
<td>€53,50</td>
<td>-31%</td>
<td>-14%</td>
<td></td>
</tr>
</tbody>
</table>
method (shipment set of input variables), can benefit and save money when using an alternative shipping based on distributor. A positive impact on environmental aspects too due to consolidation of freight by a central (probably more efficient) distributor more expensive. Changing shipping greater extent of an alternative shipping method because the larger distances centre and outside centre are relatively more expensive.

4.7.4. Remarks

The SA results are similar for average and large shipment on all scenarios. Shipments active in both centre and outside centre are relatively more expensive. These type of shipments can benefit to a greater extent of an alternative shipping method because the larger distances make the last mile trip more expensive. Changing shipping method and outsourcing part of their activities to a central (probably more efficient) distributor seems beneficial in economic terms. Moreover, this probably has a positive impact on environmental aspects too due to consolidation of freight by a central distributor.

Based on SA on tariffs all freight carriers active in both areas with similar trip characteristics (average shipment set of input variables), can benefit and save money when using an alternative shipping method (current and reduced tariff scenario).
4.8. Summary and conclusion

In this paragraph a concise summary and conclusion of chapter 4 on validation of the LMS model is given. Substantively, sub-question II-1 is answered. This section ends with some final remarks.

This chapter started with the following sub-question:

(SQ II-1) Is the LMS a valid model?

To be able to answer this question a validation framework developed by Sargent is used. This framework distinguishes conceptual model validation, computerized model verification, data validity and operational validation. These different validation processes have been treated subsequently. Furthermore, a sensitivity analysis is conducted to see test robustness of the LMS model.

Conceptual model validation

The LMS model is evaluated and compared with the problem entity. The question seeks to be answered is: *Is the model a reasonably representation of the problem entity?* In other words, is the LMS model a justified translation of reality. Is the model not too much simplified in order to execute calculations and is outcome of the model accurate, meaningful and therefore useful.

The model tries to capture and estimate last mile trips of individual freight carriers. The problem entity is the ‘unknown cost of a last mile trip’ for both freight carriers and the municipality of Delft. The LMS model uses different variables and constants to estimate and give an indication of cost of a specific shipping. The black box and the CRD are conceptual models of the LMS model. The relations between variables used by the model are logic. Although only the direction of the relation is evaluated at this stage the LMS model seems to be fairly reasonable, but simplified representation of the real situation. A simplification of the real world is insurmountable to be able to conduct calculations. In reality, last mile trips are individual cases with unique characteristics. Therefore, analysing these cases one by one is too difficult and time consuming. Assumptions of constants that represent average values are needed. The purpose of development the LMS model by MD is to identify, facilitate and regulate and is partly achieved. The first and second objective, identify activities that take place in the urban area and facilitate involved stakeholders with information on cost structures, has been succeeded since the model provides both actors of a cost indication on the last mile. The final objective, regulate, is not yet met because it is still unknown if results are accurate and valid.

Computerized model verification

In the computerized model verification phase used formulas have been introduced and evaluated. Total distance of a trip is calculated with Formula 1. Three of the four variables are calculated using an API tool developed by Google. This application ensures a high accuracy of distances since it uses precise coordinates to calculate covered distances. Formula 3, used for calculating distance per stop, is plausible because distance per stop can be calculated by multiplying the number of stops times an average distance per stop.

Formula 6 calculates total time of a trip. Total time is dependent on driving and unloading time. Driving time is dependent on average velocity of a vehicle and total distance covered. The general dimension of velocity is kilometre per hour; velocity = distance / time; time = distance / velocity. This relation is correct. Unloading time is dependent on the amount of small and large packages delivered multiplied by a constant ‘average unloading time’ per package/pallet. Unloading time can be estimated by using a constant ‘average time for unloading small/large packages’ because every unit takes time to deliver. In addition, for every delivery a general time (or penalty) that is spent on searching for a parking lot and parking the vehicle.

Total cost is calculated in Formula 9 and dependent on total time multiplied by cost per hour and total distance multiplied by cost per kilometre. This is a plausible method. The formulas introduced in paragraph 4.4 to calculate distance, time and cost of a last mile trip and relations between variables used to conduct these calculations are plausible. The accuracy and
correctness of assumptions of constants of average distance per stop, vehicle velocity, average-unloading times for small and large packages, general time, cost per kilometre and cost per hour are not yet validated.

Data validity
Data validity is conducted by validating methodologies used to collect this data. An interview conducted with a senior researcher of Research Company Panteia provided information on how data is obtained and applied. Panteia uses a benchmark methodology and works according a few rules of thumb; a minimum amount of participants (10 transport companies) need to be included to guarantee conclusions have a significant level of reliability. Another important rule is that collected data needs to be up to date in order to ensure a right reflection of reality. The bench mark methodology and strict rules that Panteia practise ensures data collection is done properly and is significantly reliable. Input data on assumptions like velocities of vehicles and cost per minute and kilometre are valid.

Data collected throughout field research is less reliable. It is difficult to state that these assumptions correspond with real world values, because background information on scope of this field research is not available and unknown. Moreover, students and not professional research employees conducted the field research which makes the research unreliable. A situation sketch on distance per stop proved that a larger distance per stop is more likely (the same applies for distance in=out). Assumptions on time for a stop and unloading times seems to be reasonable since reconstruction of the situation provides a range where set values fall within. To ensure set values are within confidence interval more information on background of the field research is needed. The advice is to increase the scope of the field research to ensure the amount of background data is large and constructed assumption are more likely to be reliable. Overall, it is difficult to state that these assumptions correspond with values in practise and are therefore not valid.

Operational validity
Operational validity is impossible due to a lack of real data. Due to a lack of real data it is impossible to crosscheck output of the LMS model with real data from the field. Freight carriers themselves do not know the cost of the last mile. They see urban freight distribution from a larger, supply chain perspective instead of a smaller, last mile perspective. The larger perspective of distributors gives them a blind spot on performance levels on the last-mile.

A cross validation check with available models is conducted. PostNL developed a model that captures current and future scenarios and compares them on environmental performance, distance covered, cost difference and number of vehicle movements. This model uses a different methodology and has other (cumulative) results (not individual as in the LMS model). Drawing conclusions is difficult since structures of the models are significantly different. In general, the LMS model puts a heavy weight (penalty) on a shipping where only 1 package is delivered. In contrary a shipment of a large pallet contributes to a greater extent to the total time in the PostNL model.

The research conducted by Roger Peters is used as reference to see if formulas used in that research have similar structures as the LMS model. The calculation model developed by Peters calculates total air quality & climate, trajectory velocity, intensity of the network, trip length and residence time in the city of Breda. It differs in output because the LMS model tries to give an indication in total time, distance and cost of an individual trip. Average velocity of vehicles can be compared. Air quality and Intensity are not included in the LMS model and cannot be compared. Total trip length is dependent on specific city characteristics of Breda and Delft and therefore hard to compare.

The model of Peters uses average vehicle velocities of 25 km/h (light vehicles), 22 km/h (middle heavy vehicles) and 17 km/h (heavy vehicles). The LMS model two vehicle velocities, not based on vehicle type, but on location. In city centre a velocity of 15 km/h is used and outside the city centre a velocity of 30 km/h. The average velocities used in the model of Peters are in between the velocities used in the LMS. This strengthens the degree of validity of velocities used in both models.

Peters calculates total trip length by multiplying the amount of trips with an average trip length multiplied by 2 (in and out). The LMS model calculates individual trip lengths not cumulative. The
average trip length is calculated with aid of Google maps and is based on the allocation of all access and exit roads and the weighted distances to the city centre. The LMS model uses a more sophisticated method because it uses an API that calculates distance of the access and exit roads to the centre of an area based on known coordinates. This tool is extremely precise. Both used methods are plausible. The method applied by the LMS model is better since it is more accurate.

The total residence time formula used by Peters is constructed from the total general time (loading, unloading and handling) plus the total driving time multiplied by the amount of vehicles. The LMS model does not calculate total times of the city of Delft but individual shipping times, therefore it is interesting to research what the average general and driving times are. The mean of all scans is 98 minutes with a standard deviation of 125.98. The total time of different types of occasional transporters, specialist and chain transporters derived from the research of Peters are respectively 46, 80 and 124 minutes. These are total trip times of shipments in Breda. The cities of Delft and Breda are quite similar in size and distances. It seems that results from both models are within plausible boundaries. Since both formulas use the same structure it is admissible that the approach that is used is right. Contrary, it is not possible to say if the results are valid because it is not known what type of vehicle trips are used in the model of Peters and if the dataset of the LMS model consist from the same types of trips and size.

**Sensitivity analysis**

Output variables are higher in case of scenarios where constants are higher. This means that all hypotheses are correct and that the LMS model gives the expected results in light of sensitivity of changing different assumptions. Overall, it can be concluded that all constants and modified values give the expected output. This argument strengthens validity of the model because, the model generates realistic and logic outputs when varying input variables and constants.

The SA results are similar for average and large shipment on all scenarios. Shipments active in both centre and outside centre are relatively more expensive. These types of shipments can benefit to a greater extent of an alternative shipping method because the larger distances make the last mile trip more expensive. Changing shipping method and outsourcing part of their activities to a central (probably more efficient) distributor seems beneficial in economic terms. Moreover, this probably has a positive impact on environmental aspects too due to consolidation of freight by a central distributor. Based on SA on tariffs only, all freight carriers active in both areas with similar trip characteristics (average shipment set of input variables) can benefit and save money when using an alternative shipping method (current and reduced tariff scenario)

Overall it can be concluded that the LMS model is a reasonable representation of the problem entity and that conceptualization and computerized model verification phases have been conducted properly. Data validity is not valid yet and can be improved on certain assumptions and the scope of the research can be more extensive. Field research methods are basic and the actual size of the research is too small to gather a significant and therefore crucial minimum amount of information and data. Operational validity is impossible due to a lack of real data and knowledge of freight carriers on the exact cost of their last mile trip. Therefore, the LMS model cannot be labelled as valid because some validation phases are not successfully completed.
5. CHAPTER 5  DATA ANALYSIS

In this chapter data collected by the LMS model is analysed. The process of data collection is examined first. Thereafter the collected data is further studied and relationships between important variables are explored. This section ends with some recommendations on how collected data can be better used to improve urban freight- distribution and related policies in the municipality of Delft.

5.1. Case study

In this paragraph the procedure of data collection by MD is evaluated.

5.1.1. DATA COLLECTION OF PARTICIPANTS

Data is collected by ‘Maatwerk Distribution’ through a website. Freight carriers are asked to fill out a scan, which they can access online on the website. In practise, participations did not volunteer to participate due to unfamiliarity with MD and uncertainty of added value of the LMS model. Therefore, MD was forced to actively collect data through telephoning freight carriers active in the urban region of Delft. In a first telephone conversation freight carriers were asked if they would like to participate in a research of the municipality of Delft. If so, they were given an account and guided to the website. A week later MD checked if all companies that were willing to cooperate completed the scan, if they did not they were phone called a second time with a friendly reminder. In this conversation freight carriers were asked if they had time to complete the scan immediately, together. This process was repeated a few times until a critical amount of scans were completed to gather enough data to be able to conduct analysis.

Unfortunately, freight carriers would not update their profiles at a later stage. Also, the amount of completed scans or new participants was not growing naturally due to a number of factors. Reasons mentioned by participants are ‘unknown routes’, ‘variations in routes’, ‘outsourcing’, ‘unknown added value of the scan’ and ‘the scan is time consuming’ (Maatwerk Distributie, 2015).

5.1.2. SAMPLE SIZE COLLECTED BY MD

MD has collected data from freight carriers active in Delft, Rijswijk, Leidschendam-Voorburg, Pijnacker-Nootdorp, Den Haag and Leiden. Added together an amount of 525 scans have been filled out by freight carriers active in one or more of the listed above cities. In Table 32 the distribution of the total amount of scans gathered over the different regions is displayed.

Table 32 - Total amount of trips collected by the LMS model

<table>
<thead>
<tr>
<th>City</th>
<th>Complete</th>
<th>Incomplete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intension</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delft</td>
<td>22</td>
<td>41</td>
</tr>
<tr>
<td>Rijswijk</td>
<td>22</td>
<td>41</td>
</tr>
<tr>
<td>Leidschendam</td>
<td>16</td>
<td>38</td>
</tr>
<tr>
<td>Pijnacker-Nootdorp</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>Den Haag</td>
<td>23</td>
<td>52</td>
</tr>
<tr>
<td>Leiden</td>
<td>23</td>
<td>48</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>120</td>
<td>253</td>
</tr>
</tbody>
</table>

Not all of these 525 scans are completed. Data analysis in the next paragraph is on completed scans only. Scans from all cities are used in order to reach a significant amount of data. Freight carriers who ticked an intension box to ‘yes’ can be contacted again and are open to be approached by a central distributor. The central distributor who won the tender issued by the municipality of Delft is PostNL. The reason that this company won is because they scored extra points on being active on social sustainable business activities (Brandligt, 2014). Because they were the winning distributor they have developed the concept of ‘Stadslogistiek Delft’. This concept uses small e-vehicles only to transport
freight in the urban area of Delft. The sustainable point of view of PostNL resulted in collaboration between the municipality of Delft and PostNL. The municipality provided an empty factory to PostNL on the edge of the city that can be used as a distribution centre. The list of potential freight carriers is provided to PostNL to give them an opportunity to create new partnerships with them to distribute freight from distribution centre ‘stadslogistiek Delft’. Freight carriers that ticked intension ‘no’ were not be contacted again.

5.2. Analysis of data sample

In this section collected data by MD is explored. Distributions of the data sample on amount of stops, load (packages and pallets), frequency, type of vehicles and cost/unit are given. Furthermore, relations between important variables like distance, time and total cost are analysed. In addition, influence of variables ‘number of stops’ and ‘size of shipment’ on cost is explored. Finally, relationships between total cost of a trip resulted (outcome of the model) and total cost of a trip when carried out by PostNL are compared.

5.2.1. DISTRIBUTION OF INPUT VARIABLE SHIPPING LOAD

In this paragraph the distribution of stops, load (packages and pallets), frequency, type of vehicles and cost/unit are explored. The distribution of load, distinguished on packages, pallets and total load are presented. First the amount of small packages versus amount of trips is shown. Secondly, the amount of pallets versus the amount of trips is given. Finally, shipping load (package + pallets), total load versus amount of trips is presented.

Input variable small packaged and large pallets

Figure 36 and Figure 37 present the distribution in a histogram of shipping load (packages and pallets separately). Frequencies are displayed on the y-axis and number of packages/pallets on the x-axis. Analysing Figure 36 tells that the balance of the graph is between 0 and 2 small packages. There are a lot of trips that do not ship small packages at all, this is almost 40% of all shipments and there are a lot of trips that ship 1 or 2 packages only. The median of last mile trips is 0 package (100 trips). The average number of packages shipped per trip is 4,5.

Figure 36 – Histogram of shipping load (small packages)
Figure 37 shows that the centre of gravity is between 0 and 2 pallets per shipment. Summed up they cover over 65% of all shipping’s. The median of trips ship 1 pallet (75 trips). The average number of pallets per trip is 3,8.

Figure 37 - Histogram of shipping load (pallets)

Undefined input variable total shipping load
Due to the fact that there are a lot of trips that either ship 0 packages or 0 pallets it is worth to have a closer look at the total shipping load (packages + pallets). The total shipping load versus amount of trips is presented in Figure 38. The median of trips ship 2 units (56 trips). The average number of total load per trip is 8,4.

Figure 38 - Histogram of total shipping load (package + pallets)

The centre of gravity is shifted to the right and is basically concentrated around two peaks; a total load between 1 and 4 units and a peak between 10 and 20. This information shows that most trips are either relatively small (low loading rate, inefficient) or relatively large (high loading rate, efficient).
Output variable ‘total load’ is not yet available in the LMS model but as mentioned can be easily mutated by the sum of small package plus large pallets.

### 5.2.2. DISTRIBUTION OF INPUT VARIABLES STOPS, FREQUENCY AND TYPE OF VEHICLE

**Input variable stops**

Figure 39 present the frequency histogram of amount of stops. The chart shows that most trips only have 1 stop. Two third of all trips have between 1 and 3 stops. The average amount of stops of the entire data sample is 4.2 stops per trip.

![Figure 39 - Histogram of LMS data sample of stops](image)

**Input variable frequency**

Figure 40 shows activity per week versus total amount of trips. The average activity per week is 3.2. The majority of trips are active on a daily base.

![Figure 40 - Distribution of amount of stops (activity per week versus trips)](image)
Input variable type of vehicle

Figure 41 displays how types of vehicles are distributed around the data sample with regard to the amount of trips. All types of vehicles are present with one exception since there are none ‘truck + supporter’ in the data sample. Furthermore, the simple size seems a reasonable representation of reality and is balanced, because all types of vehicles are present.

![Figure 41 - Distribution of LMS data sample of stops (type of vehicle versus trips)](image)

5.2.3. **OUTPUT VARIABLES DISTANCE, TIME AND COST**

The distribution of output variables of distance, time and cost are presented and discussed next.

**Output variable distance**

Figure 42 presents a histogram of output variable distance. Formula 1, presented in paragraph 4.4.1 calculates output variable distance. The majority of trips, around 75%, cover a smaller distance than 10 kilometres. This means that the most last-mile trips do not cover a large distance. Interested outliers cover around 5% of all trips and are larger than 24 kilometres. The average distance covered is 8.59 kilometres.

![Figure 42 – Histogram of output variable distance](image)
Output variable time

The time it takes to cover these distances are presented in Figure 53 below. Formula 6 introduced in paragraph 4.4.2 shows how output variable time is calculated. The average time of all trips is 100 minutes. This is a relatively long time compared to the average distance covered since this is only 8,59 kilometres. The distribution of time looks similar to the distribution of distance. The majority of these trips are relatively short. Most of these trips are performed by small businesses. On the other end of the histogram a few longer trips can be seen. These trips take longer than 200 minutes and are often executed by large and efficient freight carriers.

![Histogram of LMS data sample of output variable time](image)

Figure 43 – Histogram of LMS data sample of output variable time

Output variable cost

Figure 44 present the distribution of output variables cost. Formula 9 in paragraph 4.4.3 shows how output variable cost is calculated. This output is the most important output variable of the LMS model. The cost of all trips is distributed quite evenly between 0 and 100 euro. The centre of gravity lies between 10 and 40 euro. The average cost of all trips is 36,56 euro.

![Histogram of output variable cost](image)

Figure 44 - Histogram of output variable cost
5.2.4. RELATIONSHIPS OF OUTPUT VARIABLES DISTANCE, TIME AND COST

The relation between distance versus cost per trip, time versus cost per trip and time versus distance is also interesting to explore. Below scatter plots of all data collected by the LMS are displayed.

Output variables cost and distance
In Figure 45 a scatterplot of the relation between output variables cost and distance are given. The relation seems to have a linear course in general. Some data points are not in line with the linearity, because in some cases longer trips are not more expensive (data points that fall in the right bottom corner). These data points represent relatively inexpensive longer trips. Another extreme are relatively expensive short trips. These trips can be explained because they have only a few stops with large shipments (restock of supermarkets) or have many stops with small shipments (e-commerce). The last takes a lot of time and distance and is therefore costly.

Output variables time and cost
In Figure 46 output variables time and cost are displayed in a scatterplot. The relationship between these two variables is a clear linear relation (for most data points). Longer trips cost relatively more money. In SA conducted in paragraph 4.7 is concluded that time related variables have the largest impact on cost compared to distance related variables. The same can be concluded from these figures due to a very clear linear relationship between time and cost, which means that these variables are strongly correlated.
Output variables time and distance

Next, Figure 47 is a scatterplot of the relation between output variables time and distance. Again, the relationship between these two variables can be labelled as correlated. In this scatterplot a linear relation can be seen, but it is not as clear as in previous scatterplot of time versus cost. Concluded from this chart is that trips that cover a large distance take more time. This relation between these two variables is what would have been expected.

All scatterplots of output variables of the LMS model show expected relationships and results. The structure of the LMS model is linear based. All formulas and relationships between variables used in the LMS model are linear relationships. Outcomes of graphs of the relationships between distance, time and cost are mostly linear featured as well. This conclusion strengthens validity of the LMS model slightly.
5.2.5. Other Distributions

Interesting distributions that are not directly calculated by the LMS model yet, but can be created by applying a simple mutation of output variables of the data sample. These mutated variables can be seen as criteria or key performance indicators to see how different freight carriers are performing. KPIs that are explored in this paragraph are cost per unit; cost per minute; cost per kilometre; cost per m3. The histograms of these distributions are treated next. The KPIs are also used in chapter 6.

Cost per unit

Cost per unit is the ratio between total cost and total shipping load (packages plus pallets). Output variable cost is divided by load. Outcome of this mutation is an average cost per unit for every trip. This information shows what types of trips are relatively expensive and what amount (or percentage) of trips can be considered as trips that can benefit from choosing an alternative shipping method. Figure 48 displays the distribution of all trips from the data sample regard cost/unit.

![Figure 48 – Histogram of LMS data sample of KPI cost/unit](image)

Trips that are relatively expensive per unit, in this case less than 6,5 euro per unit (average tariff of packages and pallets of PostNL, 3,95 + 9 = 6,5) can benefit from choosing an alternative shipping method. Mean of this variable is 9,81 euro/unit.

Cost per minute

Cost per minute is calculated by dividing output variable cost by output variable time. This key performance indicator tells something about how cost efficient freight carriers are operating. In other words, how much they spent every minute. The histogram of KPI cost/minute is shown in Figure 51.
The histogram shows 2 peaks. The first peak represents freight carriers that are extremely cost efficient per minute. The cost for these freight carriers lay between 0 and 0,3 euro per minute. The second peak in the histogram is larger and represents freight carriers that are less cost efficient every minute. The mean of the data set is 0,51 cost per minute. Based on these results the second group can be interesting to approach by the municipality of Delft since these carriers have a higher probability to benefit from an alternative shipping method.

**Cost per kilometre**

Key performance indicator cost per kilometre is calculated by dividing output variable cost by output variable distance. This indicator provides information on how freight carriers perform in economic terms on distance, so how much is spent every kilometre. Figure 52 shows the distribution is well balanced between 0 and 15 euros per kilometre. There is no clear distinction in two groups as is seen on KPI cost per minute. The mean of the data set is 8,69 euro/kilometre.
Cost per cubic
KPI cost per cubic (m3) can be calculated by dividing output variable cost per trip by average size of a shipment. The average size of a shipment is dependent on amount of packages plus amount of pallets. Average size of a package and pallet is calculated by using standards used by PostNL on maximum sizes for tariffs. The maximum size of a package that is handled for a tariff of 3,95 is 1,75 x 0,78 x 0,58 = 0,8 m3. The maximum size of a pallet that is handled for a tariff of 9,00 is 0,8*1,2*2 = 1,92 m3 (PostNL, 2015). On average the size of a package plus a pallet has an average size of 0,8 + 1,92 / 2 = 1,36. This is an assumption on the basis majority of units is smaller than the maximum calculated size. Figure 51 shows the distribution of cost/m3 versus amount of trips. The mean of the data set is 14,3 euro per m3.

5.2.6. OTHER RELATIONSHIPS OF VARIABLES

In this section other relationships of variables are explored. In sequence, the relationships of cost versus number of stops and shipping load versus cost are treated.

Stops and cost
Figure 52 presents a scatterplot of input variable stops versus outcome variable total cost. The relation between these variables is not a clear linear relation, since data points on the scatterplot are spread over the entire field. For example, all cases that have a limited amount of stops, between 1 and 5 stops can heavily vary in cost. Some trips are relatively cheap (only a few euros) while some trips are relatively expensive (around 100 euro). This seems somehow not only dependent on the amount of stops because both cases occur.
Another relationship interesting to explore is the relation between shipping load and cost to see what influence shipping load has on cost of a trip. There are a lot of data points from the sample that can differ heavily with regard to cost of a trip compared to the shipping load. This is actually not strange because, some shipments are similar in size but have different characteristics with regard to type of vehicle, amount of stops, activity in different areas and so on. For this relationship, as well as previous relationship between stops and cost the relation cannot be determined as linear. Larger total shipping loads is not always more expensive this it is also dependent on other characteristics of a last mile trip.
5.2.7. Relationship between output variable cost and cost PostNL

In Figure 54 the relationship between costs of the LMS versus cost of PostNL is presented. The green dots present all data points of cost per trip (Post NL) versus total load (packages + pallets). The scatterplot is completed with a linear trend line. R² of the linear trend line of cost PostNL is 0.830 that value means a very good fit of the trend line of the model with regard to the real data. A value of 1 is a perfect fit. The blue dots present all data points of cost per trip (output LMS) versus total load (package + pallets). Again, the scatterplot is completed with a linear trend line which does not have a very good fit.

![Scatter plot of total load versus cost per trip (PostNL & LMS)](image)

The trend line of total cost of PostNL is a significant steeper linear relationship as the trend line of total cost LMS. This implies that as shipping load increases (packages + pallets) alternative shipping method PostNL is more expensive in comparison to a shipment conducted by a freight carrier internal. The intersection is interesting and lies at a shipping load of 5 units (packages + pallets). In the majority of cases (data points) a shipping load of 5 or smaller (relatively smaller shipments) are cheaper to be shipped by an alternative shipping method (PostNL). In majority of cases larger loading ratios (relatively larger shipments) benefit to be executed by a freight carrier internally.
5.3. Summary and conclusion

In this paragraph a concise summary and conclusion of chapter 5 on data analysis is given. Thereafter, sub-question II-2 is answered.

This chapter started with the following sub-question:

(SQ II-2) How is data collected and in what conclusions can be drawn from the data sample?

Case study

Data is collected by ‘Maatwerk Distribution’ through a website. Freight carriers who can fill out a scan can access the LMS online. In practise, participations did not actively participate due to unfamiliarity reasons and the lack of knowledge of the added value of the LMS. MD has collected data from freight carriers active in Delft, Rijswijk, Leidschendam-Voorburg, Pijnacker-Nootdorp, Den Haag and Leiden. Added together an amount of 525 scans have been filled in by freight carriers active in one or more of the listed above cities.

Distributions such as shipping load and stops have the centre of gravity lying at the start of the distribution. This means that most trips only have a few stops to make and packages to unload. Most of the shipments are therefore relatively small shipments. Furthermore, most carriers are active multiple days per week and the largest group is active on a daily base. The distribution of type of vehicles is quite evenly balanced except truck + supporter is not active at all. These types of vehicles are too large to manoeuvre in urban city centres.

Analysis of data sample

The majority of trips, around 75%, cover a smaller distance then 10 kilometres. This means that the most last-mile trips do not cover a large distance. The average time of all trips is 100 minutes. This is relatively long since the average distance covered in 100 minutes is only 8,59 kilometres. The cost of all trips is distributed evenly between 0 and 100 euro. The centre of gravity lies between 10 and 35 euro. The average cost of all trips is 36,56 euro.

Relationships of output variables

All scatterplots of output variables cost, time and distance show expected relationships and results. The structure of the LMS model is linear based. All formulas between variables used in the LMS model are linear. Outcomes of graphs of the relationships between distance, time and cost show linear featured as well. These type of relationships are in line with expectations and therefore strengthen validity of the LMS model slightly.

The relation between cost and distance seems to have a linear course in general. Some data points are not in line with the linearity, because in some cases longer trips are not more expensive (data points that fall in the right bottom corner). These data points represent relatively inexpensive longer trips. Another extreme are relatively expensive short trips. These trips can be explained because they have only a few stops with large shipments (restock of supermarkets) or have many stops with small shipments (e-commerce).

The relationship between time and cost is a clear linear relation (for most data points). Longer trips cost relatively more money. In the SA is concluded that time related variables have the largest impact on cost compared to distance related variables. The same can be concluded from these figures due to a very clear linear relationship between time and cost, which means that these variables are strongly correlated.

The relationship between time and distance can be labelled as correlated. A linear relation can be seen, but it is not as clear as in the relationship between time and cost. A conclusion is that trips that cover a large distance take more time. This relation between these two variables is what would have been expected.
Other distributions
Interesting distributions that are not directly calculated by the LMS model yet, but can be created by applying a simple mutation of output variables of the data sample. These mutated variables can be seen as criteria or key performance indicators to see how different freight carriers are performing. KPIs that are explored in this paragraph are cost per unit; cost per minute; cost per kilometre; cost per m3.

Relationships of variables
The relation between stops and cost is not a clear linear relation, since data points are spread over the entire field. For example, all cases that have a limited amount of stops, between 1 and 5 stops can heavily vary in cost. Some trips are relatively cheap (only a few euros) while some trips are relatively expensive (around 100 euro). Cost are not only dependent on the amount of stops.

The relation between shipping load and cost is not clear. A lot of data points differ heavily with regard to cost of a trip. This is not strange because some shipments are similar in size but have different characteristics with regard to: type of vehicle, amount of stops, activity in different areas and so on. This and previous relationship between stops versus cost cannot be determined as linear. Larger total shipping loads are not always more expensive.

Cost LMS versus cost PostNL
The trend line of total cost of PostNL is a significant steeper linear relationship as the trend line of total cost LMS. This implies that as shipping load increases (packages + pallets) alternative shipping method PostNL is more expensive in comparison to a shipment conducted by a freight carrier internal. The intersection is interesting and lies at a shipping load of 5 units (packages + pallets). In the majority of cases (data points) a shipping load of 5 or smaller (relatively smaller shipments) are cheaper to be shipped by an alternative shipping method (PostNL). In majority of cases larger loading ratios (relatively larger shipments) benefit to be executed by a freight carrier internally.
6. **CHAPTER 6  CLUSTER ANALYSIS**

6.1. **Introduction**

In this paragraph, the methodology of a cluster analysis is introduced first. The importance of this analysis is to support statistically a classification of distributors dependent on certain attributes or performance. Further substantiation and support gathered through literature research and expert interviews is used.

The identification of groups of individuals that are similar to each other but different from other individuals can be of added value to companies to increase profits or to scientific research to make assumptions or draw conclusions. Clustering individual freight carriers in categories can increase understanding in what drives them. A cluster is a group of relatively homogenous cases or observations (Aldenderfer, M.S., Knoll & Blashfield, 1984).

The dependence and segregation of clusters is realized on the basis of different attributes and characteristics. Parameters of the LMS can serve as a first selection on how to cluster these individual cases. Furthermore, clusters can be labelled and weighted on important criteria (also called key performance indicators) to measure sustainable urban freight distribution on economic performance, and environmental aspects. Next to statistically cluster individual freight carriers, human reasoning and conducting literature research can also create clusters.

The result of this analysis could give insight to the problem owner, the municipality of Delft, on different types of carriers active in the region of Haaglanden. This information could give them insight on what stakeholders contribute in sustaining the UFD system and what stakeholders are performing badly from a societal point of view. This gives the municipality of Delft knowledge to develop custom made policy suitable for the region and on a more detailed carrier level.

All data collected by MD is used in the cluster analysis. A total of 267 scans are collected over six regions. All types of freight carriers are present and thereby all types of shipments.

6.2. **Cluster analysis methodology**

Distinction of freight carriers can be based on attributes or KPIs as mentioned earlier in this thesis. The attributes that can be used to distinguish clusters are given below. Most attributes are already present in the model. Some KPIs are not yet present and can be calculated by conducting a few simple mutations. These KPIs are cost per unit/minute/km and footprints. These KPIs are used as criteria to see how well a cluster (group of freight carriers that are similar) performs on different KPIs.

Attributes present in LMS model

- Distinction on the base of cost per trip;
- Distinction on the base of time per trip;
- Distinction on the base of distance per trip;
- Distinction on the base of load (package);
- Distinction on the base of load (pallets);
- Distinction on the base of number of stops;
- Distinction on the base of vehicle type;
- Distinction on the base of total load (package plus pallets); not yet present in LMS model

Key Performance Indicators (KPIs) (not present yet)

- Distinction on the base of cost per unit;
- Distinction on the base of cost per minute;
- Distinction on the base of cost per kilometre;
- Distinction on the base of footprints;
Figure 55 captures the framework of the cluster analysis. The cluster analysis methodology clusters the dataset statistically on chosen inputs or attributes. Thereafter it scores these clusters on chosen evaluation fields. Multiple cluster analysis can be conducted based on different attributes/inputs and evaluation fields.

![Cluster analysis framework](image)

Earlier formulated attributes and KPIs need to correspond with parameters present in the LMS model. Parameters can be used when they are present as a set variable in the model or can be calculated. Parameters that need to be created by conducting a simple calculation are all evaluation fields parameters or KPIs. Table 37 gives an overview of which parameters of the LMS match which distinction base and what simple mutations needs to be conducted.

### Table 37 – Attributes of freight carriers and corresponding parameters LMS model

<table>
<thead>
<tr>
<th>Distinction base</th>
<th>Parameters LMS model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Attribute/ input variables</strong></td>
<td></td>
</tr>
<tr>
<td>Distinction on the base of cost per trip</td>
<td>Output variable cost</td>
</tr>
<tr>
<td>Distinction on the base of time per trip</td>
<td>Output variable time</td>
</tr>
<tr>
<td>Distinction on the base of distance per trip</td>
<td>Output variable distance</td>
</tr>
<tr>
<td>Distinction on the base of load</td>
<td># of pallets/packages</td>
</tr>
<tr>
<td>Distinction on the base of number of stops</td>
<td># of stops</td>
</tr>
<tr>
<td>Distinction on the base of vehicle type</td>
<td>Type of vehicle</td>
</tr>
<tr>
<td><strong>Key Performance Indicator</strong></td>
<td></td>
</tr>
<tr>
<td>Distinction on the base of cost per unit</td>
<td>Output variable cost divided by; # of pallets/packages</td>
</tr>
<tr>
<td>Distinction on the base of cost per minute</td>
<td>Output variable cost divided by; output variable time</td>
</tr>
<tr>
<td>Distinction on the base of cost per km</td>
<td>Output variable cost divided by; output variable distance</td>
</tr>
<tr>
<td>Distinction on the base of footprints</td>
<td>Footprints calculated by output variable distance; type of vehicle; emission table</td>
</tr>
</tbody>
</table>

A freight carrier can be classified and evaluated on parameters represented in Table 33. A category is based on one or more input variables (attributes). With regard to the problem owner, the municipality of Delft is interesting to see what freight carriers perform well on KPIs such as environmental and economic aspects. Environmental aspects can be added to the LMS model by calculating footprints of trips with aid of an emission table. Footprints can be calculated by using output variable distance multiplied by the value derived from the emission table (based on type of vehicle and activity in peak hour). All other KPIs can be easily calculated by conducting a few simple mutations as mentioned in the table.
Software package SPSS statistically creates clusters on the base of chosen attributes/inputs. After these clusters are formed an average value on chosen inputs and evaluation fields is provided. Evaluation fields are in this case the key performance indicators. This line of reasoning can also be turned around since clusters can also be created on the base of KPIs, in other words attributes/inputs can also be KPIs. A cluster can be developed on the basis of performance indicator cost/unit (economic) and/or footprints (environmental). In general, the possibilities of creating clusters and analysing data are endless. Greater knowledge can be gathered by using this type of analysis.

Clusters can be easily constructed by filtering the data sample by using Table 33. From this table different starting points can be chosen dependent on the objective that the municipality has to gather information on what attributes or performance. MD can develop a filter tool on their website so participants can choose different KPIs. Furthermore, the municipality of Delft can filter and distinguish the entire data sample set to generate classifications on chosen inputs and evaluation fields.

6.3. Application of a cluster analysis

As mentioned in previous paragraph the data sample is information that can be used more optimal by the municipality of Delft to gather knowledge on performance of distributors active in the urban area. In this section the cluster analysis is conducted. The first cluster analysis is based on inputs and evaluation fields presented in Figure 56.

Cluster analysis economic aspects

![Cluster analysis economic aspects, chosen inputs and evaluation fields](image)

The results of the cluster analysis with the above settings are presented in the figures below. The evaluation fields are economic of nature. Figure 57 gives a model summary of the analysis conducted in SPSS. The cluster analysis has used a Two Step algorithm. In total three inputs created a total of four clusters. Furthermore, the cluster quality is around 0,6 which is rather good.

![Model summary of cluster analysis on economic aspects](image)
As setting a minimum number of 4 clusters is chosen. Each cluster can be labelled based on the evaluation fields (performance) that are in this analysis economical of nature. The clusters are generated on the basis of shipping load (number of packages and pallets) and number of stops. Cluster one consists of a relative small shipping load (1,23 packages and 2,27 pallets) and a few stops (2,21) and is the largest cluster (73,5% of the dataset, 197 cases). Cluster three has a medium size shipping load (12,46 packages and 1,46 pallets) and a medium amount of stops (6,38). In total 37 cases are included in this cluster. The second cluster has a medium size shipping load (3,04 packages and 20,42 pallets) and a high amount of stops (11,33). In total 24 cases are included in this cluster. The fourth and smallest cluster has a relatively large shipping load (43,60 packages and 3,40 pallets) and consist of many stops 18,30). In total 10 cases are included in this cluster. All results are presented in Figure 58.

The first cluster can be labelled as inefficient because it scores relatively bad on evaluation fields cost per min and cost per unit. Variables related to time are most important variables because they have the greatest influence on cost as is proved in sensitivity analysis conducted in chapter 4. Comparing or valuating clusters on evaluation fields cost per unit is difficult because shipments consist of pallets and/or packages that differ in cost, time and effort. This is confirmed by looking at clusters 3 and 4 (both large amount of packages). These clusters have a relatively low score on evaluation field cost per unit due to a shipping load with relatively many packages.

<table>
<thead>
<tr>
<th>Clusters</th>
<th>Input (Predictor) Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><img src="6-102" alt="" />0.8 0.4 0.2 0.0</td>
</tr>
</tbody>
</table>

### Table: Clusters

<table>
<thead>
<tr>
<th>Cluster</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Label</td>
<td>Inefficient</td>
<td>Medium efficient</td>
<td>Efficient</td>
<td>Efficient</td>
</tr>
<tr>
<td>Description</td>
<td>Small load</td>
<td>Medium load</td>
<td>Medium load</td>
<td>Large load</td>
</tr>
<tr>
<td>packages</td>
<td><em>many packages</em></td>
<td><em>many packages</em></td>
<td><em>many packages</em></td>
<td>Many stops</td>
</tr>
<tr>
<td>pallets</td>
<td>Medium stops</td>
<td>Medium stops</td>
<td>Many stops</td>
<td>Many stops</td>
</tr>
<tr>
<td>Size</td>
<td>21.9% (197)</td>
<td>13.8% (137)</td>
<td>9.0% (24)</td>
<td>3.7% (11)</td>
</tr>
<tr>
<td>Results</td>
<td>Package 1.23</td>
<td>Package 12.46</td>
<td>Package 3.08</td>
<td>Package 43.60</td>
</tr>
<tr>
<td></td>
<td>Pallets 2.27</td>
<td>Pallets 14.46</td>
<td>Pallets 20.42</td>
<td>Pallets 34.00</td>
</tr>
<tr>
<td></td>
<td>Stops 2.21</td>
<td>Stops 6.58</td>
<td>Stops 11.33</td>
<td>Stops 18.30</td>
</tr>
<tr>
<td>Evaluation Fields</td>
<td>CostPerUnit 12.17</td>
<td>CostPerUnit 3.10</td>
<td>CostPerUnit 4.25</td>
<td>CostPerUnit 1.46</td>
</tr>
<tr>
<td></td>
<td>CostPerKm 8.05</td>
<td>CostPerKm 9.41</td>
<td>CostPerKm 9.34</td>
<td>CostPerKm 9.34</td>
</tr>
<tr>
<td></td>
<td>CostPerMin 0.52</td>
<td>CostPerMin 0.38</td>
<td>CostPerMin 0.33</td>
<td>CostPerMin 0.26</td>
</tr>
</tbody>
</table>

Figure 58 - Cluster analysis results on economic aspects

Furthermore, it can be concluded that the first cluster is the largest. This means that from the entire dataset, which are actually real participants active in the urban area of Haaglanden, the majority is conducting activities relatively inefficient. For the entire cluster (or freight carriers) it is beneficial to consider a switch to a central distributor as PostNL.
Example of a classification framework
A first classification framework on economic aspects can be made. Classes are distinguished on the basis of key performance indicators cost per unit/minute/kilometre. A total of four classes are created. The classification typology is described according the following labels:
- Inefficient (relatively small load and relatively little stops);
- Medium efficient (relatively medium load, relatively many stops);
- Efficient (relatively medium load, relatively medium stops);
- Efficient (relatively large load, relatively many stops);

This is shown in Table 34. An example of each type of carrier is given.

Table 34 – A classification framework (economic aspects)

<table>
<thead>
<tr>
<th>Label</th>
<th>Dimension/input values</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inefficient</td>
<td>Small load, little stops</td>
<td>Single day fly</td>
</tr>
<tr>
<td>Medium efficient</td>
<td>Medium load, many stops</td>
<td>HoReCa</td>
</tr>
<tr>
<td>Efficient</td>
<td>Medium load, medium stops</td>
<td>Supply of supermarket</td>
</tr>
<tr>
<td>Efficient</td>
<td>Large load, many stops</td>
<td>E-commerce</td>
</tr>
</tbody>
</table>

Cluster analysis environmental aspects

Attributes/inputs
- Distinction on the base of cost
- Distinction on the base of package;
- Distinction on the base of pallets;
- Distinction on the base of number of stops;

Evaluation Fields
- Distinction on the base of footprints (CO, NOx, NO2, PM10, PM2,5);

Cluster analysis
- Statistic distinction on the base of chosen attributes/inputs and number of clusters (4) conducted by SPSS

Figure 59 - Cluster analysis environmental aspects, chosen inputs and evaluation fields

The results of the cluster analysis with the above settings are presented in the figures below. The evaluation fields are environmental of nature. Figure 60 gives a model summary of the analysis conducted in SPSS. The cluster analysis has used a Two Step algorithm. In total four inputs created a total of four clusters. Furthermore, the cluster quality is around 0,55, which is rather good.

Figure 60 - Model summary cluster analysis environmental aspects
Again, a setting with a minimum number of 4 generated clusters is chosen. The clusters can be categorized based on environmental performance. As mentioned four inputs are chosen which are cost of a trip, number of pallets, number of packages and number of stops.

Cluster number two can be labelled as a relatively medium pollutant. This group has a small shipping load (2,34 packages and 1,47 pallets), only a few stops (2,12) and is relatively cheap (18,89). Cluster number one can be labelled as a large pollutant. This group has a medium shipping load (2,54 packages and 4,00 pallets), a medium amount of stops (4,57) and is relatively expensive (58,02). Cluster number three can be labelled as a small pollutant. This group has a large load (28,22 packages and 4,83 pallets), many stops (16,00) and is average costly (51,67). Cluster number four is a small pollutant. This group has a large shipping load (0,17 packages and 30 pallets), a medium amount of stops (4,92) and is relatively expensive (76,63).

<table>
<thead>
<tr>
<th>Clusters</th>
<th>Input (Predictor) Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cluster</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Label</td>
<td>Medium pollutant</td>
<td>Large pollutant</td>
<td>Small pollutant</td>
</tr>
<tr>
<td>Description</td>
<td><em>Few packages</em></td>
<td><em>Medium packaging</em></td>
<td><em>Many packages</em></td>
</tr>
<tr>
<td>Size</td>
<td>15,00%</td>
<td>31,33%</td>
<td>8,60%</td>
</tr>
<tr>
<td>Inputs</td>
<td>18,89</td>
<td>31,97</td>
<td>76,83</td>
</tr>
<tr>
<td>Evaluation Fields</td>
<td>CO\text{gram}</td>
<td>NO\text{gram}</td>
<td>PM\text{mg}</td>
</tr>
</tbody>
</table>

Figure 61 - Cluster analysis results environmental aspect

The labels seem to be contradictory towards the evaluation fields. Comparing the clusters on absolute terms on the evaluation fields is not correct since large shipments of course emit a larger absolute amount of emission. Relatively, in terms of emit per stop or per total load this can differ. The evaluation field (KPI) is the total amount emitted during a last mile trip and is not corrected by the size of the shipment. In order to compare these generated clusters, the amount of emitted pollutants divided by the amount of stops and total shipping load, which can give an indication on the performance of the shipment based on pollutant per stop and per unit. Table 35 presents the results of these mutations.
Table 35 shows that in absolute values the order of performance on environmental aspects is respectively 2, 4, 1 and 3. In relatively values compared to the amount of stops, this is very different. The order of precedence is respectively 3, 4, 2 and 1. In terms of the amount emitted per unit the order of precedence is 4, 3, 2 and 1. The conclusion is that clusters with a large shipping load score well on environmental aspects. In addition, these clusters also score well on economic aspects concluded from the cluster analysis of economic aspects. This strengthens the general conclusion that smaller shipments perform less good in general (both economic and environmental) and can better use an alternative shipping method.

Table 35 – Rating per cluster relatively to the amount of stops

<table>
<thead>
<tr>
<th>CLUSTER</th>
<th>2</th>
<th>1</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL PER STOP</td>
<td>TOTAL PER STOP</td>
<td>TOTAL PER STOP</td>
<td>TOTAL PER STOP</td>
<td></td>
</tr>
<tr>
<td>COST</td>
<td>18.89</td>
<td>58.02</td>
<td>81.67</td>
<td>76.63</td>
</tr>
<tr>
<td># OF PACKAGES</td>
<td>2.34</td>
<td>2.54</td>
<td>28.22</td>
<td>0.17</td>
</tr>
<tr>
<td># OF PALLETs</td>
<td>1.47</td>
<td>4.83</td>
<td>30.05</td>
<td>30.17</td>
</tr>
<tr>
<td>TOTAL LOAD</td>
<td>3.61</td>
<td>6.54</td>
<td>33.05</td>
<td>30.17</td>
</tr>
<tr>
<td>STOPS</td>
<td>2.12</td>
<td>4.57</td>
<td>16</td>
<td>4.92</td>
</tr>
<tr>
<td>CO</td>
<td>33.15</td>
<td>15.64</td>
<td>8.70</td>
<td>79.98</td>
</tr>
<tr>
<td>NOx</td>
<td>32.60</td>
<td>15.38</td>
<td>8.56</td>
<td>77.70</td>
</tr>
<tr>
<td>NO2</td>
<td>1.85</td>
<td>0.87</td>
<td>0.49</td>
<td>4.40</td>
</tr>
<tr>
<td>PM10</td>
<td>0.86</td>
<td>0.41</td>
<td>0.23</td>
<td>2.04</td>
</tr>
<tr>
<td>PM2.5</td>
<td>0.43</td>
<td>0.20</td>
<td>0.11</td>
<td>1.02</td>
</tr>
<tr>
<td>RANKING ABS.</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>RANKING STOP</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>RANKING UNIT</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
6.4. **Practical usability**

The practical usability of the analysis is discussed here. The usability is a list of recommendation for the municipality of Delft in how to use collected data properly to classify distributors and how the cluster analysis framework can be of added value to the municipality.

**Develop custom policy**

The first method to use the data sample and the classification framework is to identify different classes of distributors and score them on performance. Performance, also criteria can be formulated based on different starting points. Problem owner, the municipality of Delft, is interested in economical but also environmental aspects. Based on identified classes and available information collected by the LMS model, knowledge on performance of individual freight carriers in the UFD system for the development of custom policies should be used.

This can be clarified with an example. All trips can be rated on environmental footprints (methodology on how to calculate and implement this aspect is introduced in paragraph 7.6.1). Based on these results the municipality of Delft can implement policies towards individual freight carriers that have certain characteristics (old vehicles, conventional fuels, size of a vehicle, small shipping load etc.). Distributors that cannot meet standards or targets set by the municipality on amount of emission exhausted can get a penalty. A cost-based or penalty based system can be implemented in order to realize lower emission levels in the urban area.

**Specific knowledge gathering**

Another example is that the municipality of Delft can use the sample data and cluster analysis methodology to see what distributors/clusters perform relatively bad (inefficient) on defined key performance indicators. Freight carriers with bad performance on economic and environmental terms are better of using a central and larger distributor such as PostNL (conducting all here activities with electric vehicles). This is the case for the freight carriers themselves but also for other involved stakeholders such as the municipality of Delft en residents due to better environmental performance of a central distributor.

Furthermore, collected data and methodology of classification can be used to see how many heavy vehicles are active in the municipality in general and during peak hours. The pressure on the urban area is the highest during these hours. A classification on the performance indicators (environmental and economic) in conjunction with activity during peak hours can generate valuable information that can be further used to develop and optimize measurements such as time windows.

**Mediating cooperation**

Finally, results from the cluster analysis can be used by the municipality to gather knowledge for participants on how they perform on output variables cost, time and distance and specific defined key performance indicators and footprints. These results can be compared with the entire data sample to see how well freight carriers are performing compared to competitors. This benchmark methodology can be implemented by conducting a few simple calculations. These shipping’s can be compared to an alternative shipping method to see what types of vehicles or type of freight carriers can benefit the most from improving cooperation on all possible manners. This information can contribute as mediating tool among stakeholder to increase cooperation.
6.5. Summary and conclusion

In this paragraph a concise summary and conclusion of chapter 6 on the cluster analysis is given and how the municipality should use the developed cluster analysis framework. This paragraph ends with an answer on sub-question II-4.

This chapter started with the following sub-question:

*(SQ II-3)* How can a cluster analysis be conducted to see performance levels of different types of freight carriers on formulated key performance indicators?

Distributors can be classified based on characteristics or on performance levels. Characteristics are translated into attributes/inputs and performance levels into key performance indicators/evaluation fields. To be able to filter the data sample these characteristics need to match parameters present in the LMS model. Distinction is based on parameters presented in Table 36.

**Table 36 – Attributes of freight carriers and corresponding parameters LMS model**

<table>
<thead>
<tr>
<th>Distinction base</th>
<th>Parameters LMS model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Attribute/ input variables</strong></td>
<td></td>
</tr>
<tr>
<td>Distinction on the base of cost per trip</td>
<td>Output variable cost</td>
</tr>
<tr>
<td>Distinction on the base of time per trip</td>
<td>Output variable time</td>
</tr>
<tr>
<td>Distinction on the base of distance per trip</td>
<td>Output variable distance</td>
</tr>
<tr>
<td>Distinction on the base of load</td>
<td># of pallets/packages</td>
</tr>
<tr>
<td>Distinction on the base of number of stops</td>
<td># of stops</td>
</tr>
<tr>
<td>Distinction on the base of vehicle type</td>
<td>Type of vehicle</td>
</tr>
<tr>
<td><strong>Key Performance Indicator</strong></td>
<td></td>
</tr>
<tr>
<td>Distinction on the base of cost per unit</td>
<td>Output variable cost divided by; # of pallets/packages</td>
</tr>
<tr>
<td>Distinction on the base of cost per minute</td>
<td>Output variable cost divided by; output variable time</td>
</tr>
<tr>
<td>Distinction on the base of cost per km</td>
<td>Output variable cost divided by; output variable distance</td>
</tr>
<tr>
<td>Distinction on the base of footprints</td>
<td>Footprints calculated by output variable distance; type of vehicle; emission table</td>
</tr>
</tbody>
</table>

Distributors can be classified based on all above parameters. Most parameters are already present in the LMS model or can be easily created by a simple mutation. The possibilities are endless since all attributes and KPI’s can be used as inputs and/or evaluation fields both. The cluster analysis can give the municipality valuable knowledge on how freight carriers are performing on key performance indicators formulated by the municipality. Depending on the objective and need for specific information, the right settings can be chosen. The right setting for the municipality is probably a combination of economic and environmental aspects.

The conclusion is that clusters with a large shipping load score well on environmental aspects (defined environmental key performance indicators). In addition, these groups of carriers also score well on economic aspects (defined specific economic key performance indicators) concluded from the cluster analysis on economic aspects. This strengthens the conclusion that smaller shipments perform less good in general (both in economic and environmental terms) and can better use an alternative shipping method. In chapter 5 the suggestion that smaller shipments are relatively expensive was already put forward and is now again supported by the cluster analysis.

The practical usability of the cluster analysis is three-folded. First, the analysis gathers detailed knowledge on already available data derived by the LMS model for both participants (freight carriers) and the municipality of Delft. Secondly, this knowledge can be used to develop custom policy for specific freight carriers that are performing undersize. Thirdly, the results can contribute in mediating cooperation between freight carriers because the analysis provides them with specific knowledge on their performance on economic and environmental indicators. This performance is compared to the entire data sample to see how well they are performing with regard to competitors. This benchmark methodology can be implemented by a few simple calculations.
7. Chapter 7 Shortcomings of the LMS

In this chapter, problems faced during the development and during actively usage of the scan are treated. Some of these problems were solved during the development process while others are not. In addition, important trade-off decisions are discussed. Finally, this chapter ends with a list of shortcomings and potential development directions to improve functioning of the LMS.

7.1. General remarks

The LMS model needs input data from distributors. These participants are not keen to spend a lot of time filling in questions and participating in the scan. For them, the benefit of the LMS model is not clear. For them, participating as a compulsory task with no to little advantages for them (Coremans, 2015).

Difference in perspective

Distributors think from a supply chain perspective. This means from the origin to destination and back. The LMS scan focuses on the last mile, in terms of a supply chain this is the final section. The difference in perspective between the model and participants of the scan in geographic terms can lead to lower usability of the LMS and can, in worst-case scenario, result in biased conclusions. Solving this problem is not possible, although increasing awareness among distributors of bad performance of the last mile can still be a contribution in moving towards a more sustainable urban freight distribution system.

Data availability

During development of the LMS model, data availability became an issue. The issue of data availability was not solely scarcity of data but also lack of reliable data. Panteia did a great job in collecting real data from transportation companies. The uniqueness of this data and the high degree of reliability was crucial for development. Panteia did not solve the data availability issue because the model needs more input data. Other data retrieved by means of field research is used to make assumptions on constants. Assumptions based on (small) field research conducted by unprofessional researchers are less reliable.

Furthermore, another problem is lack of real from the field. This is needed to conduct operational data validity where outcome of the LMS model is compared to data outside measurements of the model. This validation step cannot be conducted. This influences the validity judgement causing effective validation is impossible.

Arbitrary decisions

Another problem MD faced during the development phase is the difficulty of making arbitrary decisions on assumptions and to way to calculate cost of the last mile. These assumptions are needed to be able to make the necessary calculations. Decisions on these assumptions or choice of approach can have a large impact on results. The next paragraph gives an example on a debatable approach to determine the number and thereby size of an area.

The LMS model divides every region in a number of areas. The number of areas is dependent on size of a region. The choice to have relatively small areas has impact on the total number of areas, which increases when areas are small in geographic terms. A region is divided into a limited amount of areas, two or three or into a higher amount of areas, more than five. The LMS model divides the region of Delft into two areas, which are centre and outside centre. The advantage of using multiple relatively small areas is that level of detail and therefore accuracy improves. The drawback of using a higher level of detail is that complexity increases. This is not on the degree of performing calculations but on a level of usability for freight carriers. Participants need to answer more questions about different areas. Increasing the amount of areas decreases ease of usability and participation and probably results in a (even) lower participation rate.
Nature of model

The deterministic nature of the model is debatable. In a real world, every trip differs from another. A possible solution is extending the model by use of stochastic input variables to move towards a better representation of reality. This is further elaborated in next paragraph.

Linearity of LMS model

Another remark is the linearity of the LMS model in multiple directions. The first direction where linearity of the model has a misfit is on economies of scale. This is best explained with an example. Table 37 gives a set of input variables of a last mile trip of medium size. To analyse linearity of the model input variables shipping load and stops are varied. Table 38 present these variations and corresponding scenario results. Scenario 0 (base scenario) and 1, 2 and 3 are presented.

Table 37 – Set of input variables

<table>
<thead>
<tr>
<th>Input variables</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>City</td>
<td>Delft</td>
</tr>
<tr>
<td>Vehicle type</td>
<td>Truck of 12-16 ton</td>
</tr>
<tr>
<td>Peak hour</td>
<td>Yes</td>
</tr>
<tr>
<td>Active in area</td>
<td>Both</td>
</tr>
<tr>
<td>Access road</td>
<td>A13 Delft North</td>
</tr>
<tr>
<td>Exit road</td>
<td>A4 Provinciale weg</td>
</tr>
<tr>
<td># of small packages</td>
<td>4</td>
</tr>
<tr>
<td># of large packages</td>
<td>2</td>
</tr>
<tr>
<td># of stops</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 38 – Overview scenarios input variables

<table>
<thead>
<tr>
<th></th>
<th>Scenario 0 (base)</th>
<th>Scenario 1 2x Stop</th>
<th>Scenario 2 2x Load</th>
<th>Scenario 3 2x all</th>
</tr>
</thead>
<tbody>
<tr>
<td># of small packages</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td># of large packages</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td># of stops</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Outcome of LMS (EUR/trip)</td>
<td>€ 42,34</td>
<td>€ 56,68</td>
<td>€ 69,65</td>
<td>€ 83,99</td>
</tr>
</tbody>
</table>

The output of the LMS model on different scenarios show that base scenario is 42,34. Compared to scenario 3 (shipping is twice as big in both load and stops) almost the double amount of cost, namely 83,99 is found. This means linearity is almost perfect in the way the LMS model calculates cost of a trip. In reality, the relation between different shipping loads and stops of a trip is a negative exponential relationship. Trips with larger shipping loads are relatively cheaper (in terms of cost per unit) and therefore more efficient then trips with smaller shipping loads.

Lack of information on type of vehicle

Information on type of vehicle is good to have but is not sufficient if environmental aspects need to be included, because performance levels of vehicles are for example dependent on vehicle age (year of built) and type of fuel (conventional versus electric vehicles). The municipality of Delft can use this information to examine performance of freight carriers on environmental aspects and to develop transport policies to ban old, conventional vehicles from the urban areas.
7.2. Trade-offs

In this paragraph different trade-offs during development of the LMS model are discussed.

**Complexity versus accuracy versus reliability versus ease of usability**

During development of the LMS model trade-offs between complexity of the model versus degree of accuracy and reliability versus ease of usability are made. A higher complexity of the model probably increases reliability and accuracy but decreases ease of use for participants. The next example elaborates on this.

An extended scan concerning the number of questions and degree of detail results in detailed information that gives the model better and more reliable inputs to conduct calculations. Specific shipping destinations are an example of detailed information that potentially increases accuracy of the model. Complexity of the model goes up due to usage of more complex formulas. Contrary, usability of the scan goes down because a participant needs to fill out a more extensive scan, which is time consuming. The probability of not completing the scan goes up due to lack of time and lack of knowledge and information of participants on (too) specific questions. The total amount of scans and therefore gathered information is less. The search for finding the right balance is essential to ensure success of the LMS in practise.

**Stochastic versus deterministic**

The LMS is a deterministic model that provides the same answer every time the same input variables are used. In practice, every trip is different from another. Even if shipments are the same in terms of amount of stops and packages, variety in length and cost of a trip occur. The deterministic nature of the model can be converted into stochastic model if constants are replaced by stochastic input variables. If this increases model fit with the real world is the question.

The deterministic nature of the LMS model is debatable but the same statement on implementing stochastic input variables to increase variation in results can be argued. Replacing input variables from constants into stochastic distributions can result in a better fit with the real world but increases complexity of the model on the other hand. Is variation in outcome a necessity or is a deterministic outcome sufficient?

A possible solution is the replacement of deterministic input variables by stochastic inputs. This has the advantage of generating more random (to a certain extend) input values that result in variations in output variables. For example, changing input variable $\text{Stops}$. The deterministic set value of this input variable is 4 minutes for the centre of Delft. The stochastic alternative of this value is a distribution with a minimum of three, a maximum of five and average of four. The results of stochastic input are variation in outcome of the LMS model but only until a certain extend. To be able to replace all input variables, extensive field research on distributions of assumptions and constant needs to be conducted.
7.3. Unilateral aspects

“The key findings show that consumer demand was the main driver of urban freight activity. Therefore, there is a need to incorporate representatives from local businesses and freight companies, who are providing services to meet this demand into the planning process. Currently there is little co-operation between the freight, retail and planning sectors, this needs to be improved in order to achieve efficiency” (Brigitte Jessica Allen, 2011).

This paragraph threats the unilateral approach of the LMS model. This one-sided view is applicable on the following points.

- Single actor involvement
- Only economic drivers are included
- Lack of environmental and social aspects

The LMS is developed to provide distributors with information on the cost structure of the last mile. The focus of the scan is on this group of actors. The only aspect that is captured is of economic nature. Conclusions drawn from chapter 3 on actor analysis and multi-actor theory are that proper functioning of a system is only possible when needs of more stakeholders are captured. If coalitions and common grounds are not achieved stakeholders that are not satisfied with the current state can become a major problem in blocking proper functioning of the system.

Based on the actor analysis conducted in paragraph 3.1. stakeholder groups ‘manufacturers/wholesalers/retailers’ and ‘distributors’ are interested in economic aspects especially. Other stakeholders do think economic aspects are important but also agree that social and environmental aspects matter evenly. These stakeholders are the municipality and citizens of the municipality.

LMS focus is to narrow, since the focus is on only one group of actor. The rate of success or the potential improvement that can be achieved by cooperating is relatively low since other stakeholders do not see the benefit of the model. Other aspects of SUFD, like social and environmental aspects, need to be included in the LMS to attract and seduce more stakeholders to participate in the process.

Another problem of the urban freight distribution system in the municipality of Delft is that the social cost and benefits are not with the same stakeholder. For example, external costs such as pollution of greenhouse emissions that are created by distributors have a negative impact on the citizens of the region. They bear the negative cost. The difficulty of changing this imbalance of external cost (polluter is not paying) is difficult to solve. The municipality could implement a policy that polluters or polluted vehicles should pay a fine or pay to operate inside an urban area. They could also forbid them to operate at all and higher the standards in the same municipality towards electric vehicles only.
7.4. Context needs versus output LMS model

This paragraph compares context needs versus output of the LMS model. The importance of this analysis is that the model meets needs of involved stakeholders to ensure usage and benefit of the model. The context needs are derived from paragraph 2.1.8 on social cost and benefit and paragraph 3.1 on actor analysis. The results are given again below.

Concluded from the actor analysis is that stakeholders involved have different interests, objectives and problem perspectives. Furthermore, it shows that two groups of stakeholders, cargo owners and distributors, have a lot of power and are critical stakeholders since these groups need to be involved in the process to sustain the UFD system. In addition, these groups retain an adverse position towards the main objective and interest, sustaining urban freight distribution, of the problem owner, the municipality of Delft.

Table 39 - Social cost and benefits for stakeholders of UFD

<table>
<thead>
<tr>
<th>Shippers/cargo owners</th>
<th>Residents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time profit (+)</td>
<td>Quality improvement of shopping area (+)</td>
</tr>
<tr>
<td>Stock reduction at site (+)</td>
<td>JIT deliveries at home (+)</td>
</tr>
<tr>
<td>Flexibility of delivery (+)</td>
<td>Time window restrictions (+)</td>
</tr>
<tr>
<td>Time window restrictions (-)</td>
<td>Obligation to small vehicles (+)</td>
</tr>
<tr>
<td>Purchase of electric vehicles (-)</td>
<td>Obligation to electric vehicles (+)</td>
</tr>
<tr>
<td>Cost for (un)loading tariffs (-)</td>
<td>Longer lead-times supply of goods (-)</td>
</tr>
<tr>
<td>Congestion (-)</td>
<td>Safety issues due to large trucks (-)</td>
</tr>
<tr>
<td>Low loading rates (-)</td>
<td>Congestion (-)</td>
</tr>
<tr>
<td></td>
<td>Noise nuisance (-)</td>
</tr>
<tr>
<td></td>
<td>Vehicle kilometres on roads in urban area (-)</td>
</tr>
<tr>
<td></td>
<td>Greenhouse emission (CO2, NO etc.) (-)</td>
</tr>
<tr>
<td>Distributors/carriers</td>
<td>Planners and regulators</td>
</tr>
<tr>
<td>Separation of supply and return flows (+)</td>
<td>Income from (un)loading tariffs (+)</td>
</tr>
<tr>
<td>Bundling opportunities (+)</td>
<td>City maintenance costs (+)</td>
</tr>
<tr>
<td>Fleet optimization (+)</td>
<td></td>
</tr>
<tr>
<td>Time window restrictions (-)</td>
<td></td>
</tr>
<tr>
<td>Purchase of electric vehicles (-)</td>
<td></td>
</tr>
<tr>
<td>Cost for (un)loading tariffs (-)</td>
<td></td>
</tr>
<tr>
<td>Congestion (-)</td>
<td></td>
</tr>
<tr>
<td>Low loading rates (-)</td>
<td></td>
</tr>
<tr>
<td>Societal</td>
<td></td>
</tr>
<tr>
<td>Vehicle kilometres on roads in urban area (-)</td>
<td></td>
</tr>
<tr>
<td>Greenhouse emission (CO2, NO etc.) (-)</td>
<td></td>
</tr>
<tr>
<td>Exhaust of fossil fuels (-)</td>
<td></td>
</tr>
</tbody>
</table>

A main shortcoming of the LMS model is that it addresses only cost components. The potential effects of policies and improvements on the urban freight distribution system in general or broader oriented and affect one or more stakeholders of the system. This is captured in social cost and benefit Table 39. As the LMS model outcome captures time, distance and cost only a small amount of potential effects are included.

With regard to the social cost and benefit table the LMS model captures the following effects: time profit (total time for a trip), cost for (un)loading tariffs (tariffs of PostNL), vehicle kilometres on roads in urban area. (total time of a trip) These effects have an impact on the stakeholder’s shippers/cargo owners, residents, distributors/carriers and societal in general.

To ensure an increase in fit with context needs the LMS should be improved or extended by including the potential effect ‘greenhouse emission’. More general effects such as congestion, obligation to electric vehicles, obligation to small vehicles and noise nuisance are difficult to include in quantitative matters. The direction of these potential effects can be operationalized because choosing an alternative shipping method (use of a central distributor as PostNL) effects these general effects in a positive matter. Congestion goes down due to consolidation of freight (fewer vehicles for the same amount of freight). The share of electric and small vehicles on the total amount of vehicles goes up because PostNL only operates using small, electric vehicles. These vehicles produce less noise nuisance so the effect on this cost goes down as well. An alternative shipping method increases sustainability of the urban freight system on various potential effects.
7.5. Functionality LMS model and stakeholder support

In this paragraph, functionalities of the LMS model with regard to support that the model can have on certain decisions of involved stakeholders are analysed. Stakeholders that are important to the urban freight distribution system and can use the model are included. These are freight carriers, the municipality of Delft, residents and central distributor, PostNL.

7.5.1. Freight carriers

Value added functionalities of the LMS model for freight carriers are gather insight on performance on their last mile. Performance on general indicators total time, distance and cost is valuable information for them. This information can support them in deciding to conduct a shipment internally or externally (outsourcing the shipment to PostNL). Freight carriers making decisions purely based on economic terms, so performance indicator total cost and performance indicator total cost PostNL. The last indicator is not defined specifically yet in the model.

The model can compute more specific cost parameters to support freight carriers in making decisions. Indicator total cost can be defined in specific key performance indicators: cost per minute, cost per unit, cost per kilometre, and cost per cubic. In addition, total cost of an alternative shipping method needs to be calculated. A comparison on current (cost last mile) and future scenario (cost PostNL) can give specific knowledge and increase support that the LMS model can provide for freight carriers on how to organize freight distribution.

The model can calculate and define emission parameters. Results on specific emission performance indicators do not result in freight carriers’ changing shipping method directly, but can create awareness if knowledge on their individual burden on the environment is known. Specific emission parameters (or KPIs) that can be computed are CO [gram/trip], NOx [gram/trip], NO2 [gram/trip], PM10 [mg/trip], PM2.5 [mg/trip], footprints per stop [g/stop] and footprints per unit [g/unit].

Besides outcome of the model should give a value on specific key performance indicators it can use a benchmark methodology to give freight carriers information on their performance in comparison with competitors or carriers with similar shipment characteristics. The cluster analysis in chapter 6 used as guidance to construct groups of freight carriers where the benchmark methodology can be applied to. This awareness creates urgency to freight carriers that are performing relatively bad on for them important key performance indicators. Eventually, the ideal situation can be created that freight carriers will try to improve their performance, which can lead to overall improvements of the urban freight distribution system.

Awareness on environmental burden and performance on economic aspects can support freight carriers on how to organize freight distribution. Since freight carriers do not always have information on economic performance on the last mile the model can provide them of information (on both current and future situation) to support in making considered decisions.

7.5.2. Municipality of Delft

The functionalities of the LMS model can support the municipality of Delft in gathering information and improving knowledge on functioning of the urban freight distribution system. This knowledge is helpful because it tells how freight carriers perform on economic and environmental key performance indicators. Previous chapters on data and cluster analysis contribute in improving usage of model results and on how gathered data can be interpreted. The cluster analysis is beneficial to see what stakeholder groups need to improve performance to enable a sustainable urban freight distribution system.

7.5.3. Residents

Functionalities of the LMS model cannot support residents because this stakeholder group has no power (to make decisions) or direct influence on how the urban freight distribution is designed. As
mentioned in previous paragraph, the municipality of Delft can use results from the model to support their argument on progressive policies that might be implemented in the near future. These policies can positively affect well-being of residents because both stakeholder groups (municipality and residents) share the same interests and objectives towards sustaining urban freight distribution.

7.5.4. PostNL

Functionalities of the LMS model cannot directly support PostNL. Data gathered by MD is not available for public usage but only individual results are available for participants and all data is available for the municipality of Delft. However, PostNL has won a tender issued by the municipality. The winner of the tender received a list of participants (freight carriers) that ‘checked’ the intention box. All these carriers are open to be approached by PostNL. This list can support PostNL organizing urban freight distribution in Delft because all these companies are potential customers known by PostNL.

Having knowledge of active companies in the urban area of Delft sounds very promising. PostNL received a list of potential companies in 2015. In an interview conducted with Dhr. K.W. Rademakers head of city logistics of PostNL, he stated: Not all companies are willing to work together with PostNL in their new ‘Stadslogistiek Delft’ distribution centre. Barriers of economical, psychological, administrative, juristic and insurance grounds stop them in transferring their cargo to PostNL. In practice, not even one company of the entire list of companies collected by MD was willing to transfer cargo to PostNL.
7.6. Potential development directions

The LMS is a unilateral representation of reality because it only takes in consideration economic aspects. Social and environmental aspects are not included. This is not a problem if it would still succeed in achieving purpose of development. The purpose is providing information for both the municipality of Delft as freight carriers on cost structures of the last mile, gathering data and using this information to govern new policy. Nevertheless, it is a missed change that social and environmental aspects are not included. The LMS calculates total cost of the last mile. Better and more extensive usage of collected data is possible. This data is valuable information for both the municipality as other involved stakeholders like residents. Next paragraphs elaborate on potential development directions and ideas.

7.6.1. Include environmental aspects (footprints)

Applying footprints to carriers by including environmental aspects by including an emission matrix that calculates the amount of emission based on vehicle type and length of a trip. This provides the municipality of Delft with information on what companies should be excluded from the city centre based on their environmental performance, which is an important key performance indicator.

A general emission matrix derived from TNO and PBL that can be used to calculate footprints is presented in Table 41. The table distinguishes different types of exhaust. CO; NOx; NO2; PM10 and PM2.5. It also provides levels of exhaust on different roads and velocities. The classification that is used is city stagnant; city normal; city normal; rural road and highway (average). Last, it presents exhaust on the base of vehicle weight that is divided in light; middle heavy; heavy and bus.

As mentioned in paragraph 4.6.2 on the research of Peters, knowledge of variables emission rate and length of a trip are needed to calculate footprints. Results of the LMS model can be linked to this emission factors table Therefore the correct vehicle type needs to be defined in terms of vehicle weight class. The list of available vehicle types in LMS model categorized on different weight classes is shown Table 40.

Table 40 - Overview of type of vehicles and corresponding weight classes

<table>
<thead>
<tr>
<th>Number</th>
<th>Type of vehicle</th>
<th>Weight class</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Van (GVW 1000 kg)</td>
<td>Light</td>
</tr>
<tr>
<td>2</td>
<td>Van (GVW 1350 kg)</td>
<td>Light</td>
</tr>
<tr>
<td>3</td>
<td>Van (GVW 1650 kg)</td>
<td>Middle heavy</td>
</tr>
<tr>
<td>4</td>
<td>Truck (GVW &lt;4000 kg)</td>
<td>Middle heavy</td>
</tr>
<tr>
<td>5</td>
<td>Truck (GVW &lt;12 ton)</td>
<td>Heavy</td>
</tr>
<tr>
<td>6</td>
<td>Truck (GVW 12 - 16 ton)</td>
<td>Heavy</td>
</tr>
<tr>
<td>7</td>
<td>Truck (GVW &gt;16 ton)</td>
<td>Heavy</td>
</tr>
<tr>
<td>8</td>
<td>Truck + trailer</td>
<td>Heavy</td>
</tr>
<tr>
<td>9</td>
<td>Tractor + trailer</td>
<td>Heavy</td>
</tr>
</tbody>
</table>

Furthermore, the last mile trip needs to be linked to a road and situation. The last mile trips take place in urban areas only. The road situation class used is city stagnant (active in peak hours) and city normal (not active in peak hours). Applicable factors are highlighted green in Table 41. The method on how footprints can be included is applied in the cluster analysis conducted in chapter 6. Environmental aspects defined as key performance indicator are used to see how different freight carrier categories are performing in environmental terms.
7.6.2. Exploration of Relationships of Variables

Collected data can be used to explore interesting relationships such as price of package/pallet versus number of companies and cost of a trip versus cost of PostNL. This provides the municipality of Delft and PostNL with valuable information on which companies can benefit of an alternative shipping method and are therefore a potential customer to PostNL. Previous chapter on data analysis is dedicated to this potential development direction.

7.6.3. Cluster Analysis

Collected data from the LMS model can be used to conduct a cluster analysis on freight carriers. It should be possible to make a distinction on the base of characteristics. This categorization can be used to see how types of freight carriers perform on different performance indicators. This provides the municipality with information what freight carriers should be excluded from the city centre on the base of what indicators. Next chapter explores this potential development direction.

7.6.4. Define Specific Key Performance Indicators

A possible development direction of the LMS model is to include specific key performance indicators. This improvement correlates with a cluster analysis because as in and output of the cluster analysis KPIs are used. A few simple mutations from existing output and other variables already available in the model need to be executed. Specific KPI’s introduced in paragraph 5.2.5 can be consulted on necessary mutations.

7.6.5. Interface of LMS Model

The usability of the LMS is an important factor that ensures collected data is gathered more easily and naturally because barriers to participate disappear. The interface needs to be user friendly to increase the amount of freight carriers completing the scan. The interface and application should be improved significantly. Carriers should have an app on their smartphone that can provide them of information at any time of the day to compare shipments cost (current and alternative method). The development
of an application to reduce complexity is a potential focus point. Potential improvements are discussed next.

**Difficulty and amount of questions**
Completing a scan takes time. It should be as quick as possible to complete a scan. The questions can be difficult (some information needs to be looked up) and participants experience filling out a scan takes a long time due to the amount of questions. This prevents them from updating their profile. The results are that potential participants do not create a profile or fill out a scan. The type and amount of questions cannot be reduced because this input data is needed for calculations.

**Use of cookies and automatic log on**
The scan can be improved in ways of remembering answers and saving login information. This increases ease of usability and lowers the time it takes to update or re-do a scan.

**Smartphone application**
The LMS model is a desktop application. Development of an application operating on smartphones significantly increases the amount of participants. The application is always at hand and can be quickly consulted.

**Design of website**
The layout and look of the website should be more attractive. The look is not inviting and has a feel of being out-dated. This affects the perception of participants negatively. A fresh and new look is more inviting and has a positive effect on the perception of the LMS. The perception is crucial for participants in experiencing how they feel it could help them in their activities.

### 7.6.6. Explicitly Communicate Added Value of Model

The LMS model has a low and one-sided participation degree. Carriers are not willing to participate naturally by filling out a scan. They cannot see the benefit of participation directly and how the model can support them in making decisions on how to organize freight distribution. This should be stated explicitly on the website before a scan is conducted.
7.7. Ideal LMS model

In this paragraph, a conceptual framework of the ideal LMS model is presented. In the first section, the conceptual framework of the current and future models is presented. The second part provides the municipality with guidelines how the renewed LMS model can be developed and used.

7.7.1. Conceptual framework of ideal LMS model

The current conceptual framework of the LMS model is presented below.

```
INPUT VARIABLES
Vehicle type
City
Route In
Route Out
Active in area
Active in peakhour
# of days active
# of small packages
# of large packages
# of stops

CONSTANTS
dInOut
dStops
TSstops
tSmallPackage
tLargePackage
wArea
vOutsideArea

LMS Model

FORMULAS

CALCULATIONS

OUTCOME
Cost [euro]
Distance [km]
Time [min]
Probability of saving [%]
```

Figure 62 - Conceptual framework current LMS model

In this chapter, shortcomings of the LMS model are identified and potential extensions and improvements are introduced. Extensions and improvements that can be implemented use available data. Some of the extensions need extra information from freight carriers to calculate key performance indicators; this extra information is included as input. The conceptual framework of the improved and extended LMS model is presented in Figure 63.

```
INPUT VARIABLES
Vehicle type
Vehicle age/year built
City
Route In
Route Out
Active in area
Active in peakhour
# of days active
# of small packages
# of large packages
# of stops

CONSTANTS
[stochastic]
dInOut
dStops
TSstops
tSmallPackage
tLargePackage
wArea
vOutsideArea

LMS Model

FORMULAS

CALCULATIONS

EMISSION TABLE

OUTCOME (KPIs)
Cost parameters
• Total cost [euro/trip]
• Cost per minute [euro/min]
• Cost per unit [euro/unit]
• Cost per kilometre [euro/km]
• Cost per cubic [euro/m3]
Distance [km]
Time [min]

Emission parameters
• CO [gram/trip]
• NOx [gram/trip]
• NO2 [gram/trip]
• PM10 [mg/trip]
• PM2.5 [mg/trip]
• Footprints per stop [g/stop]
• Footprints per unit [g/unit]
Total cost alternative shipping method [euro]
```

Figure 63 - Conceptual framework renewed LMS model

All changes are discussed per section below. Extensions of input variables are limited to including vehicle age/year built. Constants can be improved by including stochastic inputs instead of deterministic inputs or set assumptions. Formulas and calculations need to be extended in order to calculate specific KPIs. In addition, an emission table needs to be included in the renewed LMS model.

Input variables
A question added to the scan is: What year is the vehicle built? This gives information on the environmental performance of the vehicle and last mile trip. To calculate footprint, this information is needed. This change is not yet added to the model but can be easily implemented.
**Constants**

Another change is to replace constants (assumptions) by stochastic inputs or distributions. Greater knowledge and further research to define these distributions is a necessity. For example, the average stopping time is determined throughout field research. Besides average numbers (which are calculated), a minimum and maximum stopping time needs to be available and the entire data set on field research must be known to construct distributions of constants. Further research is needed to gather information on distributions before static constants can be replaced by stochastic distributions. This research falls outside the scope of this thesis.

**Emission table**

An emission table needs to be added to be able to classify vehicles on their environmental performance. Classification is based on the age and size of the vehicle and the type of activity they conduct (driving in urban areas in or outside peak hour). The emission table is added in previous chapter on cluster analysis. Although vehicle age is not yet known, footprints have been calculated based on vehicle type, activity during peak hour and output variable distance.

**Outcome (KPIs)**

Outcome of the LMS model needs to be extended significantly by including more detailed key performance indicators. Conducting mutations can create cost parameters, which can function as economical KPIs. Variables to conduct these changes are already present in the model. In addition, the total cost of the alternative shipping method can be calculated with current variables. These mutations are already implemented in the chapter 6 on data analysis and chapter 7 on cluster analysis. Furthermore, footprints or environmental performance can be calculated by use of the total distance, vehicle year built and size of the vehicle, type of activity and the added emission table. The exact methodology is presented in paragraph 7.6.1.

**Guideline how to develop and use the renewed LMS model**

The improved LMS model provides the municipality but also participants (freight carriers) with more detailed information on key performance indicators. Therefore, the municipality is able to compare performance of different freight carriers in more detail instead, only on general output variables total cost, time and distance. The municipality can create benchmarks between competitors to compare them on different KPIs or performance in general.

Specific KPIs needs to be computed. Data already available in the model can be used. KPIs are distinguished on economic and environmental aspects. Economic aspects can be created by mutation of defined output variables cost, time and distance and undefined input variables total load and size of shipping load. These mutations have been introduced in paragraph 5.2.5. There, specific KPIs are calculated which are cost per unit, cost per minute, cost per kilometre and cost per cubic. In addition, performance on environmental aspects can be measured by creation of footprints. A distinction on different types of exhaust is introduced in paragraph 7.6.1. Specific KPIs are CO, NOx, NO2, PM10 and PM2.5.
7.8. Summary and conclusion

In this paragraph a concise summary and conclusion of chapter 7 on shortcomings of the LMS model is given. Thereafter, an answer on sub-question II-4 is given.

This chapter started with the following sub-question:

*SQ II-4* What are shortcomings and potential improvements of the LMS and does the model fit UFD context needs?

**General remarks**

The model uses a last-mile perspective that differs from the common supply chain perspective of freight carriers. This difference in point of view can lead to lower usability of the LMS and can, in worst-case scenario, result in biased conclusions. In addition, data availability and especially operational data of cost on the last mile is unknown by freight carriers or not available due to protection of valuable information by the same freight carriers. During the development phase, MD made a few arbitrary decisions on assumptions and to way to calculate cost of the last mile. These assumptions are needed to be able to make the necessary calculations. Decisions on these assumptions or choice of approach can have a large impact on results. The LMS model is a deterministic model. Similar inputs generate the exact same output. Replacement of static assumptions by stochastic distributions should be considered to have a better fit with reality. Another debatable characteristic is the linearity of the model. The model does not take into account the theory of economies of scale. Shipments above a certain amount are therefore biased.

**Stakeholder support functionalities LMS**

The LMS model does not fit context needs of all involved stakeholders derived from the stakeholder analysis. This unilateral approach includes economic aspects only while the context needs are broader and include social and environmental aspects as well.

**Freight carriers**

Value added functionalities of the LMS model for freight carriers are gather insight on performance on their last mile. Performance on general indicators total time, distance and cost is valuable information for them but more specific cost parameters can even increase support for freight carriers in making the right decisions. Besides outcome of the model should give a value on specific key performance indicators it can use a benchmark methodology to give freight carriers information on their performance in comparison with competitors or carriers with similar shipment characteristics. This information can support them in deciding to conduct a shipment internally or externally (outsourcing the shipment to PostNL).

**Municipality of Delft**

The functionalities of the LMS model can support the municipality of Delft in gathering information and improving knowledge on functioning of the urban freight distribution system. This knowledge is helpful because it tells how freight carriers perform on economic and environmental key performance indicators. Previous chapters on data and cluster analysis contribute in improving usage of model results and on how gathered data can be interpreted. The cluster analysis is beneficial to see what stakeholder groups need to improve performance to enable a sustainable urban freight distribution system.

**Residents**

Functionalities of the LMS model cannot support residents because this stakeholder group has no power (to make decisions) or direct influence on how the urban freight distribution is designed. As mentioned in previous paragraph, the municipality of Delft can use results from the model to support their argument on progressive policies that might be implemented in the near future. These policies can positively affect well-being of residents because both stakeholder groups (municipality and residents) share the same interests and objectives towards sustaining urban freight distribution.

**PostNL**

Functionalities of the LMS model cannot directly support PostNL. Data gathered by MD is not available for public usage but only individual results are available for participants and all data is
available for the municipality of Delft. However, PostNL has won a tender issued by the municipality. The winner of the tender received a list of participants (freight carriers) that ‘checked’ the intention box. PostNL received a list of potential companies in 2015. In an interview conducted with Dhr. K.W. Rademakers head of city logistics of PostNL, he stated: Not all companies are willing to work together with PostNL in their new ‘Stadslogistiek Delft‘ distribution centre. Barriers of economical, psychological, administrative, juristic and insurance grounds stop them in transferring their cargo to PostNL. In practice, not even one company of the entire list of companies collected by MD was willing to transfer cargo to PostNL.

**Ideal LMS model**

Potential development directions are identified based on this research. These can be summarized in the following extension possibilities. First, environmental aspects can be included by adding emission factors assigned to vehicle type, length of trip and activity during peak hour. Furthermore, specific key performance indicators on economic aspects should be added to outcome of the model. This can be easily realized with a few simple mutations. The cost for an alternative shipping method should be stated explicitly. Finally, all these KPIs should be compared using a benchmark methodology to provide freight carriers not only with information on individual performance but also give them knowledge on performance relatively to similar freight carriers. The ideal LMS model should capture all these defined key performance indicators (economic and environmental), footprints, benchmark results and transparent alternative shipment cost.

The usability of the LMS is an important factor that ensures collected data is gathered more. The interface needs to be user friendly and attractive to increase the amount of freight carriers completing the scan. The interface should be improved significantly. This can be realized by development of an application that can be used on smartphones and simultaneously develop a new website. This can result in higher degree of usability and an increased benefit to freight carriers.
PHASE III CONCLUSION, RECOMMENDATION AND REFLECTION

This phase describes how an ideal LMS calculation model looks like and how the municipality of Delft can better use it to further sustain the urban freight distribution system. Furthermore, some conclusions drawn from the research are discussed. The structure of phase III is displayed in Figure 64.

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Figure 64 - Structure of phase III

Chapter 8 Conclusion
In this chapter general conclusions from the research are drawn. The research question is answered and the main objective is critically reviewed.

(SQ III -1) What conclusions can be drawn based on this research?

Chapter 9 Recommendation
In this chapter an ideal LMS is threatened that can help and guide the municipality of Delft in how to use the LMS model to be able to further sustain urban freight distribution in Delft. Furthermore, some future research topics are discussed.

(SQ III-2) What will the ideal LMS model look like and how can the municipality of Delft best use it?

Chapter 10 Reflection
In this chapter, a critical reflection on the process of writing this thesis is conducted. Next to the process itself, the results are evaluated. This chapter ends with an overview of lessons learned when writing this thesis.

(SQ III -3) What lessons are learned during the process of writing this thesis?
8. CHAPTER 8 CONCLUSION

In this chapter, conclusions drawn from the research are discussed. The main research question formulated in the beginning of this thesis is:

*How can data and information collected by the LMS be of extended usage to the municipality of Delft to serve the purpose of improving urban freight distribution taking into account all stakeholder interests such as economic inefficiencies, (greenhouse) emissions, noise nuisance, air quality, safety and congestion issues?*

**Context of urban freight distribution**
Urban freight distribution problems vary in nature and are characterized as economic, environmental or socially grounded. Urban freight distribution operates in urban areas where space is in short supply. These residency areas are the homes of many people. Considering most vehicles still drive on conventional energy sources this results in greenhouse emission problems in cities. Safety and noise issues regarding old vehicles operating in urban areas also have a negative impact on liveability of cities.

The social need to sustain urban freight distribution and to develop and improve the urban freight distribution system in high-density urban areas is large. The concept of sustainable development seeks to meet needs of present and future generations without denying the fact that future generations are not able to meet their needs. The concept of sustainable developments can be divided in three principles, which include economic growth, social equity and environmental protection.

The context of urban freight distribution is rather complex. It holds various problems of different kinds of nature. Besides, available solutions (theoretical and practical) are not proven to solve the entire problem or only favour some of the involved stakeholders. Both problems as available solutions are not entirely clear and differ for every stakeholder due to different points of view. This complexity is even further increased by the multi-actor context of urban freight distribution and the fact that stakeholders do not always carry (social) cost and benefits both. In addition, measures that could be implemented by the municipality of Delft disrupt market functioning what could result in higher cost for distributors or other actors and eventually result in products that are more expensive for end consumers.

**Multi-actor context**
Stakeholders identified in urban freight distribution can be distinguished in five categories. These groups are cargo owners, distributors, residents, planners and regulators and interest associations and environmental groups. Each category consists of a number of stakeholders. Cargo owners and distributors are participants of the scan and possess a high degree of power to influence the UFD system because they possess important resources due to their strategic position in the network. In general, these involved stakeholders have conflicting interest and objectives with the problem owner, municipality of Delft. They mainly seek to optimize profit while the main concern of the municipality is to sustain the urban freight distribution system. These stakeholders are dedicated and have a high interest towards the researched entity. In general, conflicting interest, different levels in degrees of power, bilateral dependencies and resource dependency makes it difficult to implement solutions, create sense of urgency to change and activate stakeholders to contribute.

**Validation process**
The conceptual framework developed by Sargent is used as guidance in the validation process of the LMS model. All four phases of the validation process in the conceptual framework are conducted. These phases are conceptual model validation, operational validation, computerized model verification and data validity. In addition, a sensitivity analysis or what-if analysis is conducted.

**Conceptual model validation**
The LMS model uses different variables and constants to estimate and give an indication of cost of specific shipping. The black box and the CRD are conceptual models developed to conduct conceptual
model validation. The relations between variables used by the model are logic. Although only the direction of the relation is evaluated at this stage, the LMS model seems to be fairly reasonable, but simplified representation of the real situation. The purpose of development the LMS model by MD is to identify, facilitate and regulate is partly achieved. The first and second objective, identify activities that take place in the urban area and facilitate involved stakeholders with information on cost structures, has been succeeded since the model provides both actors of a cost indication on the last mile. The second objective, facilitate, can be improved in providing freight carriers with more detailed information. The final objective, regulate, is not met because it is still unknown if results are accurate and similar to real data.

**Computerized model verification**

Total distance of a trip is calculated using an API tool developed by Google. This application ensures a high accuracy of distances since it uses precise coordinates to calculate covered distances. The formula used for calculating distance per stop is plausible because distance per stop can be calculated by multiplying the number of stops times an average distance per stop. Total time is dependent on driving and unloading time. Driving time is dependent on average velocity of a vehicle and total distance covered. The general dimension of velocity is kilometre per hour; velocity = distance / time; time = distance / velocity. This relation is correct. Unloading time is dependent on the amount of small and large packages delivered multiplied by a constant ‘average unloading time’ per package/pallet. Unloading time can be estimated by using a constant average time for unloading small/large packages because every unit takes time to deliver. Total costs are calculated and dependent on total time multiplied by cost per hour and total distance multiplied by cost per kilometre. This is a plausible method. The formulas to calculate distance, time and cost of a last mile trip and relations between variables used to conduct these calculations are plausible.

**Data validity**

The benchmark methodology and strict rules that Research Company Panteia practise ensures data collection is done properly and is significantly reliable. Input data on assumptions like velocities of vehicles and cost per minute and kilometre are valid. Data collected throughout field research is less reliable. It is difficult to state that these assumptions correspond with real world values, because background information on scope of the field research is not available and unknown. Moreover, students and not professional research employees conducted the field research, which makes the research unreliable. The advice is to increase the scope of the field research to ensure the amount of background data is large enough and constructed assumption are more likely to be reliable. Overall, it cannot be stated that assumptions correspond with values in practise. Constants are therefore still assumptions and not valid as truth-values.

**Operational validity**

Operational validity is impossible due to a lack of real data, which makes it impossible to crosscheck output of the LMS model with real data from the field. Freight carriers themselves do not know the cost of the last mile. A cross validation check with available models is of PostNL and the model developed by Roger Peters is conducted. The model of PostNL uses a different methodology and has other (cumulative) results (not individual as in the LMS model). Drawing conclusions is difficult since structures of the models are different. The research conducted by Roger Peters is used as reference to see if formulas used in that research have similar structures as the LMS model. The model differs in output because the LMS model tries to give an indication in total time, distance and cost of an individual trip. Average velocities are similar in both models. All other variables differ and are hard to compare due to specific city characteristics of Breda and Delft.

**Sensitivity analysis**

All output variables are higher in case of scenarios where constants are higher. This means that all hypotheses are correct and that the LMS model gives the expected results in light of sensitivity of changing different assumptions. Overall, it can be concluded that all constants and modified values give the expected output. This argument strengthens validity of the model because, the model generates realistic and logic outputs when varying input variables and constants.

**Data analysis**

The majority of trips, around 75%, cover a smaller distance then 10 kilometres. This means that the most last-mile trips do not cover a large distance. The average time of all trips is 100 minutes. This is
relatively long since the average distance covered in 100 minutes is only 8,59 kilometres. The cost of all trips is distributed evenly between 0 and 100 euro. The centre of gravity lies between 10 and 35 euro. The average cost of all trips is 36,56 euro.

All scatterplots of output variables cost, time and distance show expected relationships and results. The structure of the LMS model is linear based. All formulas between variables used in the LMS model are linear. Outcomes of graphs of the relationships between distance, time and cost show linear featured as well. These types of relationships are in line with expectations and therefore strengthen validity of the LMS model slightly.

Interesting distributions that are not directly calculated by the LMS model yet, but can be created by applying a simple mutation of output variables of the data sample. These mutated variables can be seen as criteria or key performance indicators to see how different freight carriers are performing. KPIs that are explored in this paragraph are cost per unit; cost per minute; cost per kilometre; cost per m3.

The relation between stops and cost is not a clear linear relation, since data points are spread over the entire field. The relation between shipping load and cost is not clear either. Many data points differ heavily with regard to cost of a trip. This is not strange because shipments can be similar in size but differ on characteristics with regard to: type of vehicle, amount of stops, activity in different areas and so on. Larger total shipping loads are not always more expensive.

The trend line of total cost of PostNL is a significant steeper linear relationship as the trend line of total cost LMS. This implies that as shipping load increases (packages + pallets) alternative shipping method PostNL is more expensive in comparison to a shipment conducted by a freight carrier internal. The intersection is interesting and lies at a shipping load of five units (packages + pallets). In the majority of cases (data points) a shipping load of five or smaller (relatively smaller shipments) are cheaper to be shipped by an alternative shipping method (PostNL). In majority of cases, larger loading ratios (relatively larger shipments) benefit to be executed by a freight carrier internally.

**Cluster analysis**

Distributors can be classified based on all parameters in the LMS model or parameters not yet present but easily created by a simple mutation. The possibilities are endless since all attributes and KPI’s can be used as inputs and/or evaluation fields both. The cluster analysis can give the municipality valuable knowledge on how freight carriers are performing on key performance indicators formulated by the municipality. Depending on the objective and need for specific information, the right settings can be chosen. The right setting for the municipality is probably a combination of economic and environmental aspects.

A conclusion drawn from the cluster analysis is that clusters with a large shipping load score well on environmental aspects (defined environmental key performance indicators). In addition, these groups of carriers also score well on economic aspects (defined specific economic key performance indicators) concluded from the cluster analysis on economic aspects. This strengthens the conclusion that smaller shipments perform less good in general (both in economic and environmental terms) and can better use an alternative shipping method. In chapter 5 the suggestion that smaller shipments are relatively expensive was already put forward and is now again supported by the cluster analysis.

The practical usability of the cluster analysis is three-folded. First, the analysis gathers detailed knowledge on already available data derived by the LMS model for both participants (freight carriers) and the municipality of Delft. Secondly, this knowledge can be used to develop custom policy for specific freight carriers that are performing undersize. Thirdly, the results can contribute in mediating cooperation between freight carriers because it provides them with specific knowledge on their performance on economic and environmental indicator. Comparing this information with the entire data sample gives them knowledge how well they are performing with regard to their competitors. This benchmark methodology can be implemented by a few simple calculations.
9. **CHAPTER 9  RECOMMENDATION**

This chapter threats recommendations for the municipality of Delft that can be used as manual to improve usage of the LMS model. First, the general remarks are discussed. Thereafter recommendations to the municipality of Delft are threatted. This chapter ends with some future research topics. This chapter started with the following sub-question:

**(SQ III-2)** What will the ideal LMS model look like and how can the municipality of Delft best use it?

### 9.1. Shortcomings of LMS model

General shortcomings of the model are summed up first to be able to see what should be improved to provide the municipality of Delft recommendations on how to better use the LMS model and how to interpret information properly. The main goal of the municipality of Delft is to increase awareness among distributors and to mediate between (smaller) freight carriers and a larger and cleaner central distributor. This approach can contribute in achieving a sustainable urban freight distribution system.

The focus of the LMS model is too narrow, since it addresses one group of stakeholders only. The rate of success or the potential improvement that can be achieved by cooperating is relatively low since other stakeholders do not see the benefit of the LMS model. Other aspects of sustainable UFD such as social and environmental aspects need to be included to attract more stakeholders to participate in the process. Output of the LMS model does not have a good fit with context needs of multiple involved stakeholders. It only addresses general needs of freight carriers and these needs are unilateral (economical only). Furthermore, output variables are too general and more specific key performance indicators need to be defined.

Distributors think in means of an entire supply chain from origin towards destination. This perspective is geographically larger and can have one or more last-mile regions in it. The LMS calculation model has a last-mile perspective. These different approaches can lead to unknown benefit of the LMS under participants. This shortcoming cannot be solved since freight carriers would not change perspective and focus point of the LMS knowingly chosen to be on the last mile. Another shortcoming was data availability during the development phase. Development of the LMS without accurate data or field research with a significant level of detail or size is difficult and can result in a too simplified model. During development, arbitrary decisions on assumptions and how to structure the LMS model had to be made. These decisions have not always resulted in finding the right level of accuracy of output variables. The deterministic nature of the model can be seen as a shortcoming of the model. In a real world, every trip differs from another. Another debatable characteristic is the linearity of the model. The model does not take into account the theory of economies of scale. Shipments above a certain amount are therefore biased.

### 9.2. Recommendation

First, two general notes need to be made. The larger geographic perspective needs to be taken in mind while using the LMS model by the municipality of Delft. At the same time, the linear structure of the LMS model should not be forgotten since this can lead to biased conclusions when data is analysed to gather knowledge on performance levels of freight carriers.

The first recommendation is that data availability and the amount of data collected can be increased significantly by making it compulsory for freight carriers to participate in the LMS. This can be done to introduce a system that freight carriers need to have a certificate to operate in the urban area of Delft. All stakeholders receive a certificate if they provide the municipality with information by participating and filling out the last mile scan.

The LMS model should be improved and extended on the following aspects: improve the usability of the LMS, include stochastic inputs (further research is needed), include environmental aspects, extent
output variables (KPIs) with specific defined cost parameters, extent output variables with total cost of an alternative shipping method and include benchmark results.

The usability of the LMS is an important factor that ensures collected data is gathered more. The interface needs to be user friendly and attractive to increase the amount of freight carriers completing the scan. The interface should be improved significantly. This can be realized by development of an application that can be used on smartphones and simultaneously develop a new website. This can result in higher degree of usability and an increased benefit to freight carriers.

The deterministic nature of the model can be upgraded by using stochastic input variables instead of deterministic set values in order to move towards a better representation of reality. This can be reached by replacing assumptions and constants into stochastic input variables. Future research needs to be conducted to explore stochastic distributions of used assumptions from the LMS model.

Applying footprints to carriers by including environmental aspects. This provides the municipality of Delft with information on performance of individual freight carriers on aspects other than economical. It gives them information on what companies could be banned from the urban area due to their bad environmental performance. In addition, information on vehicle types should be extended by year of built since this is an important factor that is needed to estimate performance with regard to environmental aspects. Footprints should be created as output variables in the LMS model. These footprints are exhaust per stop and exhaust per unit. General total emission parameters that need to be included are: CO, NOx, NO2, PM10 and PM2.5.

Finally, the outcome of the LMS model needs to be extended significantly by including more detailed key performance indicators. Conducting a few simple mutations can compute specific cost KPIs. The necessary variables to conduct these changes already exist in the LMS model. More detailed knowledge on performance is crucial for the municipality of Delft to draw conclusions and give direction to policy. This information is even as crucial for freight carrier since total cost, time and distance does not give them enough insight on level of performance. Specific cost output variables are cost per minute, cost per unite, cost per kilometre and cost per cubic.

The alternative shipping method (conducted by PostNL) should be defined as output variable. The cost of this alternative needs to be visible to freight carriers so they can compare outcome of the LMS model (estimation cost of last mile trip) with an alternative shipping method directly to create a sense of urgency.

Finally, all these KPIs should be compared using a benchmark methodology to provide freight carriers not only with information on individual performance but also give them knowledge on performance relatively to similar freight carriers. All changes are implemented in the improved and extended LMS model are presented below.

![Figure 65 - Conceptual framework renewed LMS model](image-url)
9.3. Future research

In this paragraph, future research topics are introduced.

Stochastic input distributions
Future research on input distributions of assumptions can be conducted to be able to replace all static values of constants to more dynamic stochastic inputs. The replacement increases fit of the LMS model with reality. The deterministic nature of the model can thereafter be changed to a stochastic nature. Similar input data of a last mile trip have variation in outcome after this implementation. The LMS model has a better fit with real world data and can therefore be considered as a better simulation model.

Field research on input data of LMS model
The field research conducted by NHTV students (Breda University of Applied Science) is a future research topic. The scope of this field research is unknown but can be based on 1 or 2 counting days where a limited amount of data is collected. This research is used to define values of assumptions (constants) used in the LMS model. An extensive field research on values of the assumptions can benefit and support validity of the LMS model in general.

Data collection research on real data
The topic of this research is focused on collecting real data to conduct operational validation so real data can be compared with output of the LMS model. An extensive survey needs to be conducted among freight carriers active in the region Haaglanden. In addition, semi-structured interviews with the same stakeholders should be conducted to gather a sufficient amount of data.

Development of application
The LMS model is a desktop application. Development of an application operating on smartphones can significantly increase the amount of participants. The application is always at hand and can be quickly consulted. A future research topic is the design of an application that is available for smartphones. At the same time, the layout and look of the website should be made more attractive. The current look is not inviting and has a feel of being out-dated. This affects the perception of participants negatively. A fresh and new look can have a positive effect on the perception on how the last-mile scan is seen. The perception is crucial for participants in experiencing how they experience the scan could help them in their activities.
10. CHAPTER 10 REFLECTION

In this chapter, a critical reflection on the process of this thesis is threats. This reflection identifies lessons learned during the process. This phase started with the following sub-question that is answered in this chapter:

(SQ III -3) What lessons are learned during the process of writing this thesis?

Planning
The planning of the thesis has often been revisited. The reason for re scheduling is two-folded. First, I did not put enough time on making a decent planning from the start. In the beginning of the process, this resulted in absence of deadlines in general. After a (soft) deadline could not be made, the damage was already done and eventually resulted in not revisiting the planning at all. This problem has been solved over time after I shared it with my first supervisor Dhr. Ron van Duin. I suggested planning a meeting every 2 or 3 weeks to monitor the process together. This push helped me a lot in moving forward and working towards a feasible result. In general, I could have managed the process of this thesis better if more time was invested in making a realistic planning. A good preparation would have made it easier to actual carry out the planning and shorten the amount of time I spent on writing this thesis.

Structure of thesis
Another problem I faced during the process of writing this thesis had to do with searching for the right structure and finding the specific research topic. During the process, I switched multiple times of scope. In the beginning, the scope was excessively broad. This resulted in an extensive literature research where too many topics (definitely outside the scope of this thesis) were researched. This literature research gave me deeper knowledge on the topic of urban freight distribution, which is of course a positive thing. On the other hand, it also resulted in a lot of text that was not directly relevant for this thesis and was moved to the Appendix or even was left out of this thesis at all. Revising of research conducted took me too much time due to the amount of text already written. I tackled this problem in the end with help of first supervisor Dhr. Ron van Duin and by having multiple meetings with external supervisor Dhr. Bram Coremans.

Consultation of supervisors
During the process, I have learned I could have consulted my supervisors more often and use their knowledge more efficiently. In the beginning I tried to do a lot of work alone because I thought I could handle it without help of my supervisors. This resulted in earlier mentioned problems as too broad research scope, a wrong delineation, too much time and effort put into literature research and eventually in starting almost all over again. After I decided to ask for help, my first supervisor guided me onto the right path. I found the plenary meetings very helpful. After these meetings, I mostly felt that the direction I moved to was the right one.

Implementation and report writing
I underestimated the amount of work it took to implement and write the actual report. Writing in English is not my strongest suit. During the process, I experienced writing the report went more smoothly. The main reason for this was a better structure and delineation. The focus and scope of research improved which made it significantly easier to decide to leave unnecessary topics out of the report. In finalizing my thesis, I still had some trouble in making the right decisions on what should be left out or could be moved to the Appendix (again, this had to do with the amount of text I already produced during the entire process).

Lessons learned
In general, the main lesson I have learned of writing this thesis is the importance of a well-defined research scope. This first step is potentially beneficial during the entire process of writing a thesis. In cohesion with a proper delineation, an extensive planning with realistic deadlines needs to be produced before starting with the actual writing.
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14. APPENDICES

A. Background information on UFD

Below the formula that describes the amount of CO₂ emission released in a transport system is shown.

\[ CO₂\, Emissions = \frac{\text{TransportWork}}{\text{GNP}} \times \frac{\text{TrafficWork}}{\text{TransportWork}} \times \frac{\text{CO₂\, Emissions}}{\text{TrafficWork}} \]

Figure 66 - Formula of amount of CO₂ emission in a transport system (Behrends, 2008)

The amount of CO₂ emissions emitted (energy used by the transportation system) is dependent on the gross national product (GNP) (which is desirable) * the traffic intensity (TrafficWork/TransportWork) * the technical capabilities (CO₂ Emissions/TrafficWork) of the traffic system. The energy needed for a specific transportation system can be lowered by either reducing the amount traffic intensity or the traffic intensity or by increasing technical capabilities.

Freight Transport

According to Hesse & Rodrique the realm of logistics is considered as the science of physical distribution (Hesse & Rodrigue, 2004). It represents the entire system of space and time interdependencies. Handfield and Nichols have defined logistics as: ‘the wide set of activities dedicated to the transformation and circulation of goods, such as the material supply of production, the core distribution and transport function, wholesale and retail and also the provision of households with consumer goods as well as related information flows’. This integrated demand can be called logistics and can be further defined and divided in two functions: physical distribution (PD) and materials management (MM). The integrated transport demand is dependent on these two functions where PD is driven by MM. Figure 67 is a representations of the interdependencies between MM and PD.

![Diagram of Logistics and integrated transport demand](image)

Figure 67 - Logistics and integrated transport demand (Hesse & Rodrigue, 2004)

Materials management is specified as all the stages of production relating to the manufacturing of commodities. These include the following activities: production planning, demand forecasting, inventory management, purchasing and packaging but also return flows such as recycling of disposed material (Hesse & Rodrigue, 2004).

Physical distribution is the derived from materials management and can be further specified as the distribution of goods from start to end, from manufacturing to consumption. This function the following activities are considered: transportation services, warehouse services, transhipment, wholesale, trade and retail (Hesse & Rodrigue, 2004).
The evolution of logistics over the years (1960-2000), from independent activities towards integrated Supply Chain Management is nicely captured in by Hesse & Rodrigue in Figure 68 below.

Figure 68 - Evolution of logistical integration between 1960 -2000 (Hesse & Rodrigue, 2004)

Nowadays, information technology, marketing and strategic planning play a more dominant role in logistics. Furthermore, all activities that were organized independent and were separately controlled are now integrated and connected. Logistics in 2015 are interconnected on all different sections and levels. The total integration of the supply chain is controlled by complex IT systems that often operate without human interaction. The complexity and integration of logistics have been improved enormously and is still developing rapidly. This integration and complexity also holds the advantage of infinite opportunities to improve logistics.

B. Multi-actor context

Multi-actor systems
To describe multi-actor systems, we first need to compare network structures with hierarchical ones. These structures differ on a number of characteristics. This paragraph starts with an elaboration on differences between these two structures. Thereafter, the decision making process in networks is explored and why this process is somehow different from regular decision making models (de Bruijn, J.A. & Heuvelhof, 2008). Table 42 displays characteristics of hierarchy structures and networks.

Table 42 - Characteristics of a hierarchy of a network (de Bruijn, J.A. & Heuvelhof, 2008)

<table>
<thead>
<tr>
<th>Hierarchy</th>
<th>Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniformity</td>
<td>Variety</td>
</tr>
<tr>
<td>Unilateral dependencies</td>
<td>Mutual dependencies</td>
</tr>
<tr>
<td>Openness/receptiveness to hierarchical signals</td>
<td>Closeness to hierarchical signals</td>
</tr>
<tr>
<td>Stability</td>
<td>Dynamic</td>
</tr>
</tbody>
</table>

Networks are characterized by a great variety in various dimensions like many different actors, products, interest and means of power. In contradiction, hierarchy structures can be labelled as uniform where objectives are clear and only one actor has to power to make decisions despite the interest of other actors involved.
Furthermore, multi-actor environments are characterized by many actors influence the process and mutual dependencies among them are a fact. Directives initiated by one actor cannot always encounter full support of all actors involved. Dependencies and relations can vary of nature. A few examples of possible variations are single value versus multi-value, bilateral versus multilateral, synchronous versus asynchronous, sequential versus simultaneous and static versus dynamic.

Moreover, actors might be open towards intervention of other actors or can neglect hierarchical signals. This cannot be predicted beforehand and can change overtime or due to an event.

**Six-step stakeholder analysis procedure**

The systematic procedure covers the following six steps.

1. formulation of a problem as a point of departure;
2. inventory of the actors involved;
3. exhibiting the formal chart: the formal tasks, authorities, and relations of actors and the current legislation;
4. determining the interests, objectives and problem perceptions of actors;
5. mapping out the interdependencies between actors by making inventories of resources and the subjective involvement of actors with the problem;
6. determining the consequences of these findings with regard to the problem;
7. formulation

The actual stakeholder analysis is executed in the next paragraph by guidance of the use of the six-step framework presented above. ‘Power vs. interest’ grids are drawn to see where the different groups of actors are situated.

Actors can be categorized on dedicated versus non-dedicated actors, critical versus non-critical actors and joint perceptions and objectives versus opposed perceptions and objectives.

<table>
<thead>
<tr>
<th>Table 43 - Characteristics of actors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Dedicated actors</td>
</tr>
<tr>
<td>Critical actors</td>
</tr>
<tr>
<td>Joint perceptions and objectives</td>
</tr>
<tr>
<td>Opposed perceptions and objectives</td>
</tr>
</tbody>
</table>

**Actor analysis**

The context of a network can be characterized as dynamic. All characteristics mentioned above can change rapidly overtime. Mutual dependencies, the variety of a network and the openness towards intervention can change due to different factors or strategic behaviour. Overall, cooperation and finding common ground among stakeholders involved is key to move forward in organizing systems properly.
<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Interests</th>
<th>Desired situation/objectives</th>
<th>Existing or expected situation and gap</th>
<th>Causes</th>
<th>Possible solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer/wholesaler/retailer</td>
<td>Maximizing profit by selling goods/services</td>
<td>No policy implemented that restricts current operations and increases costs</td>
<td>Policy on vehicle restrictions (size and type) and other policies</td>
<td>More urban freight, lack of space in urban areas and higher demands on environmental issues</td>
<td>Consolidate freight to lower the social and environmental burden</td>
</tr>
<tr>
<td>Habitats</td>
<td>Clean, safe and attractive municipality</td>
<td>No emission, no accidents, no congestion and as little as possible traffic</td>
<td>In various areas in the municipality the air quality is worse than determined by law</td>
<td>There is no policy that limits the social and environmental burden (air, noise, safety and congestion)</td>
<td>Demand laws and regulations on polluting vehicles</td>
</tr>
<tr>
<td>Road user</td>
<td>Low prices, proper roads and no congestion</td>
<td>No congestion and well maintained roads</td>
<td>Possible restrictions on small and high-congested city roads</td>
<td>More urban freight and lack of space in urban areas</td>
<td>Expansion of existing road network</td>
</tr>
<tr>
<td>Distributor</td>
<td>Maximizing profit by means of transportation</td>
<td>No policy implemented that restricts current operations and increases costs</td>
<td>Policy on vehicle restrictions (size and type) and other policies</td>
<td>More urban freight, lack of space in urban areas and higher demands on environmental issues</td>
<td>Consolidate freight to lower the social and environmental burden</td>
</tr>
<tr>
<td>Municipality of Delft/Ministry of Infrastructure and Environment</td>
<td>Sustainable, attractive municipality and satisfied citizens</td>
<td>Improve cooperation and information sharing to realize sustainable urban freight system</td>
<td>No improvement in cooperation or information sharing since stakeholders preferable operate solely</td>
<td>There is no policy that limits the social and environmental burden (air, noise, safety and congestion)</td>
<td>Improve cooperation among stakeholders and create incentives</td>
</tr>
<tr>
<td>EVO/TLN</td>
<td>Well-maintained traffic network and good image to the outside world</td>
<td>No policy implemented that restricts current operations of transport companies</td>
<td>Policy on vehicle restrictions (size and type) and other policies</td>
<td>More urban freight, lack of space in urban areas and higher demands on environmental issues</td>
<td>Increase efficiency and cooperation among stakeholders</td>
</tr>
<tr>
<td>Environmental group</td>
<td>Less pollution and more sustainability</td>
<td>No conventional and/or large vehicles in urban areas</td>
<td>In various areas in the municipality the air quality is worse than determined by law</td>
<td>There is no policy that limits the social and environmental burden (air, noise, safety and congestion)</td>
<td>Demand national legislation to ensure policy restrictions in urban areas</td>
</tr>
</tbody>
</table>
C. Objective Tree(s)

Planners and regulators (Municipality of Delft)

Figure 69 - Objective tree regulator (Municipality of Delft)

The main objective of the municipality of Delft is to improve the urban freight distribution system and make it more sustainable. This can be realized by [1] lowering the amount of pollution in the municipality, [2] improving liveability and [3] make the system more efficient.

These three objectives can be operationalized and measured by the following low-level objectives.

Less pollution in the municipality can be reached by [1.1] less freight distributed via vehicles that use conventional energy sources, [1.2] only smaller trucks are allowed in the municipality or larger trucks cannot enter, [1.3] support use of e-vehicles and [1.4] lower the amount of noise nuisance in the municipality. Better liveability can be achieved by [2.1] having less congestion/traffic in the urban area, [2.2] increase the number of small vehicles and improve the small versus large vehicle ratio and [2.3] improving road and car safety en lower the amount of traffic accidents.

Higher urban freight efficiency can be achieved by [3.1] increasing consolidation of freight from the demand perspective, [3.2] increasing consolidation of freight from the supply perspective and by [3.3] improve cooperation among stakeholders. This is all stimulated and the main objective of LMS model since it is a mediation tool to bring involved stakeholders together.

These five objectives can be operationalized and measured by the following low-level objectives.

Fulfilling a facilitating role can be reached by [1.1] support sustainable initiatives and [1.2] bringing companies and organizations together to improve information and knowledge sharing on sustainability. Improvements on CLAs can be achieved by [2.1] increase the amount of CLAs and [2.2] improve the quality of CLAs. Improving infrastructure and roads can be [3.1] influenced by the amount of roads built by the government and [3.2] claim regular maintenance of roads conducted by the government. Improving the image of the transport sector is done by [4.1] launching marketing campaigns and [4.2] promote to further sustain the sector. Finally, (technical) developments in transport and logistics can be reached by [5.1] improving mobility, [5.2] improve entrepreneurship in transport and logistics to improve innovation potential and [5.3] improve road safety by supporting technical developments and regulations.
The main objective of the cargo owners/shippers is to have a reliable, quick and cheap distribution of freight. This can be realized by [1] low prices for distribution of cargo, [2] fast distribution of cargo and [3] a high reliability of transportation.
Distributors/ freight carriers

Efficient, fast and cheap distribution of freight

Efficient distribution of freight
- Consolidation of orders/demand
- Well developed IT systems
- Fully integrated Supply-Chain Management (SCM)

Cheap distribution of freight
- No restrictions in urban areas
- Low fuel prices
- Low commitments of CAOs

Fast distribution of freight
- No congestion in urban areas
- Well-maintained roads
- Large city centres

Figure 72 - Objective tree distributor/freight carrier
Residents of city of Delft

A emission-free, safe, congestion-free and spatial municipality

Low or none freight vehicles on conventional fuels
- Restrictions towards freight vehicles on conventional fuels
- Beneficial policies towards e-vehicles

No large vehicles in urban areas/city centres
- Restrictions towards large freight vehicles
- Beneficial policies towards small(er) vehicles

Efficient freight distribution
- High cooperation among stakeholders
- High competition to increase efficiency
- Restriction of distribution during peak hours

Good infrastructure in municipality
- Well maintenance policy by ministry
- Increase the amount of parks
- Increase the number of car-free zones

Figure 73 - Objective tree residents of city of Delft
D. Theory on validation techniques

**SELECTION OF VALIDATION METHODOLOGIES**

In this paragraph, a selection of validation methodologies and verification techniques is made. The selection process is conducted using a qualitative analysis by reasoning what methods are applicable, useable/feasible to execute and fall within time constrains. First, the criteria used in the analysis are addressed and the reason why these criteria are used is argued. Secondly, throughout the process of introducing a number of validation methodologies and frameworks a selection of suitable approaches take place and some methodologies and techniques are chosen.

**CRITERIA**

**Applicability**
This criterion values the relevance of the method towards the problem, topic and structure of the LMS. To be able to rate the methodologies on the criterion the following questions need to be answered. ‘Is the method relevant and does it contributes to the validation of the LMS?’

**Usability/Feasibility**
This criterion values the ease to use, appliance and feasibility of the method. Questions like: ‘can the method be applied, is the method feasible to apply?’ The feasibility aspect focuses on the complexity of the method and the cost of appliance.

**Time**
The last criterion has to do with time constrain. The different methodologies need to fit within tight time constrains since the amount of time for the research is limited.

**DEFINITIONS OF VALIDATION**

Validation challenges credibility and accuracy of a model. Model validation answers relevant questions such as; ‘do model predictions correspond to real behaviour of a system?’ Moreover, a comparison on adequacy of the simulation is generally not sufficient to say if a model is validated (Mankin, J.B., O’Neill, R.V., Shugart, H.H., Rust, n.d.).

Validation of a model is not only comparing outcome of a simulation model with reality. The model purpose determines how a model is designed, what variables are used and what mathematical representation is chosen. Comprehensive model validation starts by analysing project objectives. Possible purposes of models can be; predicting system behaviour, guiding research, summarize large data sets (linear regression equations to substitute slopes and intercepts) and replacement of field experiments.

Model validation is a process, not an event. This process takes place over a period. Devised experiments should be executed to determine the regions of system behaviour that can be simulated successfully. The following general perspectives on validation are interesting to discuss shortly. These statements come from the research of (Law, 2004).

A ‘valid’ model can be used to make real world decisions that could be made based on model outcome instead of conducting unfeasible and costly experiments in practise. The ease or difficulty of the validation process is dependent on the complexity of the system that is modelled. In addition, the amount of available real world data can make a difference in building and validating models. Even though the real system is rather complex and there is sufficient real world data available a simulation model is still an approximation to the actual system.
This is captured in Figure 74 where costs are compared to model confidence (R. G. Sargent, 2005). The amount of money invested and the degree of model confidence relates, which means invested money has a positive influence on model confidence.

![Figure 74 – Trade-off between costs versus model confidence (R. G. Sargent, 2005)](image)

A simulation model should always be developed for a particular set of objectives and is only valid for this set not for different objectives. Validation is not something that needs to be attempted after model building is executed. Often validation is done at the end of a simulation study if only if there is money and time left to do so. This is not how it should be since validation is an on-going process.

**LITERATURE REVIEW ON VALIDATION METHODOLOGIES**

In the following paragraphs, a structured literature review is executed. As guidance and approach the ten-stage model of (Tranfield, Denyer, & Smart, 2003) on ‘structured literature review’ (SLR) and the ‘Rapid Structured Literature Review’ (RSLR) approach of (Armitage & Keeble-Ramsay, 2009) is consulted. The systematic review investigates all relevant (un)published scientific studies on validation methodologies. The result of this analysis provides a complete list of available methodologies and validation techniques from all scientific literature. Relevant and usable methodologies are chosen and applied at a later stage.

**SLR**

This paragraph starts with a short explanation on what a Structured Literature Review (SLR) is and how this should be executed. Thereafter, multiple validation methodologies are introduced, sometimes supported with conceptual models. This paragraph ends with a conclusion where a selection of relevant studies which are given.

**(Rapid) Structured Literature Review**

In this section, a SLR is introduced. The ten-stage structure literature review that is developed by (Tranfield et al., 2003) is used as guidance throughout this paragraph. Firstly, the ten-stage model is introduced and discussed concise. In the figure below the ten stage model is displayed.

![Figure 75 - Stages of a systematic review (Tranfield, Denyer, & Smart, 2003)](image)
The first stage focuses on preparing the literature review. The second stage is dedicated to execution of the review. Finally, in the last stage the documentation of the review takes place. This ten-step approach is used as guidance in the next section to perform a SLR. This does not mean that every step is explicitly taken one by one. It is used as a framework to structure the analysis.

**MODELLING PROCESS AND VALIDATION AND VERIFICATION FRAMEWORK**

In the scientific field of validation of models, simulation model verification, statistical techniques and validation methodologies only a couple of authors have made a significant contribution and shared important publications. The main authors in this field are Sargent, R.G. and Kleijnen, J.P.C. Furthermore, some other publications are worth including in this RSLR. These publications come from various authors like Law, Refsgaard, Hendriksen, Whitner and Balci (Law, 2004)(Refsgaard & Hendriksen, 2004)(Whitner & Balci, 1989).

Sargent has made several publications on verification and validation techniques. In these publications, he introduces several conceptual models on modelling processes. He presents several paradigms on model development. In the next section, a simplified and more complex paradigm is discussed.

Figure 76 below is a simplified version of a modelling process. The *problem entity* is the system (real or proposed), idea, situation, policy or phenomena. The *conceptual model* is the mathematical/logical/verbal representation of the *problem entity*. The *conceptual model* is developed through *analysis and modelling* and is an iterative process. Translating the conceptual model into a computer/programming language takes place in the computer-programming phase and implementation phase develops the computerized model. Furthermore, the *computerized model* can execute *experimentations*, *which* can be used to compare the model with the real system (R. Sargent, 2001).

![Figure 76 - Simplified version of the modelling process (Sargent, 2001)](image)

This modelling process shows four different validation/verification processes. These are conceptual model validation, operational validation, computerized model verification and data validity. Conceptual model validation is defined by determining if the theories and assumptions underlying the conceptual model are correct. Furthermore, it validates if the conceptual model is a reasonable representation of the problem entity and if it serves the purpose and reason of development. Computerized model verification is defined as determining if the computer programming (the
translation of assumptions and theories into computer language) and implementation is right. Operational validation is the process of verifying the outcome of the computerized model if it has sufficient accuracy in relations to the intended purpose of development. Finally, data validation is the process of determining if the data that is used for model building, model evaluation and testing is adequate and correct (R. Sargent, 2001).

Sargent has developed various verification and validation techniques. Figure displays the real world versus the simulation world and the different entities that are part of the real or the simulation world. The conceptual framework describes the process of how to get from one entity to another. Furthermore, four different validation and verification phases are at various points in the conceptual model (R. G. Sargent, 2005). This paradigm is a bit more complex than the simplified version of the modelling process represented in Figure 76 but consist of the same validation and verification processes. Computerized model verification is now split up in specification verification process and the implementation verification process. Furthermore, conceptual model validation has now a derivative, which is theory validation. In the basic version, theory validation was part of the conceptual model validation phase.

Figure 77 - Real world versus simulation world - verification and validation techniques (Sargent, 2005)
Refsgaard and Henriksen developed a paradigm that is quite comparable with the modelling process of Sargent, Figure 76 and Figure. They proposed the terminology and methodological framework represented in Figure 78 (Refsgaard & Henriksen, 2004). This framework is quite similar to the simplified version of the modelling process developed by Sargent.

Four independent validation processes with corresponding activities can be distinguished. These are analysis & model confirmation, programming & code verification, model set-up & model calibration and simulation and model validation.

**Figure 78 - Elements of a modelling terminology. Modified after Schlesinger et al.**

**Remark**
The three frameworks introduced in the previous paragraph; [1] simplified version of the modelling process (Sargent, 2001), [2] real world versus simulation world - verification and validation techniques (Sargent, 2005) and [3] elements of a modelling terminology, modified after Schlesinger et al. are all quite similar. In general, the simplified version of the modelling process framework is the most complete one since it includes the real world into the framework. All these frameworks are potentially applicable, usable and could be applied within time constrains as guidance in the validation process of the LMS conducted in chapter 4. The approach highlights all relevant aspects of a thorough validation process.

**OTHER VALIDATION APPROACHES**

**Sensitivity analysis**
Sensitivity analysis (SE) or what-if analysis is a validation technique that is applied often. The technique is especially suitable if there is no or only scarce data available (Fossett & Harrison, 1991). This type of study tries to analyse how the outcome of a model apportioned to sources of uncertainty in its inputs. Sensitivity analysis can support validation of a model. Parameters can be varied to see if outcomes of the model agree with experts prior knowledge. Furthermore, sensitivity analysis can give an indication in the importance of factors/parameters (Kleijen, 1999).

There are different forms of sensitivity analysis. The simplest type is the one-way sensitivity analysis. This analysis changes one variable or parameter at the time to see what the impact is on the outcome of the model. This is called ‘main effect’ in ANOVA, Analysis of Variance (Kleijen, 1999)(M. Taylor, 2009). A more complex type of sensitive analysis is the multi-way sensitivity analysis. It might be important to examine the relationship of two or more parameters at the same time (M. Taylor, 2009).

**Guidelines for selecting and using simulation model verification techniques**
Withner and Balci developed a guideline that can support in the decision what model verification techniques should be applied and gives an overview on what techniques are available in the
simulation community. Their research is mainly focused on software developing and verification and they claim that there is a lack of sufficient understanding and realization of the importance of simulation model verification (Whitner, Balci). Although not all techniques can be applied in the validation process of the LMS, since it is specifically focused on software development, some of the techniques could be used and be of benefit in the validation process.

Figure 79 gives an overview of available Programmed Model Verification (PMV) techniques. The overview categories the verification process in six distinct perspectives starting from a low degree of complexity (informal, left) to a higher complexity (formal, right). Every category has a numerous of verification techniques listed. Another notable fact is that every category has its own characteristics. Human reasoning is captured in the informal category. Static analysis verifies based on characteristics evidence in the code of the programmed model. Dynamic analysis is verifying the execution behaviour of a model. The category of symbolic analysis tries to verify the transformation for model input to model output. Constrains analysis is testing model assumption and formal analysis is the ultimate baseline (Whitner, Balci).

**Figure 79 - Overview of Programmed Model Verification Techniques**

All categories differ in nature and have different characteristics. Table below summarizes the characteristics on level of formality (mathematical complexity), complexity of the associated techniques, cost in terms of human resource and effort, cost with respect to computer resource, effectiveness of the method in general, if the technique is considered instrumentation based and the relatively importance of the technique to PMV. These characteristics can help the modeller with the verification process and provide support in choosing the right techniques.
Mankin established a specific terminology to illustrate model validity, usefulness, reliability and adequacy. The figure below visualizes the terminology. Furthermore, a list of definitions is presented in Table 46. Additionally, four simple definitions are introduced and discussed.

![Venn diagram illustrating the universe P of properties observable on a system](image)

**Explanation of Figure 80:** S is a set whose elements are data from measurements on a system. M is a set of model responses. The intersection of S and M (S ∩ M) is denoted Q. Figure 80 reveals the relations between the definitions P, S, Q and M. Furthermore, the definitions of adequacy and reliability are explained in Table 46 as well.
The first definition that introduced is about validity. The definition (1) describes mathematically if a model is valid or invalid.

A model is valid if and only if $M - Q = X = \emptyset$ (1)

Where $\emptyset$ is the null set and $M - Q = X$ is the relative complement of $S$ defined as:

$$X = \{ xk : k \in K = \Delta \cap NC \} (2)$$

A model is valid if its behaviour corresponds to system behaviour under all conditions of interest. Opposite, a model is considered invalid if an experiment can be devised when the model’s outputs disagree with the system measurements. Differently formulated, if the outcome of a simulation disagrees with the values in the real world.

The second definition is about usefulness. Definition (3) describes mathematically if a model is useful or useless. The four options displayed in Figure 81 can be put in categories in a table i.e. valid, invalid, useful and useless. Figure 81 summarizes the four possible options and corresponding mathematical definitions.

A model is useful if and only if $Q \neq \emptyset$ (3)

![Figure 81 - Possible combinations of the valid-invalid and useful-useless dichotomies in terms of sets X and Q.](image-url)
Model reliability $r$ is defined as $\frac{\mu(Q)}{\mu(M)}$ (4)

Reliability $r$ is given in equation (4). The definition of reliability is defined by fraction of $M$ contained in $S$. This is the fraction of model simulation ($M$) in respect to system behaviour ($S$). The goal is to minimize the probability in making errors. A more reliable model simulates predictions with a higher probability of accuracy.

Model adequacy $\alpha$ is defined as $\frac{\mu(Q)}{\mu(S)}$ (5)

Adequacy $\alpha$ is presented in equation (5) and is defined as the fraction of system behaviour that can be explained by the model. Higher model adequacy results in a larger value of equation 4.

**Building Valid and Credible Simulation Models**

Not only the verification and validation process is important but also the way a model is built in the first place. Having a definitive approach for a simulation study is critical to the success of the study and tells something about the credibility of the model. Refsgaard & Henriksen developed a seven-step approach for conducting a successful simulation study that can be used as guidance (Law, 2004). This seven-step approach is shown in Figure 82.

The seven-step approach is a framework that provides guidance in building credible and valid simulation models. The approach consists out of seven steps. These steps are:

1. Formulate the problem
2. Collect information/data and construct assumptions document
3. Is the assumptions document valid?
4. Program the model
5. Is the programmed model valid
6. Design, conduct and analyse experiments
7. Documents and present the simulation results

This approach uses iterative loops to ensure the steps from the framework are applied properly. If this is not the case a step back is made to ensure inputs in the subsequent phase. These iterative loops are important to ensure the validity and credibility of the simulation model.

Again, not all verification techniques can be applied in the validation process. This overview provides more background knowledge on the available verification techniques.

**Figure 82 - A seven-step approach for conducting a simulation study**
E. Causal Relation Diagram

Figure 83 - Causal relation diagram LMS
This paragraph describes the Causal Relation Diagram in detail. Systematically the entire diagram is treated and the direction of the relation explained. In principal, this diagram is the conceptual framework or the visualization of the LMS model. All Formulas treated in paragraph 4.4 correspond with the CRD. Before diving deeper into relations between variables the colours and legend in general needs to be explained first.

Legend

Data
This squired box represents information from the LMS model database. This data is either data collected through conducting field research by Maatwerk Distributie, collected by Panteia, which is an independent research company that has many traffic data, or data that is distracted from expertise and logic thinking.

Criteria
This variable represents the criteria or the outcome of the LMS model. A scan or last mile trip provides results on total time; distance and cost. It also gives an indication of the percentage of saving money by using an alternative shipping method.

System variable
System variables are used to conduct calculations. Values of these variables are unknown since they are in the middle of the system.

Constant
Constants are variables that provide the system with information. ‘Maatwerk Distributie’ developed these assumptions as mentioned in section on data.

Tool
This variable represents a tool that is developed by Google, a so-called Distance Matrix. The tool can calculate distances when coordinates are known. Thereafter, the LMS model uses these distances as input for calculations.

Input LMS
This type of variable is an important one since this is the individual information needed from distributors active in urban areas on their last mile trip.

Detailed description

TotalTime
Criteria total time has a positive relation with variables unloading time of stop, number of stops and the driving time. Unloading time has a positive relation with input variables number of small and large packages and constants general time, time for a large package and time for a small package. Driving time has a positive relation with constant velocity of areas and system variables distances of areas.

TotalDistance
Criteria total distance has a positive relation with system variables distances between areas, routeln, routeOut and distance stops. System variable distance for all stops has a positive relation with system variables distance stops outside area and distance stops area.

TotalCost
Criteria total cost is positively related with criteria distance and time, but also with type of vehicle and constants cost per km and cost per hour.

P of saving
Criteria percentage of saving is negatively related to cost and negatively related with constants tariff of small and large packages and number of small and large packages.
F. Interviews

In this section, an interview with council member of the municipality of Delft of employment, sustainable development and urban management is elaborated. All other interviews with are recorded and can be consulted if needed. Interviews are conducted with Dhr. W. Ploos van Amstel professor at the University of Amsterdam, Dhr. A. van den Engels senior researcher at Panteia and Dhr. K.W. Rademakers head of city logistics in Delft of PostNL.

Dhr. S. Brandligt is a council member of the municipality of Delft of employment, sustainable development and urban management.

Dhr. S. Brandligt = B
G. Schonewille = G

B: Are you going to talk to PostNL?
G: Yes, definitely.

G: It is interesting to talk with you to see the political and policy side of the topic and to know more about what is already happening regarding urban freight distribution in the municipality of Delft. What are instruments that could be used?

G: What is your background?
B: TU Delft, aerospace engineering. Finished his study in ‘92. Started being active in political atmospheres during his study, being part of the board of VSSD. Later he was active in the town council as a counsellor of ‘Groenlinks’ starting from 2006. First started as a committee member, later in 2008 and 2010 as a counsellor. In 2012, he became alderman of sustainable development. He quit his ICT job in 2012 as well.

About MD, he hoped they were driving with electric vehicles already last year. Unfortunately, this did not happen and these kinds of projects always take more time than expected. The new coalition agreement included city distribution, which is appointed and supported. This means that it really should be realized.

G: For Delft?
B: This is specific for Delft indeed. One of the topics in the agreement is city distribution. As a municipality, the objective is to work on this and realize a sustainable city distribution system. We could do everything expect giving money (subsidizing). Instruments of the municipality of Delft are for example regulations. The main question for us is: where can we regulate and how? This is something that needs to be further researched. Regulation can also be organized from stakeholders involved in urban freight distribution.

G: Who are these stakeholders/entrepreneurs?
B: These stakeholders are especially entrepreneurs active in the city centre. The end user (stores and other companies settled in the centre) who receive the shipments. They actually start the chain of transportation activities. The residents, who place an order through e-commerce, are not included and are a different transportation stream that is not the focus point for the municipality.

G: This rather new stream of transportation is relatively efficient since distributors who can consolidate streams well execute it. They operate in rather big trucks though.
B: This is precise one of the things. The first area I would like to apply this is in the low traffic areas in Delft. These large vehicles damage the streets and should be banned from these areas. The paving needs to be replaced too often. There are more reasons why these large vehicles should be banned. For example, large vehicles exhaust relatively more emissions and drive on conventional fuels, in any case not electric. In addition, these vehicles are relatively more dangerous for pedestrians. The safety issue is important. Another reason is the touristic attractiveness of the historic centre of Delft is lower. Operational vehicles should be small, light, clean, quiet and manoeuvrable vehicles; this should
be applied in the city centre anyway. The focus area is the low traffic area in the city centre inside the polls.

The line of reasoning is that vehicles that operate conform certain standards can be active in this focus area. If the vehicles are there anyway, larger areas are covered by these small, light, clean, quiet and manoeuvrable vehicles.

Therefore, the approach is not only environmental in sense of lowering the amount of emission and CO2 and noise hindrance, but also touristic attractiveness, damaging the paving. What I am investigating now is about the poles system. This system is operational for one more year and after that, a new system is implemented. The new system uses licence plate recognition. We have to see if this new system can be used as an enforcement tool to ensure regulation.

G: How does the system work? Everyone can drive in?
B: Everyone can drive in physically, but you need to have a permit to enter, if not you receive a penalty. Another thing that can be connected to the new licence plate recognition system is the environmental zone, again another thing. The environmental zone is not in the city centre. This area is constructed there to increase the air quality so it complies with legal requirements.

A problem is that not everyone is acting according to the rules. License plate recognition could help here instead of organizing expensive enforcement. The system directly knows what kind of engine is in the vehicle and if the vehicle is allowed to drive in the environmental zone.

Now I have given three examples of how the system could be used, namely am I allowed to drive in the city centre, city distribution and enforcement of environmental zone. It would be good to organize this all from the same system. If it would work is not yet known, it would be ideal if these functions could be combined.

G: How is the enforcement organized now?
B: Twice a year we have a 100% check where all vehicles are inspected.

G: Let us stay with the topic of policy instruments. Are there instruments now by the municipality of Delft? Time windows or other instruments?
B: No, the municipality of Delft, as one of the few that have not implemented time windows. The only time that distribution is not allowed is after 23:00 on Saturday night, because of the busy streets. This again could be a function of the licence plate recognition system since implementation of time windows would be much easier to enforce.

G: Regulations is also possible on the base of maximum emission or vehicle weight etc.? Are these interesting research areas?
B: I am open to any solution. A concession model could be an option as well. This can be arranged by organizing a tender where parties could enrol for participation. Maybe one or two parties win the rights to exploit. This is also a possible solution. I am not saying this model is the solution here, but it could also be an option. An ideal solution would be one that has a minimum amount of regulations and is easy to enforce. I do not know what solution is the best; maybe experience from other regions could help.

G: What are the problems regarding city distribution in Delft?
B: Where I would find a solution for is to maintain the liveability in Delft. This has to do with emissions, noise hindrance, damaging of pavement. Delft needs to be an attractive touristic product. These are disturbing elements and needs to be removed or minimalized.

G: And congestion problems?
B: Definitely, supply of AH at the Brabantse Turfmarkt with a large truck is a problem on Saturday afternoon.

G: Night supply, is that an option?
B: At night is nuisance for residents plus the night market is constructed from 05:00 at night. Night activities result in many complaints. Night supply would work outside the city centre but not in the busy small historic centre.

G: Do large trucks cause many accidents?
B: No, have not heard about this recently.

G: City distribution is a topic that is important in Delft. Should this problem be tackled from different levels? For example: regional and/or national instead of local only?
B: Of course, if you put time and effort in it at multiple levels chances of having success increases. For example, a freight carrier from the region of Haaglanden doing a shipping in Rijswijk, Delft and The Hague. It would be easier to use one distribution centre where all shipments take place from or shipments take place from here to other distribution centres. Rules and regulations is also easier implementable and enforced if there is one way of working for all municipalities and region in a certain area for both municipalities as well as freight carriers.

G: I can imagine that if locally in a municipality, a lot of attention is paid on city distribution and in a different region, other rules and standards apply it would be difficult for a freight carrier to comply with all local regions.
B: This is true and that is why regulations apply at city centres where it is needed. All freight carriers could ship their products to the nearest distribution centres where no regulations are active.

G: So increasing the threshold in city centres, which makes it more difficult for freight carriers to operate since they need to comply with strict requirements, positively influences the attractiveness of distribution centres outside the city centre?
B: Yes, that is the idea of regulation, unless you can comply with these requirements yourself of course. For example, the requirement in Delft can be it needs to be shipped with an electrical vehicle. Then there is only one solution for freight carriers, which is transshipment at the border of the city.

G: Is city distribution on the agenda of ministers or at the central ministry?
B: No, they find this is an issue and competence of local governments. National organizations such as TLN and EVO have a negative position towards city distribution and regulations of any sort. You get into a fight with them when implementing regulations on local level.

G: Is there communication between municipalities?
B: MD is known in different municipalities and civil service levels.

G: So MD is a tool to increase communication between municipalities and different parties?
B: Yes, different concepts are known. If city distribution is on the agenda aldermen looks around what happens in other cities. Most of these concepts are subsidized and paid by government money and this might be the problem. It should be more organized from private stakeholders involved.

G: Do you communicate with different stakeholders involved, namely the stores and companies that receive the deliveries. Do you also talk to freight carriers?
B: Not yet, if regulations increase they come and find me. They have a different interest, mainly economic. Some of them have a vehicle fleet that still needs to be depreciated over time. Regulation of any kind could be a problem for them because they cannot utilize the vehicle fleet.

G: Regulations, how can this be organized? Can freight carriers do something as well?
B: Information derived from MD and PostNL is used and advice from these parties can result in implementation of different policy measures. I do not invent these regulations myself.

G: So creating a level-playing field were certain requirements are demanded so many vehicles are excluded from the city centre. A niche market filled by city distributors that comply with these requirements?
B: Yes, this should be organized naturally. This could be a working mechanism. Staalweg is a location used by PostNL that is ideal, next to the highway. There are enough locations. When the tender was
started, many large distributors with interest joined the process. The winner of the tender would receive the list generated by MD of companies active in Delft that would be interested in talking and work with a central distributor. There are enough locations that could be used as a distribution centre.

G: Why did PostNL win?
B: They scored extra points on corporate social responsibility.

G: Where there specific demands of type of vehicles?
B: Yes, about weight and electric vehicles.

G: There is not a lot of communication between retailers and freight carriers. How can these stakeholders communicate better?
B: It is always the question what a government needs to do in issues like these. Creating a situation where this naturally happens is a way to do this. This is possible when a municipality is issuing a tender to create a partnership. That way the logistic chain can be interconnected further (in and outflows). It is always the question what a government is allowed to do.

You can also work with social return of investment. The company that wins the tender need to provide a societal addition for example creating internship possibilities, education or hiring certain types of people.

An exact social return of investment is not given. Companies can bring ideas themselves and try to help out. For example, working together with a sustainable distributor when organizing shipments is also a possibility of social return of investment. Stimulating instead of compelling is the way to achieve this kind of social return. Integration on all different levels is key in this.

G: Do you think the LMS can be helpful in stimulating cooperation among stakeholders?
B: Yes, this definitely could be. No cooperation makes it more difficult.

G: How could this be stimulated?
B: The retailers could organize a group together with a certain amount of retailers so the minimum amount of freight flow is reached and freight carriers can operate more efficient.

G: MD shows how freight carriers perform in economic terms (cost output). An addition of the model could be environmental aspects. How do you think about this?
B: Yes, this would be good. That is why social cost and benefit analysis are developed. Even large distributors with large vehicles can initiate smaller and cleaner vehicles.

G: So the awareness could be increased among stakeholders?
B: Absolutely. The trend is going towards sustainable development. So also, the large distributors should think about their image and integrate sustainability in their activities.

G: Last question. How can the application be improved?
B: I am not very experienced with application. It should be as simple and accessible as possible. Maybe an incentive to win something could be included. Even when participating with the LMS.