D2.1 Report: Analysis of construction logistics calculation models and factors that obstruct their development.
<table>
<thead>
<tr>
<th><strong>General information</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Deliverable nr. and title</td>
<td>D. 2.1. Analysis construction logistics calculation models and factors that obstruct their development.</td>
</tr>
<tr>
<td>WP nr. and title</td>
<td>WP 2. Dynamic logistics optimization and scenario evaluation.</td>
</tr>
<tr>
<td>Author(s)</td>
<td>Michael Berden, MSc.</td>
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<tr>
<td>Organisation author</td>
<td>Amsterdam University of Applied Sciences (AUAS).</td>
</tr>
<tr>
<td>Reviewer</td>
<td>Dr. Walther Ploos van Amstel (AUAS), dr. Anna Fredriksson (LiU), dr. Pamela Nolz (AIT), dr. Tom van Lier and Philippe de Radiguès, MSc (VUB).</td>
</tr>
<tr>
<td>Organisation reviewer</td>
<td>AUAS, LiU, AIT, VUB.</td>
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<td>Access</td>
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<tr>
<td>Version</td>
<td>Version 3.</td>
</tr>
</tbody>
</table>

*Table 1: General information.*
Summary
This deliverable focuses on the construction industry of the Netherlands. Construction supply and return logistics have negative impacts on societal, ecological and economical aspects in urban areas. The population that lives in cities is expanding across the world and this also counts for the Netherlands. With an increase in their population, new facilities such as houses, offices, stores and infrastructure are needed.

The construction industry has a reputation for being inefficient. Innovation in construction logistics is needed to ensure that cities stay liveable. To create innovation in construction logistics, collaboration between stakeholders is necessary. However, the lack of reliable quantitative data are a problem. Reliable quantitative data are necessary to convince stakeholders for new collaborations that are needed for innovations in construction logistics. There is, therefore, a need to examine the current state of construction logistics calculation models. The integrated logistics concept (ILC) is used to examine construction logistics processes and to address factors that obstruct the development of construction logistics calculation models. Activity Based Costing (ABC method) is used to analyse the construction logistics calculation models. The results of this deliverable are reflected on the results of the SMARTSET project. The components of the ILC and ABC method are presented in the table below.

<table>
<thead>
<tr>
<th>ABC method</th>
<th>ILC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Processes.</td>
<td>1. The corporate strategy.</td>
</tr>
<tr>
<td>2. Activities.</td>
<td>2. The supply chain strategy.</td>
</tr>
<tr>
<td>4. Resources.</td>
<td>4. Personal organisation.</td>
</tr>
<tr>
<td>5. Resource drivers.</td>
<td>5. Delivery patterns.</td>
</tr>
</tbody>
</table>

Table 2. Components ABC and ILC.

This deliverable is based on 11 interviews. Interviews were conducted at larger construction companies, research institutes and municipalities. An analysis is executed regarding five construction logistics calculation models that were developed in the period 2007 – 2016.

It is observed that there is growing awareness for innovation in construction logistics. This is observed in the public sector and in the private construction sector. To map the impact of construction development on mobility became an important subject in XXX in 2007. At that time, there were limited data available. Not in literature and not in practice. It is also observed that in the past it was assumed that the % FTL was higher than is examined at this moment. At that time it was assumed that the % FTL was over 90%. At this moment, it is observed that the % FTL is around 40%. 2016 was the year when impacts of construction logistics solutions were measured for the first time. Here it is observed that the process of transportation is relatively easy to measure when it is compared to the processes warehousing and processing. The following statements can be made.

<table>
<thead>
<tr>
<th>Subject ABC</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>KPIs.</td>
<td>It is observed that models that predict construction logistics flows, or impacts of construction logistics measures, that are experimental frequently use the same KPIs. A model that focuses on measuring impacts of construction logistics solutions uses an elaborate set of specific KPIs. It is observed that mapping a wide set of KPIs is very difficult. The focus, therefore, needs to be on a small set of specific KPIs.</td>
</tr>
<tr>
<td>Structure.</td>
<td>It is observed that models that have a comparable purpose use a comparable structure.</td>
</tr>
<tr>
<td>Data input.</td>
<td>It is observed that the development of a reliable construction logistics calculation model requires much and specific data. Authors of the models were frequently surprised by the amount of necessary data that are needed to generate simple outputs.</td>
</tr>
</tbody>
</table>
Until 2016, construction logistics calculation models were based on data from literature or from expertise. This means that their outcomes can deviate from reality. This must not be seen as a downfall. All models are very useful for their purposes. It is observed that subcontractors were, frequently, not aware of data regarding their logistics processes. The first model, were impacts of construction logistics solutions were measured, is developed in 2016.

The progress of the development of a construction logistics calculation model is dependent on its purpose. Models that predict the impact of construction development on mobility are relatively easy to develop. Here it was difficult to find reliable data/norms to use in formulas. Subcontractors simply did not know about their logistics processes. Models that measure the impacts of construction logistics solutions are hard to formulate. ERP and TMS are an essential.

The following statements can be made regarding the analysis of the construction processes on the components of the ILC. The most important observations that obstruct the development of reliable construction logistics calculation models are presented below.

<table>
<thead>
<tr>
<th>Subject ILC</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corporate strategy.</td>
<td>• There were no factors observed that hinder the development of construction logistics calculation models.</td>
</tr>
<tr>
<td>Personal organisation.</td>
<td>• It is observed that there is no universal organisational structure available within larger construction companies for construction logistics. It is also observed that construction logistics is a new phenomenon, which indicates that new work processes need to be obtained. This can obstruct the progress of collecting reliable data from construction partners.</td>
</tr>
<tr>
<td>Supply chain strategy.</td>
<td>• It is observed that horizontal, vertical and longitudinal fragmentation hinders the development of reliable construction logistics calculation models. Difficulties regarding coordination of information between construction partners form a barrier. • It is observed that subcontractors and suppliers frequently offer all-in prices for their services. Cost prices are needed to formulate calculations regarding innovative logistics measures. This can be seen as an important barrier.</td>
</tr>
<tr>
<td>BIM.</td>
<td>• IT is far from integrated in the construction industry. This can be seen as a barrier.</td>
</tr>
<tr>
<td>Delivery patterns.</td>
<td>• It is observed that materials and construction phases each have different characteristics. These characteristics result into different necessities regarding data. Unique data per type of materials or process are necessary.</td>
</tr>
</tbody>
</table>

The barriers of the SMARTSET project, which focuses on the innovation regarding Urban Freight Terminals, are reflected on the results of this deliverable. The reflection is presented in the table below.

<table>
<thead>
<tr>
<th>Barriers</th>
<th>Observed</th>
<th>Barriers</th>
<th>Observed</th>
<th>Barriers</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Political support.</td>
<td>This does not form a barrier.</td>
<td>Identification of value.</td>
<td>This does not form a barrier.</td>
<td>Vehicles.</td>
<td>No information is obtained.</td>
</tr>
<tr>
<td>Personnel and competence.</td>
<td>This forms a barrier.</td>
<td>Invisible transport costs.</td>
<td>This forms a barrier.</td>
<td>Location of terminal.</td>
<td>This does not form a barrier.</td>
</tr>
<tr>
<td>Network.</td>
<td>This forms a barrier.</td>
<td>Sharing information.</td>
<td>This forms a barrier.</td>
<td>Enforcement regulations.</td>
<td>No information obtained.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Critical mass.</td>
<td>This forms a barrier.</td>
</tr>
</tbody>
</table>

Table 3: Observations.

Table 4: Observations.

Table 5: Reflection barriers SMARTSET.
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# List of Abbreviations

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<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>3PL</td>
<td>Third Party Logistics</td>
</tr>
<tr>
<td>ABC</td>
<td>Activity Based Costing</td>
</tr>
<tr>
<td>BIM</td>
<td>Building Information Modelling</td>
</tr>
<tr>
<td>CCC</td>
<td>Construction Consolidation Centre</td>
</tr>
<tr>
<td>CSR</td>
<td>Corporate Social Responsibility</td>
</tr>
<tr>
<td>EMVI</td>
<td><em>Economisch Meest Voordelige Inschrijving</em></td>
</tr>
<tr>
<td>ERS</td>
<td>Enterprise Resource System</td>
</tr>
<tr>
<td>FTL</td>
<td>Full Truck Load</td>
</tr>
<tr>
<td>GWW</td>
<td><em>Grond, Weg- en Waterbouw</em></td>
</tr>
<tr>
<td>IFC</td>
<td>Industry Foundation Classes</td>
</tr>
<tr>
<td>ILS</td>
<td><em>Informatieleveringsspecificatie</em></td>
</tr>
<tr>
<td>IT</td>
<td>Information Technology</td>
</tr>
<tr>
<td>ILC</td>
<td>Integral Logistic Concept</td>
</tr>
<tr>
<td>KPI</td>
<td>Key Performance Indicators</td>
</tr>
<tr>
<td>MEAT</td>
<td>Most Economically Advantageous Tender</td>
</tr>
<tr>
<td>PAE</td>
<td><em>PersonenAuto Equivalent</em></td>
</tr>
<tr>
<td>SCM</td>
<td>Supply Chain Management</td>
</tr>
<tr>
<td>TMS</td>
<td>Transport Management System</td>
</tr>
<tr>
<td>UFT</td>
<td>Urban Freight Terminal</td>
</tr>
<tr>
<td>WMS</td>
<td>Warehouse Management System</td>
</tr>
</tbody>
</table>
1. Project framework

The framework of the deliverable is presented in chapter 1. This chapter starts with a brief introduction that presents recent developments regarding the subject. The aim and product of the deliverable are written in paragraph 1.2. The research questions are written in paragraph 1.3 and in paragraph 1.4 the reading guide is formulated.

1.1 Introduction

Construction supply and return logistics have negative impacts on societal, ecological and economical aspects in urban areas (Lundesjö, 2015). A lack of a proper planning of these construction logistics flows results into inefficient flows, which lead to unsafe and unhealthy environments. Inefficient flows also lead to congestion, which lead to financial losses for businesses (Huang and Hinze, 2003).

The population that lives in cities is expanding across the world and this also counts for the Netherlands. The Randstad is the densest area in the Netherlands and it is estimated that the Randstad will be even denser in the upcoming decennia. It is estimated that the population of Utrecht will grow with 21 percent, Amsterdam with 18 percent, The Hague with 13 percent and Rotterdam with 10 percent (Kooiman, De Jong, Huisman, Van Duin, Stoeldraijer, 2016). These cities are striving to locate their construction projects within the existing urban areas (Municipality of Utrecht, 2004; Municipality of Amsterdam, 2011; Municipality of The Hague, 2005; Municipality of Rotterdam, 2007).

With an increase in their population, new facilities such as houses, offices, stores and infrastructure are needed. There is also a strong need to upgrade or redevelop existing facilities in urban areas. Currently, there are 1,000 construction projects that are being executed in Amsterdam. All these projects have their own construction logistic flows. As an example, the redevelopment of Utrecht Central Station resulted in a construction logistic flow of 250 trucks per day (XXX, 2016). It can, therefore, be stated that construction has a substantial impact on daily activities of residents and businesses in cities. This leads to an increase in construction supply logistics such as material, equipment and workers and construction reserve logistics such as waste (Anand, Haji, Gouderjaan and Ploos van Amstel, 2016).

The construction industry has a reputation for being inefficient (Josephson and Saukkoriipi, 2007). Innovation in construction logistics is needed to ensure that cities stay liveable (Anand et al, 2016). A construction consolidation centre (CCO) is frequently proposed as a suitable logistics innovation. To create innovation in construction logistic, collaboration between stakeholders is necessary (Brown, 2015). Due to different interest among construction stakeholders, there is a need for reliable business models (Vries and Ludema, 2012). However, according to Noordhuis (2016), a lack of reliable quantitative data is a problem. Reliable quantitative data is necessary to convince stakeholders for new collaborations that are needed for innovations in construction logistics. IT devices hold huge potentials for the construction industry, which includes construction supply and return logistics (Lundesjö, 2016). There is, therefore, a need to examine the current state regarding IT usage in and reliability of construction logistics calculation models.

The Integrated Logistic Concept (ILC) is frequently used in the logistics sector in the Netherlands, to determine the layout of logistics functions in an organisation (Van Goor, Ploos van Amstel and Ploos van Amstel, 2014). The focus needs to be on system-wide management of the entire logistics chain as a single entity, instead of separate management of individual
logistical functions. The ILC is used to examine construction logistics processes. The subjects corporate strategy, personal organisation, supply chain strategy, Building Information Modelling and delivery patterns will be examined to address factors that hinder the development/improvement of construction logistics calculation models.

1.2 Aim task 2.1 and product

This deliverable has two aims. Firstly, the deliverable gives insight into the current state of construction logistics calculation models in the Netherlands. How these models are structured, with which indicators and with which data will be examined. Secondly, this deliverable gives insight into factors that hinder the development of these construction logistics calculation models. The product of this deliverable is a report on problem description and data analysis.

1.3 Research questions

The following questions have been determined to give insight into the process of formulating a construction logistics calculation model. S. Balm (AUAS), W. Haji (AUAS) and W. Ploos van Amstel (AUAS) and Anna Fredriksson (LiU) agreed upon these questions.

1. Which indicators have been used in currently used construction logistics calculation models?
2. How are construction logistics calculation models structured?
3. Which input is necessary to develop a construction logistics calculation model?
4. Are data measured, expertise or from literature in currently used construction logistics calculation models?
5. Which difficulties did the author of these construction logistics calculation models experience?
6. Which factors of the ILC hinder the development of construction logistics calculation models?

1.4 Reading guide

The deliverable is structured into five parts. The first part consists of the methods that have been used to formulate this deliverable. The second part consists of a literature study in which the need for innovation in construction logistics is addressed. Also, the usability of the ILC for the construction industry is explained. Literature regarding construction logistics processes are structured among the components of the ILC and problems are identified. The literature study functions as an analytical framework. The third part consists of an analysis regarding currently used construction logistics calculations models. The focus is on their reliability. The fourth part consists of an analysis regarding factors that obstruct the development of construction logistics calculation models. These factors are structured among the components of the ILC. The fifth part consists of the answers to the research questions that are presented in paragraph 1.3. The results of this deliverable are reflected on the results of the SMARTSET project.
2. Methods

The research methodology is described in this chapter. The research strategies are described in paragraph 2.1. The methods of data collection are described in paragraph 2.2 and in paragraph 2.3 the methods of data analysing are described.

2.1 Research strategies

To formulate this deliverable, several research strategies have been selected. A desk research and case studies are selected as a research strategy. These strategies are explained below.

2.1.1 Desk research

A desk research is a non-empirical research strategy where the researcher uses material that is produced by others. In many cases, the documents that are used in this strategy are written from another perspective. Therefore the information is not directly usable for the purpose of this deliverable, but can give information for a context. The goal of the desk research is to formulate a theoretical foundation for the deliverable (Saunders et al, 2009).

2.1.2 Case study

A case study is an empirical research strategy. This means that data will partly be obtained by own observations (Saunders et al, 2009). By using this strategy, the holistic characteristics of causes and effects will be described in a selected area. The case study is selected for the results regarding the construction logistics calculation models (paragraph 4.2). The construction logistic calculation models function as a case study and are presented in the table below.

<table>
<thead>
<tr>
<th>Code</th>
<th>Name of the case study</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1.</td>
<td></td>
<td>2007.</td>
</tr>
<tr>
<td>Model 4.</td>
<td></td>
<td>2012.</td>
</tr>
<tr>
<td>Model 5.</td>
<td></td>
<td>2016.</td>
</tr>
</tbody>
</table>

Table 6: Case studies (Author, 2017). CLASSIFIED

2.2 Methods for data collection

2.2.1 Literature study

In the desk research, a literature study is used to collect data for an analytical framework. Dr. Ploos van Amstel (AUAS) indicated subjects that could hinder the development of construction logistics calculation models and these subjects were reviewed in the literature. Because these subjects could be related to the ILC, this concept is used to structure the literature study. The literature study functions as an analytical framework. The analytical framework links the theoretical questions to the empirical analysis. There are different methods available. A quantitative method refers to a method where many documents are being used to collect data. A qualitative method refers to a method where little documents are being used to collect data (Doorewaard and Verschuren, 2010). In chapter 3, the focus is on peer-reviewed literature by using a qualitative method.
2.2.2 Interviews

Interviews are conducted to provide the deliverable with empirical data. The interviews improve the reliability of the deliverable because data of the literature study will be reviewed. By creating a dialogue, data can be corrected and specific data can be obtained. By conducting semi-structured interviews, topics are mentioned, but sufficient space is given to deviate from the topic (Doorewaard and Verschuren, 2010). The interviews are recorded and transcribed. The interview guides are included in Appendix 1. The interview guides for interviews 1 – 5 are structured on construction logistics processes, activities, and resources (ABC method). The interview guides for interviews 6 – 8 have an explorative function and do not have a specific structure. The interview guides for interviews 9 – 11 are developed by Chalmers for deliverable 3.1. The respondents are presented in the table below.

<table>
<thead>
<tr>
<th>Code</th>
<th>Purpose</th>
<th>Name</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respondent 1.</td>
<td></td>
<td></td>
<td>39.45 min.</td>
</tr>
<tr>
<td>Respondent 2.</td>
<td></td>
<td></td>
<td>19.11 min.</td>
</tr>
<tr>
<td>Respondent 3.</td>
<td></td>
<td></td>
<td>25.36 min.</td>
</tr>
<tr>
<td>Respondent 4.</td>
<td></td>
<td></td>
<td>63.11 min.</td>
</tr>
<tr>
<td>Respondent 5.</td>
<td></td>
<td></td>
<td>64.58 min.</td>
</tr>
<tr>
<td>Respondent 6.</td>
<td></td>
<td></td>
<td>61.09 min.</td>
</tr>
<tr>
<td>Respondent 7.</td>
<td></td>
<td></td>
<td>64.55 min.</td>
</tr>
<tr>
<td>Respondent 8.</td>
<td></td>
<td></td>
<td>43.47 min.</td>
</tr>
<tr>
<td>Respondent 9.</td>
<td></td>
<td></td>
<td>37.28 min.</td>
</tr>
<tr>
<td>Respondent 10.</td>
<td></td>
<td></td>
<td>60.36 min.</td>
</tr>
<tr>
<td>Respondent 11.</td>
<td></td>
<td></td>
<td>64.24 min.</td>
</tr>
</tbody>
</table>

Table 7: Interview respondents (Author, 2017).

2.3 Methods for data analysis

To structure the data regarding the construction logistics calculation models, components of the Activity-Based Costing method (ABC method) are used. The ABC method recognises the causal or direct relationship between activities, cost objects, resources and resource drivers and can, therefore, help to determine the current state of construction logistics calculation models. The results are presented in paragraph 4.1. The components of the ILC are used to provide insight into construction logistic processes. The components of the ILC are the corporate strategy, personal organisation, supply chain strategy, Building Information Technology and delivery patterns. The ILC enables us to address factors that hinder the development of reliable construction logistics calculation models. The results are presented in paragraph 4.2. The 10 barriers that were identified by the SMARTSET project are explored in this deliverable by using the following codes.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>2.</td>
<td>3.</td>
<td>4.</td>
<td>5.</td>
<td>6.</td>
</tr>
<tr>
<td>Vehicles.</td>
<td>Location of terminal.</td>
<td>Enforcement regulations.</td>
<td>Critical mass.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. Analytical framework

In this chapter, a literature study is conducted to formulate an analytical framework. This analytical framework is used to collect and structure the results from the interviews and the construction logistics calculation models. A brief literature study regarding the impact of air-polluting emissions on liveability is written in paragraph 3.1. The components of the ILC are described in paragraph 3.2. These components are used in paragraph 3.3 to describe construction logistic processes. In paragraph 3.4 the current state of innovation in construction logistics and the results of the SMARTSET project are described.

3.1 Liveability and emissions

**Liveability**

Innovation in urban construction logistics is necessary to ensure that growing cities stay liveable. Liveability includes aspects such as the built and natural environments, economic prosperity, social stability and equity, educational opportunity, culture, entertainment and recreation. Construction logistics processes influence many aspects of liveability (Ploos van Amstel, 2015). For an example, emissions that are caused by construction trucks minimize air quality and therefore have a negative influence on health. Inefficient construction logistic flows lead to unnecessary unsafe situations and congestions, which lead to financial losses for businesses.

Liveability can be defined as the extent to which the environment is in line with the demands and requirements that are imposed by humans (Leidelmeijer, Marlet, Ponds, Schulenberg, Van Woerkens and Ham, 2014). Liveability is a concept that is often used in multi actors and multi criteria decision-making, but lacks in a generally agreed upon definition. The aspects of liveability, which are influenced by construction logistics processes, therefore need to be operationalized.

The aspects that are mentioned in a BLVC-framework can operationalize liveability. BLVC is the Dutch abbreviation for accessibility, liveability, safety and communication. It is obligated for the municipality of Amsterdam to make a BLVC-framework. The obligation is dependent of the hinder that is produced by a construction project on the vicinity (SOVB, n.d) and consists of requirements that need to be taken into account by the main contractor. Requirements in this plan are included in the tender. A BLVC-framework consists of the following aspects.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessibility</td>
<td>Car, public transfer, pedestrians, parking, stalling, construction logistics, supply.</td>
</tr>
<tr>
<td>Liveability</td>
<td>Construction fences, design construction site, working times, noise minimizations.</td>
</tr>
<tr>
<td>Safety</td>
<td>Construction safety, social safety, traffic safety.</td>
</tr>
<tr>
<td>Communication</td>
<td>Stakeholders in vicinity, commuters, public events.</td>
</tr>
</tbody>
</table>

Table 8: Constructs in BLVC plan (IBA, n.d).

As presented in the table above, constructs are used that can be interpreted in different ways. It is therefore needed to be as explicit as possible in a BLVC-framework. When municipalities fail to conduct a qualitative BLVC-framework, requirements will be incorrectly integrated into tenders. The main contractor will ultimately conduct a poorer BLVC-plan.

**Air-polluting emissions**

Air quality is a topic that is getting more and more attention. The European Environment Agency (2016) indicates that air quality in the Netherlands is low, compared to other European countries.
Low air quality leads to more than 100,000 premature deaths in Europa and has therefore a big impact of liveability in cities. Traffic emissions are a major cause for low air quality. It is importation to examine the relations between construction logistics, air-polluting emissions and urban characteristics.

Air-polluting emissions of vehicles are influenced by technical, operational and logistical parameters and these parameters are affected by direct and indirect factors (Pregl, Perujo and Bonnel, 2008). It is important, when construction logistic calculations models are formalized, to measure the air-polluting emissions under real world conditions. Realistic results regarding air-polluting emissions can then be provided. Calculations that are based on the number of kilometres multiplied by an emissions norm are incorrect.

The research shows that different vehicles with different technical characteristics in real traffic produce different air-polluting emissions than presented in theory (Pregl et al, 2008). For an example, it is indicated that time and distance cannot be treated as a constant value. The following factors have an effect on the air-polluting emissions that are produced.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical factors.</td>
<td>Engine type.</td>
</tr>
<tr>
<td></td>
<td>Loading capacity.</td>
</tr>
<tr>
<td></td>
<td>Weight of the vehicle.</td>
</tr>
<tr>
<td>Operational factors.</td>
<td>Speed.</td>
</tr>
<tr>
<td></td>
<td>Driving dynamics.</td>
</tr>
<tr>
<td></td>
<td>Transportation dynamics.</td>
</tr>
<tr>
<td></td>
<td>Transport flows density.</td>
</tr>
<tr>
<td></td>
<td>Extreme situations.</td>
</tr>
<tr>
<td>Logistic factors.</td>
<td>Occupancy rate.</td>
</tr>
<tr>
<td></td>
<td>Emissions at loading and uploading.</td>
</tr>
<tr>
<td></td>
<td>Idle running of the engine.</td>
</tr>
</tbody>
</table>

Table 9: Factors on traffic emissions (Pregl et al, 2008, p. 9-10).

The above-mentioned aspects will be explored during the analysis of the construction logistic calculation models (paragraph 4.1). Additional to the above-mentioned aspects, quality of the infrastructure and the geographic position such as altitudes have an impact on emissions. A distinction has to be made between driving time within the urban area and driving time outside the urban area (Gosman and Van Wengerden, 2016).

<table>
<thead>
<tr>
<th>Recommended literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>The paper gives insight into the impact of factors that influence emissions. This paper gives insight into the complexity when real-time calculations for emissions have to be made.</td>
</tr>
</tbody>
</table>

Table 10: Recommended literature.

### 3.2 The Integral Logistic Concept

An integral logistics approach is needed to meet the challenge to keep cities liveable. The focus needs to be on system wide management of the entire logistics chain as a single entity, instead of separate management of individual logistical functions. This prevents that improvements e.g. in the procurement department have disadvantages for other chains e.g. in distribution department.
The ILC is frequently used in the Netherlands to describe logistic processes of a company and is based on four components (Van Goor et al, 2014). The ILC consists of the following components.

<table>
<thead>
<tr>
<th>Personnel organization.</th>
<th>The personal manner in which tasks for planning and control are organized within a company.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply chain strategy.</td>
<td>The primary process of a distribution chain needs to be controlled in a way that an optimum level of service can be realized.</td>
</tr>
<tr>
<td>Building Information Modelling.</td>
<td>Reliable logistics management requires information about customers, suppliers, products, resources and capabilities. This information must come from information technology systems.</td>
</tr>
<tr>
<td>Delivery pattern.</td>
<td>Represents the basic structure of the distribution, from production and distribution to customers. Important subjects are the location of production, warehousing and transportation.</td>
</tr>
</tbody>
</table>

Table 11: Components ILC (Van Goor et al, 2014).

Van Goor et al (2014) state that the four components do not function without a strategy and a description of the Key Performance Indicators (KPI). The four components, plus the strategy and KPIs will be explored in the construction industry.

<table>
<thead>
<tr>
<th>Recommended literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>This book is very useful for everybody that does not have a logistics background.</td>
</tr>
</tbody>
</table>

Table 12: Recommended literature.

### 3.3 ILC in the construction industry

The components of the ILC are described after a brief description of the construction industry in the Netherlands. The components of the ILC are described in the following order.

<table>
<thead>
<tr>
<th>Corporate strategy</th>
<th>Paragraph 3.3.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal organisation</td>
<td>Paragraph 3.3.2</td>
</tr>
<tr>
<td>Supply chain strategy</td>
<td>Paragraph 3.3.3</td>
</tr>
<tr>
<td>Building Information Modelling</td>
<td>Paragraph 3.3.4</td>
</tr>
<tr>
<td>Delivery patterns</td>
<td>Paragraph 3.3.5</td>
</tr>
</tbody>
</table>

Table 13: Paragraphs ILC.

### Context construction development in Amsterdam

Construction logistics is one of the largest logistics flows in Amsterdam and therefore need to be managed properly. Research indicates that 18 percent of trucks and 43 percent of light commercial vans in Amsterdam are related to construction activities (Ploos van Amstel, Balm and Van Merriënboer, 2015). Real estate prices in December 2016 show the largest price increase in 14 years (Cobouw a, 2017). The revenues in the construction industry grew by 9 percent (Cobouw b, 2016) and production grew by 6 percent (Cobouw c, 2016) making it a fast growing sector. Municipalities aim their construction production within existing urban areas. These urban areas are characterized by challenges regarding place, challenges regarding complexity and challenges regarding liveability and sustainability (Lundesjö, 2016).

<table>
<thead>
<tr>
<th>Recommended literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>This book gives a broad understanding of construction logistics</td>
</tr>
</tbody>
</table>
3.3.1 Corporate strategy

The managing board determines a strategy on the level of the entire company and/or on the level of every business unit within this company (Van Goor et al., 2014). To get insight into strategies from construction companies, it is important to describe what a strategy is. Grant (2002) defines a strategy as: “A strategy focuses on how a company is trying to get a favourable position in a market by using resources and organizational structures.” This strategy is important for coherence and direction of decisions and actions (Grant, 2002).

There is a mutual dependency between demanding and providing companies in the market. First, there are construction companies with goals, resources and organizations. Second, there are markets in which these companies have a position towards other construction companies and customers. A strategy is important to achieve goals and maintain or improve competitive positions (Vrolijk, 2010). Grant (2002) indicates two strategies:

- The concern strategy is focused on different markets in which the construction company wants to be operating in. Starting new departments in other parts of the construction chain, or merging with other construction companies can be related to concern strategies.
- The competitive strategy focuses on how construction companies can surpass its competitors and how this construction company can defend its benefit.

A strategy suits best when goals and the distribution of resources across the organization are aligned to the values of the company, system and its environment. Each construction company, therefore, has its own best strategy (Grant, 2002). Supply Chain Excellence is frequently used in the construction industry and provides an example for a strategic innovation. The construction company is no longer focused on its own process, but on process management in the entire construction supply chain.

3.3.2 Personal organisation

The focus of this paragraph is the internal structure of a construction company, which determines relationships between employees and departments. A construction logistic chain consists of different companies, which consist of different departments, which consist of employees. The personal organisation focuses on personal relationships.

### Organizational structures

The size of the construction company determines the organizational structure of the company. When the organizational structure does not fit the size of the company, it will hinder operational processes. Due to the complexity of construction projects, specialisation is a key subject. Departments such as acquisition, design and construction, calculation and procurement are
traditionally organized within a construction company. Here, each department represent a specialism. A project leader manages the coordination between these departments. A downfall of this structure is that each department will become an individual island of knowledge. Other organisational structures are matrix organisation, business units and the co-makership concept (see Huijbregts, 2003). The focus is on the strategic, tactic and operational level.

- A strategic plan focuses on fundamental questions regarding long-term decisions. A strategic plan describes issues such as agreements with supply chain partners and internal organization processes. It focuses on 3 to 5 years.
- A tactical plan gives detail to the strategic plan and focuses on mid-long decisions. Subjects such as allocation of labour, resources and reporting of results are agreed upon here. These decisions focus on 1 to 3 years.
- An operational plan specifies the tactical plan. Here, results and goals are realized. These decisions are focussed on the day, week or month.

<table>
<thead>
<tr>
<th>Table 16: Recommended literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>This PhD thesis focuses on the connections between supply chain planning (SCP), construction planning and individual construction projects. The thesis can be used for planning and measuring construction supply chains. It also develops a construction SCP organisation, based on the Swedish construction context (see page 48 – 54).</td>
</tr>
</tbody>
</table>

Organizational structure Construction team model

There are many ways to organize a construction organization. This paragraph focuses on the organizational structure of a construction team model (bouwteam). A construction team is a project partnership between a client and one or several experts who collaborate in the design, engineering and construction phase. The information gives insight in the personal organisation structure of the main contractor (Reniers, 2008).

The main contractor is involved in the concept design phase. With a standard list, the main contractor requires information that is needed to form a first estimation of the budget. The client evaluates the concept design and the estimation of the budget. Due to this, the project gets specified in a definite design (Reniers, 2008).

After the definite design phase, the project is transferred to a definite design phase +. This means that a contract is formalized. It is also possible that the project is transferred to the project scheme phase. This means that a project scheme is formalized based on the definite design. Hereafter, negotiations take place regarding the price. After this, contracts are formalized and the project goes to the production department (Reniers, 2008).

Internal preparation phase

Many problems that occur in the development phase are caused by errors that have been made in the internal preparation phase. The internal preparation phase starts and the project leader gets involved in preparation meetings. The goal of these meetings is to inform the project leader about the progress in the process and decisions regarding the execution of the project (Reniers, 2008). The project leader is now responsible for the project and is the representative for the external stakeholders (e.g. client, architect, advisors, engineer/constructor and strategic partners). The project manager is now in a minor way available for communication towards the client.
The work preparer receives information from the project manager. Information consists of contracts, project schemes and construction drawings. The work preparer then makes construction site drawings and detailed drawings. These drawings will be sent to subcontractors and suppliers to collect offers for specific parts of the project. Offers will be compared and subcontractors and suppliers will be contracted (Reniers, 2008). The following departments are involved in the internal preparation phase.

- Project manager.
- Project leader.
- Preparation department.
- The calculation department (for direct cost).
- Planning department (for indirect cost and planning).
- Procurement department.

The construction foreman organizes the daily work on the construction site, together with subcontractors and suppliers. The construction foreman manages the operational planning, calls of subcontractors and suppliers and monitors the progress (Poesiat, 2016). The process is presented below.

### Information flows

In this paragraph, insight will be given into the flows of information between construction companies and departments. There are two types of information: **product information** and **management information**. **Product information** focuses on the design or product itself. **Management information** focuses on finance, organisation, time, information and quality. In the preparation phase, product information is collected and distributed between the architect and the project manager. In the internal preparation phase, product information is transformed into management information. All the information is transferred between the project leader, work preparer and foremen. The information flows in the preparation phase are illustrated in figure 4 and information flows in the internal preparation phase are illustrated in figure 3.
3.3.3 Supply chain strategy

The process in a distribution chain needs to be controlled in a way that an optimum level of service can be realized (Van Goor et al., 2014). The supply chain strategy of the construction industry has been a subject of interest for many years. The construction industry tends to be fragmented, unstable and inefficient (Vrijhoef and Ridder, 2014). Fragmentation is seen as a problem in much research. Adriaanse (2014) determines three types of fragmentation.

<table>
<thead>
<tr>
<th>Fragmentation Type</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical fragmentation</td>
<td>A construction project is divided into different construction phases. In practice, a strict separation between these phases is maintained. This is due to a traditional way of working where the client formulates a design and, when the design is ready, construction companies are involved. When the construction project is completed it is transferred to the client. The result is that there is little coordination between the construction phases.</td>
</tr>
<tr>
<td>Horizontal fragmentation</td>
<td>Per construction phase, different construction companies are involved such as an architect, subcontractors and suppliers. Due to this, the fragmentation increases and coordination is hindered. The percentage of tasks that are outsourced can rise to 75% of the financial turnover (Dubois and Gadde, 2000).</td>
</tr>
<tr>
<td>Longitudinal fragmentation</td>
<td>Construction projects are being managed individually at different times and different locations. This project based characteristic makes dissemination of knowledge and experiences from one project to the other difficult (Adriaanse, 2014).</td>
</tr>
</tbody>
</table>

Table 17: Fragmentation (Adriaanse, 2014).

This fragmentation does not lend itself easily to the required collaboration to achieve innovation. Lundesjö (2016) indicates different stages of supply chain maturity and indicates the ultimate goal as being a process where demand, supply and product consideration overlap. Lundesjö (2016) indicates four stages of supply chain maturity.
1. Reacting business silos
Dominated by misaligned goals between business units. Often led by sales or manufacturing with a focus on revenues. Each business unit has different processes and KPIs.

2. Scaling and cost efficiency
Companies look to scale their operations with a focus on cost reduction. Businesses start to emerge within business units. A focus on the lowest cost of delivery emerges with a focus on standardization. Basic demand forecasting and planning capabilities develop. KPIs tend to be functionally focused.

3. Integrated decision-making
Functional barriers start to break down as decisions are being made for the entire internal supply chain. Supply chain considerations become an early input for sales processes. The focus is on the balance between cost, working capital and services. KPIs look across the entire internal supply chain.

4. Supply chain collaboration
The focus switches from within the company to the external supply chain. Revenues become second to value creation. Collaborations with customers and suppliers become more important. Processes are integrated across the extended supply chain and real time visibility and performance data covers the whole chain.

Table 18: Recommended literature.


The purpose of this paper is to analyse how suppliers and transport providers are affected by the 3PL solution. In terms of their attitudes towards the use of a 3PL, the experienced defects from the 3PL solution and their level of supply chain management (SCM) maturity.

These stages of maturity are used in this deliverable to describe the maturity of the supply chain strategy regarding construction logistics. The construction supply chain must be seen as a single entity of different subsystems, which needs to be designed (Vrijhoef and Ridder, 2014). Because the construction industry is fragmented, supply systems are often not well integrated. An implementation of a chain-wide supply system would be too complex and costly. The lack of continuity of relationships hinders the advantages of long-term collaborations.

Noordhuis (2015) describes the traditional construction process in the Netherlands. The client begins the construction process by thinking about the wishes and requirements of the end user. The client will search for a partner, such as an architect or advisors, for the engineering phase. After this, a main contractor is selected. It is the main contractor who selects the sub-contractors and it is frequently the sub-contractors who select the suppliers. It is possible that the selection of suppliers is only known just before the execution of the project (Gosman and Van Wengerden, 2016).
The selection of subcontractors is based on the project scheme (*het bestek*) and construction drawings. The focus is to *precisely* procure the construction materials and services based on fixed information. It is exactly determined what the sub-contractor needs to offer. Due to this, the risks of overpricing are minimalized but this also minimizes the incentives to develop innovations. The perspective of the client or main contractor is that involvement of contractors or subcontractors in an early phase only leads to a higher price (Noordhuis, 2015). In the figure below, construction supply chain issues are illustrated.

Figure 4: Problems in the construction chain (Vrijhoef, 1998).

Additional to figure 1, the financial crisis, which started in 2008 led to labour layoffs at larger construction companies in the Netherlands. Due to the attractiveness of the construction industry, many construction workers nowadays work as a freelancer. This increases fragmentation and makes planning and control difficult.
3.3.4 Building Information Modelling

The concept of Building Information Modelling (BIM) states 30 years back when Charles M. Eastman introduced Building Description Systems to define elements to form data for visualization and quantities (Eastman, Teicholz, Sacks and Liston, 2008). BIM is frequently presented as the solution that provides a data-rich model. Drawings can be uploaded into a database and bill of quantities, the cost and profits and energy certifications can be produced. Different processes, information and technologies can mage essential building requirements and data throughout the life cycle of the project (Whang, Park and Min, 2016).

BIM is a growing phenomenon. In the United States, the number of companies that used BIM raised from 49 percent (2009) to 71 percent (2012). In the Western European countries, this was 36 percent (2010) (Adriaanse, 2014). BIM is related to construction process integration, chain collaboration and lean construction. According to Adriaanse (2014) BIM is used as a container concept and it is, therefore, important to formulate a definition. According to NBIMS (2007), the definition of BIM is:

“A BIM is a digital representation (1) of physical and functional characteristics of a facility. It serves as a shared knowledge resource for information about a facility, forming a reliable basis (3) for decisions during its lifecycle from inception onwards. A basic premise of BIM is a collaboration (2) among different stakeholders at different phases of the lifecycle (3) of a facility to insert, extract, update, or modify information in the BIM, to support and reflect the roles of stakeholder.”

Adriaanse (2014) highlighted three aspects in this definition. BIM companies work with a digital representation of a building. This representation consists out of objects such as floors and windows. These objects also consist of dimensions such as volume, size and sort of materials. From this representation, drawings and quantities can be produced. Collaboration between construction companies can be supported due to the use of BIM. It is also stated that different companies use and add information. Herewith companies can come up with better solutions and activities. During the progress of the process different information is added to the model. A reliable basis is highlighted in the definition. This aspect is frequently missing in practice (Diersen, 2016). This leads to mistrust among stakeholders and a thought that BIM is inefficient.

Collaboration and transparency

The construction industry could see their fortunes change when innovation is realized (Brown, Chui and Manyika, 2011). The opportunity for value creation can only occur when the construction industry develops a greater degree of collaboration and integration regarding structures for information management (Lundesjö, 2016; Adriaanse, 2010). This is necessary because the value of BIM is dependent on the information that is provided.

As mentioned in paragraph 3.3.3, the construction industry is fragmented (Noordhuis, 2015). Construction companies are being pressured to form new business relationships when a new construction project is organized. Every construction project is driven by new contractual challenges, such as the agreement for the exchange of information. Often, the involved companies cannot easily exchange information electronically (Grilo and Jardim Gonçalves, 2009).

Many problems are related to the supply of incomplete and unsuitable information. Collaboration in the construction chain will result in useful information, because companies can give transparency in the information that is needed (Post, 2013). Unfortunately, IT benefits are frequently missing in the construction industry. A cultural change is needed regarding working
methods and skills to achieve the benefits of BIM. It is therefore that professionals talk about a BIM utopia (Miettinen and Paavola, 2014).

**Software context**
The number of software providers hinders software integration in the construction industry. To embrace the possibilities of BIM, interoperability becomes an important subject (Grilo and Jardim Gonçalves, 2009). Interoperability is defined as: “The ability of two or more systems or components to exchange information and to use the information that is exchanged.” Interoperability is achieved by aligning an internal data structure from a company to a universal data model. BIM can be used in an open system or in a closed system.

<table>
<thead>
<tr>
<th>Open system</th>
<th>Different companies use different models and these models are exchanged. It is a system where each company has its own model.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed system</td>
<td>Everybody is working together in one model. Individual files can be linked or an online model can be used, where several accounts can work simultaneously.</td>
</tr>
</tbody>
</table>

Table 21: BIM systems (Kooring, 2015).

With an open BIM system, different software packages are used and different models are formulated. These models focus on a specific aspect of a construction project. Often translated models are used. This means that models are exported from one software package and imported into the other. Interoperability has been recognized as a problem due to heterogeneous applications and systems that are used by different companies (Grilo and Jardim Gonçalves, 2009). Due to this, smart object are maimed into less useful data structures (Kooring, 2015).

### 3.3.5 Delivery pattern

The delivery pattern represents the physical structure of the distribution process, from production and distribution to customers (Van Goor et al, 2014). Important are the flows of materials, equipment and labour towards the construction site and/or warehouse locations (Quak, Klerks, Aa, Ree, Ploos van Amstel and Merriënboer, 2011). Different delivery patterns for construction materials can be distinguished.

| The manufacturer supplies construction materials directly to the construction site. This means the materials are warehoused at the supplier and at the construction site. Construction logistics takes place between the supplier and the construction site. |
| A construction wholesaler supplies construction materials to the construction site. This means warehousing at the supplier, the construction wholesaler and/or the construction site. Construction logistics takes place between the supplier and wholesaler and between the wholesaler and the construction site. |

Table 22. Delivery patterns (Quak et al, 2011).

Figure 5 presents the prescribe process of ordering, booking and delivering materials to the construction project, including the use of a 3PL. The numbers indicate in which order the activities occur (Ekeskär and Rudberg, 2015).

![Figure 5: Delivery pattern (Ekeskär and Rudberg, 2015)](image-url)

Although the destination is the same, the characteristics of the construction logistics delivery pattern *per material*, such as wood or concrete, can differ. Also, the characteristics of the construction logistics delivery patterns can differ *per project*. These physical characteristics determine the possibilities of innovation in
construction logistics. Also, agreements between construction companies and suppliers have an effect on innovation. Often materials are being fabricated especially for a project (Quak et al, 2011).

Construction sites in urban areas have limited space available for warehousing (Huang and Hinze, 2003). Also, urban construction sites are harder to reach due to narrow roads and congestion. Proper coordination of these logistics activities and warehousing is therefore harder to achieve (Lundesjö, 2016). Construction materials need to be delivered just in time and more frequent (Ploos van Amstel, 2015). This results in complexity within the supply chain and makes good logistics management difficult.

3.4 Current innovation in construction logistics

Lundesjö (2016) presents the current challenges in construction logistics management. Achieving high levels of productivity is one of the greatest challenges in the construction industry. Reaching a higher level of productivity contributes to the project turnover and it also increases the level of sustainability of cities. Research in the field of logistic management has demonstrated that productivity gains can be achieved when construction processes are planned from a logistics perspective.

Janné (2016) explores innovation in construction logistics by evaluating 3,230 published journal articles. The concept and processes of construction logistics innovation have had little attention in research and to some extent in practice. Only six articles (Aguirre, Hennies and Marks, 2010; Gajendran, Brewer and Marimuthu, 2013; Tanskanen, Holmström and Öhman, 2015: Huttu and Martinsuo, 2015: Sariola and Martinsuo, 2015: Lindén and Josephson, 2013) could be related to innovation in construction logistics. Three issues are highlighted to be important.

- Knowledge is an important issue for developing as well as implementing construction logistics innovations. Gajendran et al (2013) indicate that information integration and organisational integration are preconditions for supply chain integration. Supply chain integration is important to plan and control construction logistics processes.
- Technology is an important issue and is defined as technology and infrastructure or as mechanisms for developing innovative logistics services. Gajendran et al (2013) state that sensing, seizing and reconfiguring resources are vital in developing new construction logistics services.
- Relationship networks highlight the importance of organisational relationships for construction logistics innovation. Sariola and Martinsuo (2015) add that these relationships are highly dependent on personal relationships. Implementing an innovation is dependent on the communication skills of each company (Tanskanen et al, 2015). To ensure a good working relationship is to clearly define at an early stage how the innovation should work and what companies can expect. Good communication is a prerequisite for success (Lindén and Josephson, 2013; Gajendran et al, 2013; Tanskanen et al, 2015; Huttu and Martinsuo, 2015).

The above-mentioned issues are important, but give little information about how the preconditions for innovation in construction logistics need to be defined. Clark and Mattisson (2016) published the final report of the SMARTSET project. The SMARTSET project focuses on the development of urban freight terminals (UFTs). UFTs are frequently implemented at the instigation of the local authority but, however, require an involvement of a complex mix of public and private partners.
An urban UFT is a facility that allows operators of freight distribution in the city to consolidate flows of goods for the last-mile delivery. Consolidation centres reduce the number of freight movements within cities and this idea has been carried over the construction industry as well (Janné, 2016). A construction consolidation centre is often proposed as a solution for construction logistics (Lundesjö, 2016). Although a UFT differs from a construction consolidation centre, the insights can still help to identify possible disturbance factors in construction logistic innovation.

The most important conclusion of the SMARTSET project is that the development of UFTs should include market-based business models, incentives and regulations, cleaner vehicles and stakeholder interaction. Political support and courage are required to get UFTs operational. Identifying the value of the UFT, and those who will benefit from it is important to create market-based solutions. Clark and Mattisson (2016) distinguish 10 barriers to implement UFTs. These aspects are presented in the table and will be explored in the construction industry.

| 1. Political support. | The cooperation between public and private sectors is crucial to the development of UFTs. Lack of political support or changing political landscapes can result into problems. |
| 2. Personnel and competence. | The transportation market often manages freight transportations. This means that few people in local authorities and the construction industry work with freight, and that the competence of these people is crucial for success. |
| 3. Network. | If there is no network and communication between stakeholders, then there is likely to be mistrust between stakeholders. Without providing a forum which allows stakeholders to discuss with each other, trust between stakeholders cannot be created and it is difficult to get traction for ideas and solutions. This also counts for the political level. |
| 4. Identification of value. | If there is an unclear value for transporters to use UFTs, it is difficult to get it operational. The value for the customers must be identified. This is a core part of creating a business model. |
| 5. Invisible transport costs. | A problem with creating business models for UFTs is in trying to understand the transport costs. Since transport costs are not visible to the end consumer, it is not possible to have a full understanding of how much transport of goods costs, thus setting prices for goods delivery is problematic. |
| 6. Sharing information. | UFTs rely on delivering goods from numerous transport companies to the final customer. Each transport company has its own IT system while the UFT has its own too. Due to organisational barriers, transport companies are unwilling to share their data so those working at the UFT have to deal with several parallel tracking tools simultaneously. |
| 7. Vehicles. | Energy efficient vehicles are crucial for the positive environmental impact of UFTs. Cleaner vehicles, especially electric vehicles, are still more expensive than traditional vehicles, and transport companies can generally still not maintain a competitive place in the market with today’s higher investment costs. |
| 8. Location of terminal. | UFTs should be close to the area where the deliveries will be performed. However, UFTs need space in order to consolidate and store goods and also have good road access. This can be difficult to manage in a congested city centre where there are many competing demands on real estate. |
| 9. Enforcement regulations. | Regulations are key to getting UFTs to work. But there is no point in regulations if they are not enforced. |
| 10. Critical mass. | This applies for long-distance solutions in shifting freight from road to rail. It can be difficult to get an operator to drive transport and difficult to get a critical mass of customers. There must be enough freight. |

Table 23: Barriers (Clark and Mattisson, 2016).
The paper is important because it gives a current state regarding innovation into construction logistics. The context discussion in this paper is very interesting.

This report is important because it gives insight into lessons learned regarding the development of UFTs. This can also be helpful for innovation in construction logistics.

Table 24: Recommended literature.
4. Results

The results are presented in this chapter. The results regarding the analysis of the construction logistics calculation models are presented in paragraph 4.1. Paragraph 4.1. ends with a sub conclusion. Paragraph 4.2 presents the results regarding the analysis of the ILC within the construction industry. Here, each sub paragraph is concluded with a conclusion and a reflection on the barriers of the SMARTSET project (see paragraph 3.4).

4.1 Construction logistics calculation models

In this paragraph, the results of the construction logistics calculation models are presented. The construction logistics calculation models are structured on the year of development and start with the oldest and end with the newest model. The characteristics of the construction logistics calculation are presented below.

<table>
<thead>
<tr>
<th>Code</th>
<th>Purpose of the model</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Par. 4.1.1.</td>
<td>Model 1. Impacts of construction projects on construction logistic flows and infrastructure.</td>
<td>Ex-ante.</td>
</tr>
<tr>
<td>Par. 4.1.2.</td>
<td>Model 2. Impacts of construction characteristics on construction logistic flows.</td>
<td>Ex-ante.</td>
</tr>
<tr>
<td>Par. 4.1.3.</td>
<td>Model 3. Impacts of a CCC on social, ecological and economical criteria.</td>
<td>Ex-ante.</td>
</tr>
<tr>
<td>Par. 4.1.4.</td>
<td>Model 4. Impacts of construction logistics on emissions.</td>
<td>Ex-ante.</td>
</tr>
<tr>
<td>Par. 4.1.5.</td>
<td>Model 5. Impacts of a CCC on social, ecological and economical criteria.</td>
<td>Verified.</td>
</tr>
</tbody>
</table>

Table 25: Construction logistics calculations models (Author, 2017).

Construction logistics calculation model 5 is the only model where impacts are measured in practice. Models 1 to 4 are ex-ante but will nevertheless be explained. Model 5, therefore, gives valuable insights into the difficulties of making such a model. The focus, therefore, will be on model 5.

4.1.1 Model 1

<table>
<thead>
<tr>
<th>Year of development.</th>
<th>2007.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company development.</td>
<td>Municipality.</td>
</tr>
<tr>
<td>Purpose.</td>
<td>Impacts of construction projects on construction logistic flows and infrastructure.</td>
</tr>
<tr>
<td>KPIs.</td>
<td>Emissions, construction logistic flows labour, construction logistic flows materials.</td>
</tr>
<tr>
<td>Used methods for this deliverable.</td>
<td>Logistic model and interview.</td>
</tr>
</tbody>
</table>

Table 26: Information model (Author, 2017).

Introduction

This model is formulated in 2007 and focus on impacts of construction projects on construction logistic flows (labour and materials) and infrastructure. Equipment is not included. The model is used to predict, in abstract terms, these flows in the initial phase of a construction project. The author did not formulate an instruction manual for this model, but XXX (Respondent 2) evaluated this model. The model makes a distinction between preparations phase, structure phase and finishing phase.
The methods that have been used to make this model are interviews with experts such as contractors, subcontractors, architects and suppliers and a literature review (XXX, 2008: Respondent 1). Also, little empirical data from project XXX is used. This data consists of a number of construction logistics flows, related to several construction projects (Respondent 1).

Empirical data indicates that 80% of the construction logistics flows are a result of labour (XXX, 2008). Respondent 1 indicates that often respondents did not know their own logistic details. It was, therefore, difficult to obtain reliable quantitative data. Literature, at that time, was also limited (Respondent 1).

The model needs to be supplied with data regarding the size or budget of the project. The model predicts construction logistic flows in general terms. The number of construction logistics flows can be predicted per year, per quarter or per month (XXX, 2008). Results can be visualized in graphs, tables and bar charts and give insight into flows of materials and labour in time, per construction phase and per route.

Processes
This model focuses purely on transportations. At this time, the average % full truckload (FTL) is estimated to be 90%. Respondent 1 indicates that it was difficult to obtain reliable data from respondents and literature.

“What surprised me was that lots of data are needed to get any output. At that time there was almost no data available, not at respondents and not in literature. The hardest part was to get insight into data from involved companies, simply because many companies did not have it.”

Activities
From the abovementioned process, sub-processes and activities are determined. Only construction logistics flows regarding labour and materials are included in the model. The model focuses only on the number of flows, subjects such as waiting time and loading and unloading time are not included in the model (Respondent 1).

Cost objects
A cost object is an item for which costs or other resources are being measured. A Product is frequently used as a cost object. The cost objects in this model are the number of transportations of heavy materials and the number of transportations of labour.

Resources
The volume (m$^2$ or m$^3$) and budget are the main resources for this model. A bill of quantity is made from the budget and/or the size of the project. This is done by a norm, which is formulated by respondents. It is not based on calculations (Respondent 1: XXX, 2008). The bill of quantity is transformed into construction logistics flows.

From the budget, a budget for labour is calculated. This budget is translated into transportation flows, by dividing the budget by an average wage per hour. This number is divided by a norm, which calculates the number of vehicles for the whole project.
Resource drivers

The resource drivers are presented in the table below.

<table>
<thead>
<tr>
<th>Resource Driver</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>The size of the project.</td>
<td>A bigger size results into a larger number of flows.</td>
</tr>
<tr>
<td>The budget of the project.</td>
<td>A higher budget results into a larger number of flows.</td>
</tr>
<tr>
<td>The planning of the project.</td>
<td>A shorter planning results into a larger number of flows per time period.</td>
</tr>
</tbody>
</table>

Table 27: Resource drivers (Author, 2017).

4.1.2 Model 2

<table>
<thead>
<tr>
<th>Year of development.</th>
<th>2008.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company development.</td>
<td>Municipality.</td>
</tr>
<tr>
<td>Purpose.</td>
<td>Impacts of construction characteristics on construction logistic flows.</td>
</tr>
<tr>
<td>KPIs.</td>
<td>Number construction logistics flows of materials and labour.</td>
</tr>
<tr>
<td>Used methods for this deliverable.</td>
<td>Thesis, logistic model and interview.</td>
</tr>
</tbody>
</table>

Table 28: Information model (Author, 2017).

Introduction

Model 2008 has the purpose of improving model 2007 (XXX, 2008). In 2008 there was still little information available. This research aims to get insight into factors that influence the number of flows regarding two construction projects in XXX (XXX, 2008). The research focuses on subjects that are manageable by the contract, such as planning, cycle time, construction method, the number of working days and vehicle characteristics.

The research uses two case studies, a literature review and interviews. The two case studies consist of larger construction projects in the city centre of XXX. The volume of the construction projects is not included as a factor. The model determines impacts of factors within the given size of the two projects.

The construction plan is translated into norms and these norms are used to make the model. This construction plan consists out of a planning, scripts, tempo and predicted construction logistics flows (XXX, 2008). The model is not verified in practice (Respondent 2). The only verification is that outcomes of model 2007 are compared with outcomes of model 2008 (XXX, 2008).

Processes

This model distinguishes construction materials, equipment and labour.

Activities

From the abovementioned processes, sub-processes and activities are determined. The research focuses on the number of construction logistics flows. A distinction is made between heavy and light vehicles. The number, heavy or light vehicles and time are examined (XXX, 2008).

Cost objects

A cost object is an item for which costs or other resources are being measured. A Product is frequently used as a cost object. The number of construction logistics flows for materials, equipment and labour per construction phase is calculated.

Resources

The resources in this model are the number of heavy and lighter vehicles.
**Resource drivers**

Resource drives determine the number of resources. Resource drivers are planning, construction phase and method, function, number of layers below ground and amount of excavated soil.

### 4.1.3 Model 3

<table>
<thead>
<tr>
<th>Year of development</th>
<th>2013.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company development</td>
<td>XXX and research institute.</td>
</tr>
</tbody>
</table>

**Purpose.** Impacts of a CCC on social, ecological and economical criteria.

**KPIs.** Accessibility, logistic costs and emissions.

**Used methods for this deliverable.** Thesis and logistic model. No interview.

Table 29: Information model (Author, 2017).

**Introduction**

This model focuses on the renovation of a medium sized building in the city centre of XXX. The construction project consists of the development of 8 apartments and 10 business premises. The construction is planned in 27 weeks and has a budget € 1.4 million (XXX, 2013). Because bundling due to the CCC results in extra costs, the size of the construction volume becomes an important subject. Construction volumes result in construction logistics flows, and construction logistics flows lead to efficiency possibilities. Efficiency possibilities lead to financial benefits and these benefits can finance the CCC (XXX, 2013). The purpose of the model is to give insight into the possibilities for innovation in construction logistics by presenting four scenarios. The research uses two case studies, a literature review and interviews (XXX, 2013). Unfortunately was it not possible to conduct an interview with the author. The traditional construction logistics process leads 166 logistic flows. The four scenarios are.

**Scenario 1**

Construction logistics is organised trough water and road. Bundling will take place at a shipyard and at a CCC. Bulk goods will be transported with barges and finishing goods will be bundled and transported with trucks. This leads to a decrease of 39 percent regarding logistic flows, a decrease of 26 percent regarding NOx but an increase of 9 percent regarding PM10 emissions. Barges produce more PM10 than trucks.

**Scenario 2**

Construction materials are transported with electric and fossil trucks and bundled at two CCCs. One CCC is located in the north and the other is located in the south of XXX. Bulk goods will go directly to the construction project. This scenario reduces the number of flows by 17 percent and reduces NOx emissions by 28 percent. PM10. Both NOx and PM10 are more reduced in comparison to the first scenario.

**Scenario 3**

Construction materials are transported through water and road and bundling takes place at a shipyard and two CCCs. One CCC is located in the north and the other in the south of XXX. The number of transportation flows is reduced by 31 percent, the NOX emissions are reduced by 18 percent, but PM10 emissions rise by 7 percent.
Scenario 4
This scenario embraces the possibilities through water, but requires extra resources such as containers and an extra bridge. The number of trips is reduced by 55 percent, the NOx emissions are reduced by 32 percent, but PM10 emissions rise by 18 percent.

The scenarios show positive effects regarding accessibility and emissions, but are not financial beneficial (XXX, 2013). The same scenarios are therefore calculated over multiple projects to create more production. In an extent, alternatives are explored such as bundling of construction workers and transportation through vans and public transportation (XXX, 2013).

Processes
The construction logistics model focuses on two processes: transportation and warehousing.

Activities
From the above-mentioned processes, sub-processes and activities are determined. The following activities are explored.

Transportation
The model predicts that 60 percent of the transportation flows will go to the CCC. The other 40 percent will go directly to the construction site (XXX, 2013).

Inventory
The additional handlings, due to bundling and warehousing, will be important (XXX, 2013). Due to the CCC, decoupling points are added to the construction supply chain. Some operations are therefore doubled. It is estimated that handling costs are between € 32, - and € 40, - per pallet.

Cost objects
A cost object is an item for which costs or other resources are being measured. The 4 scenarios function as cost objects, because for each scenario resources are calculated.

Resources
Emissions are related to NOx and PM10. NO and NO2 emissions are caused by the engine of a transportation mode. PM10 emissions are related to wear and tear from brakes and tires. The resources are listed below:

- The number of logistic flows.
- The logistic cost.
- NOx emissions.
- PM10 emissions.

Resource drivers
Resource drives are used to determine the number of resources. The following resource drivers are used:

- The number of kilometres.
- The number of time that is driven.
- The number of bundling activities.
- The mode of transportation.
4.1.4 Model 4

<table>
<thead>
<tr>
<th>Year of development.</th>
<th>2012.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company development.</td>
<td>Municipality.</td>
</tr>
<tr>
<td>Purpose.</td>
<td>Impacts of construction logistics on emissions.</td>
</tr>
<tr>
<td>KPI.</td>
<td>Emissions, construction logistic labour, construction logistic materials.</td>
</tr>
<tr>
<td>Used methods for this deliverable.</td>
<td>Analysis construction logistic model, research report and interviews.</td>
</tr>
</tbody>
</table>

Table 30: Information model (Author, 2017).

Introduction
The model predicts emissions that are produced due to construction logistics flows (XXX, 2012). The model predicts the number of flows regarding construction materials and labour. Construction equipment is included in construction materials (Respondent 4). The model focuses on the development of an infrastructure project (Respondent 3).

First, the model is supplied with data regarding construction materials. This data is collected through construction plans, blind bill of quantities, construction drawings and planning (Respondent 4). Details such as the size of the project are determined. Second, the capacities of the transportation modes are determined and the number of construction logistics flows is calculated per construction phase. For the percentage FTL and the average driving distance, key figures are used. The model uses a 100% FTL (Respondent 4).

The model calculates construction logistics flows for labour, by using a percentage of the total budget. By an average wage, this percentage is transformed into man-hours. These man-hours are translated into labour flows. The model focuses on the construction of a local access road with two lanes, parking strips, cycle lanes and sidewalks. The construction project consists out of 17 construction phases (XXX, 2014).

Processes
The research focuses on transportation for three construction sectors, which are housing, utility buildings and GWW (infrastructure). The model focuses on infrastructure.

Activities
From the above-mentioned processes, sub-processes and activities are determined. Purely the number of transportation flows is calculated. Activities such as waiting time, loading and unloading time are not included (Respondent 3).

Cost objects
A cost object is an item for which costs or other resources are being measured. Cost objects in this research are the number of transportation flows regarding materials (and equipment) and labour.

Resources
The model determines different types of vehicles for transportation. For each activity, a different transportation mode is used. The different modes can be seen as a construction peculiarity, which suggests the wide variety of supply chains and transportation modes (XXX, 2014). A distinction is made regarding purpose, capacity, average distance and PAE-value (passenger car equivalent). The resources are.
- NOx.
- CO2.
- Particulate matter.

*Resource drivers*

Resource drives are used to determine the number of resources. The following resource drivers are used:

- The size of project.
- The budget of project.
- The planning.

### 4.1.5 Model 5

<table>
<thead>
<tr>
<th>Year of development</th>
<th>2016.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company development</td>
<td>Contractor and XXX.</td>
</tr>
<tr>
<td>Purpose</td>
<td>Impacts of a CCC on social, ecological and economic criteria.</td>
</tr>
<tr>
<td>KPI</td>
<td>Accessibility, logistic cost, emissions.</td>
</tr>
</tbody>
</table>

| Used methods for this deliverable | Analysis construction logistic model, research report, interviews and verification report. |

Table 31: Information model (Author, 2017).

*Introduction*

Due to an increase in urbanisation, construction companies are focusing on warehouse management services to optimize their construction activities. In this research it is stated that most of the models are based on expertise. This model, therefore, focuses on real-time quantitative data (XXX, 2016). XXX performed the analysis and a sub-contractor provided the data.

The research focuses on emissions, construction logistic flows and cost. The project consists of 400 apartments. The traditional process is defined as a process where all the suppliers supply their own materials to the construction site. The new process is defined as a process where materials are partly delivered to a CCC. Here, materials are bundled and supplied to the units. The materials are bundled by social workers. The process focuses on the finishing phase of the construction process (XXX, 2016).

The construction materials come from the project scheme, construction drawings and planning. The construction planning is digitalized through a Warehouse Management System (WMS) and a Transportation Management System (TMS). These programs are a fundamental requirement for a construction supply chain strategy. The research is structured on transportation, labour and cost and aims to reduce the number of truck movements, reduce emissions, reduce travel time and increase labour productivity. Cost and number of kilometres are added (XXX, 2016).

*Processes*

The construction logistics model focuses on three processes. These are transportation, warehousing and processing.
**Process 1. Transportation**

Each individual supplier delivers its construction materials from their business location to the construction site. This also counts for construction equipment and labour (XXX, 2016). In the new process, a CCC is realized because of limited space available at the construction site. A supplier can unload their materials at the CCC and the construction manager can order its materials in bulk from the CCC. Due to this, suppliers do not need to drive into the city centre. Materials will be supplied in 100% FTL and just in time (XXX, 2016). Respondent 5 indicates that this process was relatively easy to measure, compared to warehouse and labour processes. Trucks often are provided with a TMS. Although trucks are provided with a TMS, analysis was not easy due to missing and ambiguities data (XXX, 2016).

**Process 2. Warehousing**

The traditional process consists of a construction site which functions as a warehouse. Often, construction sites are not protected against aspects as weather (XXX, 2016). Also, construction materials are lost due to theft and accidents (Lundesjö, 2016).

The new process transfers the warehouse function to the CCC. Materials are stored weeks before processing and possibilities that materials are lost or not available for processing are minimized (XXX, 2016). Problems arise regarding data for warehouse management. There was no data generated regarding warehouse management at the CCC. As respondent 5 indicates:

“What is stocked at the CCC, for how long and with what value? These aspects were hard to measure. What we have learned is that you must have an Enterprise Resource System (ERS) to be able to capture all the data. After this, we can think about solutions regarding tactical and operational planning integrations.”

**Process 3. Processing**

In the traditional process, each supplier delivers its own construction materials and equipment. Construction workers, therefore, need to perform non-value adding activities, such as searching for materials (XXX, 2016). In the new process, construction materials are received, sorted and bundled at the CCC. Construction materials will be delivered just in time and in the units, processing can start directly (XXX, 2016). Due to this, expensive craftsmen can focus on value-added activities. This results in savings in labour cost for subcontractors. Respondent 5 indicate that new negotiations in the procurement are therefore necessary. This will be the next step regarding innovation in construction logistics. Respondent 5 indicate that a supplier increases their price due to new processes.

**Activities**

From the above-mentioned processes, sub-processes and activities are determined.

**Process 1: transportation delivery**

Delivery is divided into the reliability of delivery regarding time and reliability of delivery regarding desired requirements. The analysis shows the following results.

<table>
<thead>
<tr>
<th>KPI</th>
<th>Indicator</th>
<th>Process</th>
<th>Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Delivery on time.</td>
<td>Supplier – CCC.</td>
<td>100%</td>
</tr>
<tr>
<td>1.</td>
<td>Delivery on time.</td>
<td>Supplier – Construction site.</td>
<td>Not available.</td>
</tr>
<tr>
<td>2.</td>
<td>Delivery conform requirements.</td>
<td>Supplier – CCC.</td>
<td>99%</td>
</tr>
<tr>
<td>2.</td>
<td>Delivery conform requirements.</td>
<td>Supplier – Construction site.</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 32. Deliveries.
The construction materials were delivered on the CCC, two weeks before the start of the process. This ensures time to check the delivery and restore any deficiencies. All deliveries were on time, which results into 100% delivery on time. There were no time frames for the delivery at the construction site, so no results are measured here. Regarding requirements, 2 out of the 190 deliveries were damaged. This result into 99% delivery conform requirements. Deliveries from the CCC to the construction site were 100% compliance requirements, because materials were checked at the CCC (XXX, 2016).

**Process 1: transportation driving time**

Driving time is based on real traffic conditions due the use of data of the TMS (XXX, 2016). Because driving speed in urban areas is lower than outside urban areas, a CCC has advantages regarding driving time. 81 minutes per trip can be saved. Because, emissions inside urban areas are higher than outside urban areas, emissions will decrease. Waiting time in driving time can be related to traffic jams. The analysis shows the following results.

<table>
<thead>
<tr>
<th>KPI</th>
<th>Indicator</th>
<th>Process</th>
<th>Measurement</th>
</tr>
</thead>
</table>

Table 33. Waiting time.

**Process 1: transportation waiting time**

Waiting time has negative influences for different companies. Waiting time refers to the time that a truck is waiting before it can be loaded or unloaded (XXX, 2016). Waiting time leads to negative effects for the supplier because it is performing non-value adding activities, but also for the vicinity due to emissions. In the new process, time is reserved for unloading and loading at the CCC and at the construction project. Waiting time at the CCC is measured at 4 minutes and 11 minutes at the construction site. No data is available from the traditional process, so a comparison cannot be made. It is expected that waiting time in the traditional process is much higher (XXX, 2016).

<table>
<thead>
<tr>
<th>KPI</th>
<th>Indicator</th>
<th>Process</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.</td>
<td>Waiting time cons. site.</td>
<td>Construction site.</td>
<td>11 min.</td>
</tr>
<tr>
<td>4.</td>
<td>Waiting time CCC.</td>
<td>CCC.</td>
<td>4 min.</td>
</tr>
</tbody>
</table>

Table 34. Waiting time.

**Process 1: transportation loading and unloading time**

This is an important activity because the CCC leads to extra handling activities. Trucks need to be loaded at the supplier and unloaded at the CCC, and loaded at the CCC and unloaded at the construction site. The table below shows the analysis.

<table>
<thead>
<tr>
<th>KPI</th>
<th>Indicator</th>
<th>Process</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.</td>
<td>Unloading time construction site.</td>
<td>Supplier – construction site, CCC - construction site.</td>
<td>61 min.</td>
</tr>
<tr>
<td>3.</td>
<td>Unloading time CCC.</td>
<td>Supplier – CCC.</td>
<td>26 min.</td>
</tr>
</tbody>
</table>

Table 35. Unloading time.

From the 230 transportations, 190 transportations went from the CCC to the construction site and 40 went from the supplier to the construction site. There is no data available regarding the traditional process. 61 minutes unloading time is an affect due to the limited space available at the construction site (XXX, 2016). It is estimated that transportation movements were minimised with 69 percent.
Cost objects in process 1: transportation
A cost object is an item for which costs or other resources are being measured. The cost object in this process is transportation flows.

Transportation flows
Transportation flows can be from the supplier to the construction site, from the supplier to the CCC or from the CCC to the construction site. Transportation flows are used as a cost object because each transportation flow relates to activities and these activities consume resources. The number of transportation flows was not selected as a KPI, but still, data was generated. 69 percent fewer inner-city transportation flows were measured (XXX, 2016).

Resources in process 1: transportation
The resources in this model are wage due to labour and cost of transportation mode due to fuel, maintenance and devaluation (XXX, 2016). The analysis assumes that EURO5 trucks were used, both in the traditional and in the new process. Emissions are copied from www.co2emissiefactoren.nl and are therefore not measured. This is a weakness (see Pregl et al, paragraph 2.1).

<table>
<thead>
<tr>
<th>KPI</th>
<th>Indicator</th>
<th>Process</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.</td>
<td>Emissions CO2.</td>
<td>Supplier – Construction site.</td>
<td>68%. (-)</td>
</tr>
<tr>
<td>14.</td>
<td>Emissions NOx.</td>
<td>Supplier – Construction site.</td>
<td>68%. (+)</td>
</tr>
<tr>
<td>14.</td>
<td>Emissions PM10.</td>
<td>Supplier – Construction site.</td>
<td>68%. (+)</td>
</tr>
<tr>
<td>15.</td>
<td>Reduce in waste.</td>
<td>CCC.</td>
<td>5%. (+)</td>
</tr>
</tbody>
</table>

Table 36. Emissions and waste.

The reduction in waste is estimated by workers in the CCC and is not measured. Savings are therefore relatively small and can increase in upcoming projects (XXX, 2016).

Resources drivers in process 1: transportation
Resource drivers are hours and kilometres of transportations (XXX, 2016). Transportation costs are € 82,77 an hour and € 2,60 per kilometre.

<table>
<thead>
<tr>
<th>KPI</th>
<th>Indicator</th>
<th>Process</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.</td>
<td>Number of kilometres transport.</td>
<td>CCC – construction site.</td>
<td>60% (-)</td>
</tr>
<tr>
<td>8.</td>
<td>Number of avoided kilometres.</td>
<td>Supplier – construction site. CCC – construction site.</td>
<td>69% (-)</td>
</tr>
<tr>
<td>12 : 13.</td>
<td>%FTL.</td>
<td>Supplier – construction site.</td>
<td>48%</td>
</tr>
<tr>
<td>12 : 13.</td>
<td>%FTL.</td>
<td>Supplier – CCC.</td>
<td>44%</td>
</tr>
<tr>
<td>12 : 13.</td>
<td>%FTL.</td>
<td>CCC – construction site.</td>
<td>90%</td>
</tr>
<tr>
<td>Savings transportation costs.</td>
<td>Supplier – construction site. CCC – construction site.</td>
<td>71% (-)</td>
<td></td>
</tr>
</tbody>
</table>

Table 37. Number of kilometres, FTL and transportation costs.

Process 2: warehousing
In the new process, the CCC functions as a warehouse. The research does not provide any process information regarding the CCC (XXX, 2016). Respondent 5 also indicates that activities in the CCC are not measured.
### Table 38. Processing time.

<table>
<thead>
<tr>
<th>KPI</th>
<th>Indicator</th>
<th>Process</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.</td>
<td>Processing time call CCC.</td>
<td>CCC.</td>
<td>Not available.</td>
</tr>
<tr>
<td>6.</td>
<td>Processing time call supplier.</td>
<td>CCC.</td>
<td>Not available.</td>
</tr>
</tbody>
</table>

**Activities in process 2: warehousing**

- The supplier will arrive at the CCC. One activity is to receive and unload the materials.
- The received goods are stored and bundled.
- The bundled materials will be loaded on the truck.

**Cost objects in process 2: warehousing**

The model does not provide an insight into cost objects regarding warehouse activities. It only provides an overview of cost and revenues. The overview consists of fixed costs, one-off costs and variable costs. The model also does not provide an insight into the revenues. Because the number of flows and the number of kilometres are reduced for the supplier or subcontractor, time and money are saved. To finance the CCC, new negotiations in the procurement department are needed. Savings in the procurement department will finance the CCC. Savings due to procurement strategies have not been measured (XXX, 2016). Respondent 5 indicates that this will be the next step.

“New strategies for the procurement department will be our next goal. We need to define which companies will use the CCC and which companies will go directly to the construction site.”

**Resources in process 2: warehousing**

The research indicates the following resources (XXX, 2016). These resources are not measured.

<table>
<thead>
<tr>
<th>Resource Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed costs.</td>
<td>Consists of rent of the CCC, labour, software, forklifts, vans and energy.</td>
</tr>
<tr>
<td>One-off costs.</td>
<td>Consists of the construction shack, the design of the floor plan and transaction fees.</td>
</tr>
<tr>
<td>Variable costs.</td>
<td>Consists of the wage for social runners, transportation between the CCC and construction site, forklifts and rent of containers</td>
</tr>
</tbody>
</table>

Table 39. Warehouse costs.

**Resource drivers in process 2: warehousing**

No measurements have been made (XXX, 2016; XXX, 2016). Formulas in the Excel document are based on hard figures. How activities consume resources and how resource drivers influence the number of resources is unknown.

**Process 3: processing**

In the traditional process, construction workers need to perform many non-value adding activities (XXX, 2016). In the new process, these activities are performed at the CCC by social workers. Bundled goods are related and delivered inside the apartment (XXX, 2016). This increases the labour productivity on site. Labour productivity is defined as the time that a construction worker in an eight-hour day is involved in production (XXX, 2016).

**Activities in process 3: processing**

The layout of a construction site has a significant impact on labour productivity. The following distinctions in activities can be made.

- Direct productive activities are activities that yield measurable results.
Indirect productive activities are necessary to provide any value. This includes achievement of bricks or cleaning up.

Rest includes visiting the toilet, washing, drinking and changing clothes.

Preparation time and clean up time includes times before and after the job.

<table>
<thead>
<tr>
<th>KPI</th>
<th>Indicator</th>
<th>Process</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.</td>
<td>Labour productivity.</td>
<td></td>
<td>32%.</td>
</tr>
</tbody>
</table>

Table 40. Labour productivity.

Labour productivity is calculated by the difference between the initial planning and the actual planning. This result shows a significant decrease in the planning for the finishing phase. This indicates that there are still a lot of risks built into a traditional planning (XXX, 2016).

Cost objects in process 3: processing

The following cost objects have been selected in the research.

- Walking and searching.
- Collecting materials.
- Talking to crane operator.
- Waiting on materials.

Resources in process 3: processing

The resource for processing is labour cost.

Resources drivers in process 3: processing

Resource drivers for processing are the wage of construction workers and time.

Sub conclusion

1. The first observation is that construction logistics became an important issue in the municipality of XXX in 2007 (code 2). It is observed that, at that time, there was limited data available. Limited in literature and limited in practice. It is also observed that in the past it was assumed that the percentage FTL was much higher than is examined nowadays.

2. A second observation is that besides volume of the project, aspects such as construction method, function, planning, transportation modes, costs etc. all have a substantial impact on construction logistics processes. A comprehensive construction logistics calculation model therefore requires much and specific data, which need to be shared by stakeholders. Data, which need to be shared by one stakeholder, can have value for other stakeholders (code 3).

3. The third observation is that construction production is needed to create innovative logistics solutions (code 10). When there is limited construction volume available, there is too little efficiency to finance the CCC. A CCC is, therefore, no universal construction logistics solution.

4. The fourth observation is that there are different types of construction logistics calculation models available. Models 1, 2 and 4 require general input and produce general outcomes. This must not be seen as a downfall. All the models are very useful for their purpose. E.g. model 4 is developed to determine emissions and construction logistics flows
in the initial phase of a construction project. Its general output is therefore still very useful.

5. A fifth observation is that a small change in the purpose of a model will have a major impact on the structure of the model and the data that are required. A detailed consideration of processes, activities, cost objects, resources and resource drivers is necessary to determine the data and application of sensors.

6. A sixth observation is that the process of transportation was easy to measure because data were available from TMS. The processes warehousing and processing were more difficult to measure because data registration systems were not available.

7. The seventh observation is that in 2015 there was the start of data analysis regarding impacts of executed construction logistics measures. It is observed that the construction industry is still at the beginning of the IT era. It is proven that fundamental IT solutions are still needed to collect reliable data. Data regarding construction logistics flows are relatively easy to collect due to TMS in trucks. Here, it needs to be stated that this is still very difficult. Processes in warehousing and processing are still not measured in practice. An ERS is needed to measure and improve construction logistics innovations.
4.2 ILC in the construction industry

In this paragraph, factors that hinder the development of construction logistics calculations models are determined. It needs to be addressed that this paragraph focuses on the construction industry of the Netherlands. By using the components of the ILC the factors that could hinder the development of construction logistics calculation models are explored. The components of the ILC are described in the following order.

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<td>Delivery patterns</td>
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</tr>
</tbody>
</table>

Table 41: Paragraphs ILC.

Every paragraph begins with presenting the results and ends with presenting the analysis. The barriers of the SMARTSET project (see paragraph 3.4) are reflected in the results.

4.2.1 corporate strategy

Results

1. The first observation is that main contractors see construction logistics as a new phenomenon (code 2). Innovation in construction logistics is interesting to them because financial revenues can be generated (code 4). First, due to efficiencies in construction logistics cost can be reduced. Second, innovative solutions in construction logistics are frequently rewarded in tenders. Innovation in construction logistics results in a higher possibility to be awarded for projects. Minimizing the impacts from construction logistics is an important subject for the municipality of XXX (code 1). This awareness does not hinder the development of construction logistics calculation models.

2. The second observation is that main contractors are repositioning their position in the construction chain. Contractors are exploring ways to be operational in different construction processes. Contractors see their role as a coordinator and as builder. Due to this, the number of outsourced tasks will decrease and efficiencies due to process integration increase.

Analysis

In this section the corporate strategy and the need for innovation in construction logistics for tenders are described.

Corporate strategy

The strategic management of a company determines a strategy for the total company and/or for every business unit within the company. A distinction is made between a concern strategy and a competitive strategy. Respondent 5 indicates that their construction company is exploring markets and is exploring ways to increase efficiency in their construction processes. Respondent 5 indicates.

“In the future, I see our construction company as a coordinator and as a real builder who has extended his own chain. Thus, not only a company for the development of the project, but also
a company that is involved in maintenance processes. Nowadays, our company consists of 40 individual companies, each with their own friends in the region. In the future, we want to have a direct relationship with the supplier. When this happens, I see an added value due to the use of a CCC. Multiple projects can be organized through the same CCC.”

Respondent 5 indicates that their construction company is exploring new markets to operate in (see paragraph 3.3.1: concern strategy) and exploring ways to increase their position (see paragraph 3.3.1: competitive strategy). The following issues have been addressed.

- The construction company also wants to operate in the maintenance phase, instead of only in the developing phase. This minimizes the effects of vertical fragmentation, because coordination between construction phases is improved.
- The construction company wants to focus on and optimize their core business as a builder. This minimizes the effect of horizontal fragmentation. No longer will tasks be outsourced. This decreases the number of processes and increases possibilities for coordination.
- The construction company indicates a strategy to increase efficiency by aligning processes of sister companies and construction projects. This minimizes effects of longitudinal fragmentation.

All the construction companies in this deliverable are focused on improving sustainability due to their Corporate Social Responsibility (CSR). This is written on their websites. CSR focuses on taking the responsibility as a company, for the negative effects that their business produces. Respondent 5 and 11, therefore, indicate that construction logistic is a central subject in their company.

Innovation for tenders
Construction projects are often developed in city centres. In 2013, a new Tender law/act was established in the Netherlands. Due to this, clients are obligated to use quality indicators as award criteria in tenders (Economisch Meest Voordelige Inschrijving / Most Economically Advantageous Tender). Price is no longer the dominant criterion. Clients use criteria such as safety, accessibility and nuisance to stimulate the quality of construction plans that will be submitted. Innovation in construction logistics is therefore needed to win tenders. An interview is conducted to get more information about this subject. Respondent 7 indicates how an EMVI-works.

“Construction logistics is a hot topic in XXX. In a contract minimum requirements, such as nuisance of construction logistics, are formalized. ... Based on this contract, the project is set in the market based on EMVI criteria. The municipality formulates its demands regarding construction logistics in a BLVC framework. This framework will be attached to the contract. Contractors form a plan with e.g. a logistic measure. The contractor that scores best on quality criteria gets the most points. ... These points result in a fictive reduction of their submitted price. In the end, the award goes to the contractor with the lowest fictive price. The winning plan becomes a binding part of the contract.”

Respondent 9 indicates that EMVI criteria are used to award tenders and that these tenders stimulate innovation in construction logistics. Respondent 9, as a logistic manager, therefore gets frequently involved in tender procedures. Also, respondents 10 and 11 indicate that frequently EMVI criteria are used in tenders. Respondent 5 indicates that construction logistics must be seen as a corporate strategy.
“Construction logistics is a new phenomenon within our construction company. It is valuable for our business model and it connects to market demands.”

It is stated that innovation in construction logistics contributes to the financial turnover, because tenders are rewarded on EMVI criteria. Innovation in construction logistics is therefore a strategy of construction companies because it leads to competitive benefits.

4.2.2 Personal organisation

Results

1. The first observation is that organisational structures to determine construction logistics strategies differ per contractor. Each contractor has own work methods to determine construction logistics solutions.

2. The second observation is that construction logistics measures are formulated on the tactical level. The region or company director can still be involved in the development of construction logistics solutions. The director also instructs the departments regarding new work processes. Directors, tender managers, project leaders, risk managers, work preparers, representatives of planning departments, logistic managers, advisors and foremen are indicated to be involved on the tactical level.

3. The third observation is that the strategic level is also aware of benefits due to innovation in construction logistics. Here, decisions for the long term are made. These decisions relate to strategic partnerships and process innovation.

4. The fourth observation is that construction logistics activities frequently are mandated to the construction foreman, additional to his normal work. When projects are too complex, an additional foreman is enabled. A risk manager is also enabled on the operational level to monitor the progress and to translate this progress to the budget. Communication is the biggest issue. When construction logistics processes are planned, but errors occur, it is noticeable that subcontractors rapidly fall back to their own interest (code 2 and 4).

Analysis

This paragraph focuses on who takes which decision regarding construction logistics. The analysis is structured on the strategic, tactical and operational level.

Personal organisation strategic level

The strategic level focuses on long-term decisions. Most of the respondents indicate that construction logistic measures are formulated at the tactical level, but still the strategic management performs an important task. Respondent 5, who fulfils the function of a company director, mentions that he instructs departments regarding new processes that are needed to realise innovation in construction logistics. Respondent 11, who fulfils the function of a region director, indicates that he (together with several operational managers) is involved in defining the construction logistics measures for challenging projects. Respondent 9 gave an elaborate answer.

“Within our company, there is a strategic board for construction logistics. This board consists out of 5 managers. A manager work preparations, production, supply chain management, equipment and construction logistics. This strategic board determines which steps need to be taken to address construction logistics in potential projects.”

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It is interesting that this board consists out of a manager supply chain management and a manager construction logistics. It is possible that supply chain management focuses on procurement strategies and that construction logistics focuses on construction logistics measurements.

**Personal organisation tactical level**

Construction logistics measures are formulated on the tactical level (Respondent 9, 10, and 11). These construction logistics measures are formalised in a logistic plan, which is included in the offer for tenders. It is therefore that a tender manager is involved in the development of a construction logistics measure. The tender manager can be seen as a project leader, not for the execution of the project but for tenders. To create construction logistics measures, specialists such as dr. W. Ploos van Amstel are invited. Respondent 11 indicates that that a work preparer, somebody of the planning’s department, an experienced foreman and a project leader/the operational director are involved. Respondent 9 indicates that a logistic service provider is involved. The following functions can be involved in the development of construction logistics measures.

- A region director.
- The tender manager.
- The project leader.
- A risk manager.
- The work preparer.
- The planning department.
- Logistic manager.
- Advisors.
- Experienced foremen.

**Personal organisation operational level**

The respondents indicate that the construction foreman often manages the construction logistics activities. These activities are often performed additionally to his normal activities, such as progress inspections and ad-hoc activities. When construction logistic processes are too risky, construction logistic coordinators are enabled. It is also possible that an extra foreman is enabled, who in this case, did not have a logistic background. The construction foreman communicates to the operator of the CCC. Respondent 10, who focuses on an infrastructure project, indicates that a risk manager is involved in monitoring the progress of the subcontractors. Communication is the biggest issue in the operational processes. When construction logistics processes are planned, but errors occur, it is noticeable that subcontractors rapidly fall back to their own interest (Respondent 9).

### 4.2.3 Supply chain strategy

**Results**

1. The first observation is that horizontal, vertical and longitudinal fragmentations are present in the construction industry and that this hinders the development of construction logistics calculation models (code 6).
2. The second observation is that there is mistrust among construction companies. Subcontractor are frequently involved later in the process because involving them early will lead to unwanted price discussions. This can obstruct the development of construction
logistics calculation models because valid data regarding logistics flows are only known in a later stadium of the construction process (code 3).

3. The third observation is that construction logistics awareness is a new phenomenon. This can indicate that knowledge and experiences still need to be embraced by all employees and partners (code 2).

4. The fourth observation is that the strategic level of a main contractor focuses on finding long-term partnerships. A second focus is on defining steps in the process to implement construction logistics measures.

5. The fourth observation is that real construction logistics measures are defined on the tactical level.

6. The sixth observation is that BIM and SCM are cross-departmental processes. This stimulates the development of reliable construction logistics calculation models. BIM will be further elaborated in paragraph 4.2.4. The calculation department calculates the cost price and the procurement department negotiates with subcontractor and suppliers.

7. The seventh observation is that subcontractors and suppliers frequently offer all-in prices for their services (code 5). This creates a barrier for innovation in construction logistics because cost prices are unknown. These cost prices are needed to formulate calculations regarding innovative logistics measures.

8. The eighth observation is that the development of the construction is planned by lean principles. This means that subcontractor and suppliers are involved to give input on the planning. It differs per contractor what their influence can be (code 3). Planning on the operational level consists of verbal instructions and control consists of physical inspections by a construction foreman.

9. The ninth observation is that construction logistics is becoming mature (see paragraph 3.3.3). Construction logistics is evaluated into construction supply chain management. SCM is a cross-departmental process to improve cost efficiencies (stage 3). Integrated decision-making between construction companies is still not present in practice (stage 4). This stimulates the development of reliable construction logistics calculation models.

Analysis
This paragraph begins with an analysis regarding fragmentation, followed by the analysis regarding the construction supply chain strategy (cSCS) on the strategic, tactical and operational level.

Fragmentation
Adriaanse (2014) and Noordhuis (2015) indicate that the construction industry is fragmented. Respondents were asked if fragmentation effects their business operations and if fragmentation hinders innovation in construction logistics. The answer is yes. Below four citations are presented in which impacts of horizontal, vertical and longitudinal fragmentations are presented.

Respondent 5 indicates.

“The construction industry is very fragmented and this leads to problems. We, as the main contractor, contract several subcontractors and these subcontractors contract their own suppliers or freelancers. It is difficult to manage this process.”

Respondent 6 indicates.

“In the construction industry, it is difficult to control and visualize construction processes. ... We have problems to control and visualize our own processes, let’s not talk about the processes
on the construction site. ... Subcontractor are involved later in the process, because involving them early in the process will result in difficult price discussions.”

Respondent 5 indicates.

“Nowadays, our company consists out of 40 sub companies. Each construction company has its own friends (suppliers and subcontractors). ... What I have noticed is that a lot of materials remain after the construction project is finished. These are normally thrown away ... It will be beneficial when multiple projects are organized by one CCC.”

- Citation 5 and 6 show that due to horizontal fragmentation, many actors, innovation in construction logistic is hindered. Respondent 6 indicates that it is difficult to align all the actors that are involved.
- Respondent 6 adds that the main contractor has little insight into the different processes of actors that are involved. Vertical fragmentation is proven to be a problem for innovation in construction logistics.
- Respondent 5 adds that longitudinal fragmentation leads to inefficiencies. Every construction project is organized individually.

Knowledge regarding new construction logistics processes from construction projects is shared in the construction companies. This is done through meetings such as technical lunches. But frequently there is no information structure available. Only one construction company shares its knowledge by developing a construction logistic reference library.

**Strategic level**

The strategic level focuses on long-term decisions. It is observed that the strategic level focuses on process implementation and partnerships to address innovation in construction logistics.

**Partnerships**

The construction companies indicate that the strategic level focuses on finding strategic partnerships with actors, in- and outside the construction chain. As respondent 9 and 10 indicate.

“What is determined on the strategic level is who our will be partners. To give an example, collaboration with software provider Ilips will be determined on the strategic level, but applying Ilips will be determined on the tactical level.” (Respondent 9)

“The strategic management does not focus on logistic solutions, but on finding partnerships with other actors. If you are talking about real construction logistics solutions, this is on the operational and tactical level.” (Respondent 10)

<table>
<thead>
<tr>
<th>Table 42: Recommended literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Studies frequently focus on partnering between the client and the main contractor. Little attention is given to the role of subcontractors and suppliers or the multi-actor nature of the construction industry. The purpose of the paper is to examine the literature in order to identify the main assumptions about partnering in construction research and practice.</td>
</tr>
</tbody>
</table>
**Process implementations**

It is also observed that the strategic level focuses on aspects to fully address the benefits of innovation in construction logistics in potential construction projects. These projects are often larger or consist of standardised building units such as homogeneous apartments.

Respondent 9 indicates:

“In our construction company, several decisions are taken on the strategic level. These decisions are to determine how logistic solutions can be best addressed within potential projects.”

**Tactical level**

The construction companies indicate that the tactical level focuses on developing construction logistic measures (Respondent 9 and 10). Different departments within construction companies are involved in the development of construction logistic measures. These are traditional departments such as calculation, procurement and preparation. It is observed that roles of these departments are changing.

“We have normal business operational departments such as calculation and preparation and we have processes that crossover these departments. These are the processes *Building Information Modelling* and *Supply Chain Management*. ... These processes are both driven by information.” (Respondent 6)

**Building Information Modelling**

BIM relates to the innovation that construction plans were digitalised. BIM is analysed in paragraph 4.1.4. But because BIM functions as a process, it is necessary to describe it from a supply chain perspective. BIM is no longer just one step in the process, but nowadays it is a process that covers different departments (Respondent 6). Requirements to embrace benefits of BIM as a supply chain strategy are interoperability of information and standardisation of work processes. These two aspects result in problems (Respondent 6). Information is frequently not interoperable because companies often use different software programs. To align work processes, companies need to be involved early in the process. This is not the case in practice, because this often leads to price discussions.

**Procurement**

Respondents indicate that the procurement department is important for innovation in construction logistics. The procurement department negotiates with suppliers and subcontractors about price and conditions. Nowadays, procurement is redefined as SCM and focuses on approaching markets, managing risks and negotiating about prices (Respondent 6). It is observed that procurement is getting a strategic characteristic with a focus on long-term agreements with a connection to BIM. As respondent 6 indicates.

“Procurement is traditionally focussed on price and *transferring* risks. ... SCM must be seen as a professionalised procurement department. Some markets are approached purely to minimizing the price and others are approached to form long-term agreements.”

**Calculation**

The calculation department calculates the cost price of the construction projects. Based on the construction scheme and construction drawings, it is calculated what needs to be procured, which equipment need to be deployed and what the labour workload will be. Calculation is an important department because it is fundamental for negotiating with subcontractors and suppliers in the
procurement department. The cost price is necessary to formulate realistic construction logistics measures, which result in realistic offers. Respondent 11 indicates.

“In the past calculation was just calculation, but nowadays calculation is becoming a very important department. Calculation calculates the cost price of materials and services, but also thinks about construction logistics. These logistic possibilities also determine the budget.”

Respondent 5 indicate that calculating the cost price of materials leads to difficulties. As stated in paragraph 2.4.3, many companies are involved in the development of a construction project. It is observed that subcontractors and suppliers frequently offer all-in prices for their services. This means that cost regarding materials, transportation, labour and profit and risks are merged into one price. It is therefore difficult to make construction logistics calculation models, because here cost for processes and activities need to be separated and need to be calculated individually. As respondent 5 indicates.

“We need to know what the cost price is. The cost price of the entire project changes when, due to innovation in construction logistics, efficiency is increased. But nowadays nobody knows what the cost price is.”

Work preparation
Work preparation focuses on how the construction project will be executed. All the respondents indicated that the construction is planned by lean principles. The necessary resources come from a general planning and important subcontractors and suppliers are invited to give input to specify the planning. Stickers to organize activities specify the planning. Respondent 9 indicates that together with a logistic expert, smart logistic measures are discussed. This is done right after the tender phase. Respondent 11 indicates that subcontractors and suppliers are partly involved because these companies are frequently focused on their own benefits.

Operational level
The operational level specifies decisions on the tactical level. The construction logistics measures are translated into operational tasks. To predict the processes of activities mock-up units are realized. These mock-up units consist out of fully developed units to give insight into the different processes. The insights are used to make the operational planning (Respondent 9). Planning and control of processes take place by a daily instruction. A construction foreman monitors the progress of processes by a daily round on the construction site. Respondent 9 and 11 indicate that the operational level is very important. When the logic of innovation in construction logistics is not aware on the operational process, innovation will fail. Respondent 9 indicate that often subcontractor often fall back to their own interest when problems in the logistics process arise.
Figure 6: Internal construction process, plus BIM and SCM (based on Thunberg, 2016).

The figure gives insight into the building processes, including BIM and SCM. Note that BIM starts at the preliminary design, where the architect makes digital drawings and ends when the project goes into the execution phase. SCM starts at the preliminary design, where SCM can have an influence on aspects such as building method and also focuses the execution of the project.

4.2.4 Building Information Modelling

Results

1. The first observation is that IT on the operational level is far from integrated. This is especially in the housing and commercial construction sector (code 2). It is observed that the infrastructure and the maintenance sector are ahead of the housing and the commercial construction sector. The focus thus needs to be on basic IT solutions. This hinders the development of construction logistics calculation models.
2. The second observation is that on the strategic level, contractors are aware of the benefits of information technologies. Strategic partnerships with IT companies are therefore noticed. Most of the respondents indicate that IT will change the construction industry in the upcoming years. This stimulates the development of reliable construction logistics calculation models.
3. The third observation is that IT problems arise on the tactical level. It is observed that problems are related to the supply of incomplete, unsuitable and unrealizable information. These problems are related to vertical and horizontal fragmentation and data interoperability. Coordination of information is the biggest problem, thus not the technical possibilities (code 6). This hinders the development of construction logistics calculation models.
4. The fourth observation is that many construction companies have agreed upon ILS. IFC, a format to transfer construction information, still does not work properly. This hinders the development of construction logistics calculation models.

Analysis
The analysis is focused on the integration of BIM with construction logistics and is structured on the strategic, tactical and operational level.

Building Information Modelling
There is no general definition of BIM available. The meaning of BIM can, therefore, differ between managers, academics and IT specialists. Respondent 6 was asked to give a definition of BIM. As described in paragraph 4.1.3, subjects regarding information sharing and transparency are important subjects.

“BIM is a way of working, where transparency and information sharing are leading principles. It must be seen as a performance model in the initial phase of the construction project and a production model during the finishing phase of the construction project.” (Respondent 6)

IT on the strategic level
Respondents indicate that information technology is not well integrated into the construction industry. Respondent 11 indicates that their construction development department lacks behind their maintenance department. Respondent 5 indicates that the focus needs to be on basic IT solutions to collect reliable data. The construction companies are aware of the benefits of information technologies. The respondents, therefore, indicate that IT will change the construction industry in the upcoming years.

IT on the tactical level
BIM is mainly integrated into the tactical level and not in the operational level. In the preparation phase, it is useful to start with a model of the preliminary design. When the final design is defined, many companies such as subcontractors and suppliers are involved. Here problems arise. These problems are related to vertical and horizontal fragmentation and data interoperability. It is observed that problems are related to the supply of incomplete, unsuitable and unrealizable information. Information is therefore still processed manually (Respondent 5). As respondents 6 indicates.

“It is in a degree related to how the software industry is organized. Our company, for an example, has 40 software packages. Information from one software package cannot be easily transferred into another software package. A lot of information is therefore still manually processed.” (Respondent 6)

Information Delivery Manual (Informatie Levering Specificatie)
Respondent 6 indicates that language is an important issue. The respondent indicates that Informatie Levering Specificaties (ILS) is brought to life to agree upon a basic language. ILS is an agreement to determine how information needs to be structured. An example, when an IFC as an extract of a Revit document is transferred, ILS agreements must be taken into account. The respondent indicates that coordination of information due to fragmentation is the biggest problem.

“That software does not cooperate with each other is not really the problem. ... The biggest problem is what information do we need, which company has this information and who
will edit the information. ... We know BIM has a good effect on the quality of a building. Only when we formulate codes together with other companies, after a while we lose track and we do not know in what way the company receives the added value. We have little understanding of what is happening at the subcontractors.”

Industry Foundation Classes
A popular exchange format for building information is Industry Foundation Classes (IFC). Respondent 6 indicates that IFC does not function adequately. As respondent 6 indicates.

“IFC is a format, but still it gives a lot of freedom. Fire resistance for an example has to be written in a particular place in a file, that is taken care of but the discipline itself is not. For an example, fire resistance can be written as 30, 30 m., 30 minutes etc. This is not necessarily a failure of IFC. The problems are a result of a lack in discipline by people working with IFC to work adequate.”

IT on the operational level
The respondents indicate that IT on the operational level is far from integrated (Respondent 5, 9 and 11). Planning processes consist out of instructions in the morning. Control processes consist out of a daily round on the construction site to map the progress. Only respondent 10, regarding an infrastructure project, indicates that communication software is used. By using this, subcontractors, foremen and logistic managers at the CCC can communicate.

Respondent 9 indicates that in the future, Autodesk Plan will be used to integrate the production planning to the crane and logistic planning. Respondent 11 indicates that IT solutions for operational work processes will be more limited than we think. In the end, it is still a person process.

4.2.2 Delivery patterns

Results

1. The first observation is that the procurement department in a construction company often focuses on price (code 4). The procurement strategy is always a weighting between price and risks. Geographic locations are frequently not considered as important. Due to this, inefficient logistics processes often are created.

2. The second observation is that there are three delivery patterns (code 8). These are bundling at the supplier (preference), bundling at a CCC and transportation directly to the construction site.

3. The third observation is that a distinction is made between two construction phases, the structural phase and finishing phase. The structural phase consists the highest risks due to weather influences and further impacts due to delays in upcoming activities. Heavier trucks with a relatively high FTL characterize the structural phase. Smaller vans with a relatively low FTL characterize the finishing phase.

Analysis
The analysis is focused on the locations of subcontractors and suppliers, the use of CCCs, and the characteristics of call offs.

Locations
The procurement department in a construction company becomes an important aspect when locations of companies, materials and equipment and construction workers are examined. The
procurement department has a substantial influence on the organisational structure of the realisation phase of a construction project (Poesiat, 2016). Respondent 9 and 10 indicate that locations of subcontractors and suppliers are not frequently taken into account when materials are procured. Respondent 9 and 10 indicate that price is leading principle.

“Locations of suppliers will in the future be used in order to formulate construction logistic solutions, to determine waiting locations for trucks that go to the construction site. ...The geographic positions of subcontractors and suppliers in the procurement department are in many cases not leading principle, the price is leading.” (Respondent 9)

“The procurement department is involved in the tender phase. Price is not always a leading principle. It is always a weighing of price and risks ... Sometimes the geographic position is weighted in the procurement decision due to our corporate sustainability goals. ... But when a subcontractor in Amsterdam can do it for €10, ... and another one in Maastricht can do it for €7.5, our preference will be the one with the lowest price.” (Respondent 10)

Based on the above-mentioned information, it is stated that geographic locations of subcontractors and suppliers are frequently not weighted in decisions in the procurement department. It is understandable that this leads to unnecessary construction logistic flows. Price is frequently a leading principle, in special when bulk goods are procured. When specialized products need to be procured, knowledge and other value added aspects are taken into account (Respondent 6). The geographic position will in the future be weighted in decisions in the procurement department to embrace construction logistic solutions (Respondent 9). Respondent 6 indicates that the Kraljic method is used to determine the negotiation strategy when subcontractors and suppliers are approached.

CCC for construction logistics

Respondent 5 states that the traditional construction logistics process is organized in a way that each subcontractor provides its own construction materials. This results in an inefficient process in which trucks and vans are not fully utilized. Respondent 9 and 10 indicate three methods regarding construction logistics. Per type of construction material, a research is conducted to determine which logistic delivery pattern is suitable. As respondent 9 indicates.

“Per material, an investigation will be conducted to determine which logistic process suits best. This can be bundling at the supplier, which is our preference. Hereafter, there is the possibility that types of construction materials will be bundled at our CCC. Last, construction materials will go directly to the construction site.”

The involved construction companies all focus on a CCC to increase efficiencies in their construction logistics processes. Some CCCs are specially designed for construction projects (Respondent 5, 9 and 10). Respondent 11 indicates that CCCs are available in central positions in the Netherlands to supply legion construction projects. Respondent 10 indicates that bulk goods are also stored in this CCC.

Characteristics of call offs

Respondent 10 states that certain construction materials are ordered months in advance and stored in the CCC. A couple of days before processing, materials are being prepared. One day before processing, construction materials will be requested.

Respondent 11 indicates that structural phase consists of the highest risks due to weather influences and its effects on upcoming activities. When weather temperatures are below 0º, activities such as concrete pouring and working with machinery are not possible. The focus of the
main contractor is therefore mainly on the structural phase. Larger trucks with a high percentage FTL characterize this construction phase. Here, the focus of innovation in construction logistics is improving just in time delivery.

When the construction project is wind and water proof, the finishing phase begins. This phase is characterized by vans with a low percentage FTL. The focus of innovation in construction logistics is to improve efficiencies in logistic flows (Respondent 11). It needs to be stated that the uniqueness of each project and its specific stage of the construction pose different challenges for logistics management.

Respondent 9 states that there are 20 subcontractors involved during the finishing phase. Their company wants to set a number of subcontractors as a KPI in future projects. Also, respondent 4 indicates that in the finishing phase, 75 percent of the transportation vans are related to subcontractors. This percentage is measured at the construction site. Horizontal fragmentation leads to an effect that logistic flows are organized inefficiently.

“Due to new construction logistic processes, new requirements at subcontractors or suppliers will be asked such as the willingness of bundling goods of different suppliers. Not all suppliers can/want to meet these requirements.
5. Conclusion

In this chapter, the research questions are answered and the barriers of the SMARTSET project are reflected on the results of this deliverable.

**Research question 1**
Which indicators have been used in currently used construction logistics calculation models?

<table>
<thead>
<tr>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transportation</strong></td>
<td><strong>Transportation</strong></td>
<td><strong>Accessibility</strong></td>
<td><strong>Transportation</strong></td>
<td><strong>Reliability</strong></td>
</tr>
<tr>
<td>Number of construction logistics flows per project (materials and labour).</td>
<td>Number of construction logistics flows per working day (materials and labour).</td>
<td>Number of transportation movements.</td>
<td>The number of flows for construction materials (incl. equipment) per activity.</td>
<td>% Delivery on time. % Delivery conform requirements.</td>
</tr>
<tr>
<td>Number of construction logistics flows per working day (materials and labour).</td>
<td>Number of construction logistics flows between 15:00 and 16:00 (materials and labour).</td>
<td>Number of kilometres.</td>
<td>The number of flows for construction labour per activity.</td>
<td>Responsiveness</td>
</tr>
<tr>
<td>Number of construction logistics flows between 15:00 and 16:00 (materials and labour).</td>
<td>Number of construction logistics flows between 16:00 and 17:00 (materials and labour).</td>
<td>Logistics cost</td>
<td>The number of flows for construction materials (incl. equipment) per week.</td>
<td>Unloading time CCC / con. site.</td>
</tr>
<tr>
<td>Number of construction logistics flows between 16:00 and 17:00 (materials and labour).</td>
<td>Construction logistics flows in PAE between 15:00 and 16:00 (materials and labour).</td>
<td>Transportation costs labour.</td>
<td>The number of flows per week.</td>
<td>Waiting time CCC / con. site.</td>
</tr>
<tr>
<td>Construction logistics flows in PAE between 15:00 and 16:00 (materials and labour).</td>
<td>Construction logistics flows in PAE between 16:00 and 17:00 (materials and labour).</td>
<td>Transportation costs materials.</td>
<td>Agility</td>
<td>Processing time CCC.</td>
</tr>
<tr>
<td>Construction logistics flows in PAE between 16:00 and 17:00 (materials and labour).</td>
<td>Alternative routes 15:00 and 16:00 (materials and labour).</td>
<td>Handling cost.</td>
<td></td>
<td>Processing time supplier.</td>
</tr>
<tr>
<td>Alternative routes 15:00 and 16:00 (materials and labour).</td>
<td>Alternative routes 15:00 and 16:00 (materials and labour).</td>
<td>Warehousing costs.</td>
<td>Costs</td>
<td>Number of kilometres.</td>
</tr>
<tr>
<td>Alternative routes 16:00 and 17:00 (materials and labour).</td>
<td>Infrastructure/capacity ratio alternative routes 15:00 and 16:00 (materials and labour).</td>
<td>Logistics cost</td>
<td>Number of kilometres avoided.</td>
<td>Number of kilometres avoided.</td>
</tr>
<tr>
<td>Infrastructure/capacity ratio alternative routes 15:00 and 16:00 (materials and labour).</td>
<td>Infrastructure/capacity ratio alternative routes 16:00 and 17:00 (materials and labour).</td>
<td>Transportation costs labour.</td>
<td>Waiting time traffic jams.</td>
<td>Waiting time traffic jams.</td>
</tr>
<tr>
<td>Infrastructure/capacity ratio alternative routes 16:00 and 17:00 (materials and labour).</td>
<td></td>
<td>Logistics cost</td>
<td>Emissions</td>
<td>Assets</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transportation costs materials.</td>
<td>NOx</td>
<td>Consolidation factor.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Handling cost.</td>
<td>PM10</td>
<td>Stocks at CCC.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Warehousing costs.</td>
<td></td>
<td>FTL weight and FTL volume.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Emissions</td>
<td>CO2 / NOx emissions regarding construction materials (incl. equipment).</td>
<td>Environment</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CO2 / NOx emissions regarding construction labour.</td>
<td>Go2 emissions.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Waste reduction.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Nuisance for vicinity.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Productivity.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Duration construction activities.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Procurement result.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cost savings in procurement.</td>
</tr>
</tbody>
</table>

Table 43: KPIs.
**Research question 2**
How are construction logistics calculation models structured?

It needs to be stated that a small change in the purpose of a model will have a major impact on the structure of the model. The results are presented in the tables below.

**Model 1**
1. The size of a construction project is translated into a total budget.
2. Price standards are used to estimate the material quantities.
3. Material quantities are translated into construction flows for materials.
4. A percentage of the total budget is used to determine labour costs.
5. The labour costs are divided by an average wage, which results in labour hours.
6. Labour hours are divided by a norm, which results into logistics flows for labour.
7. Transportation flows are weighted on infrastructure/capacity ratios from different routes.

Table 44: Structure model 1.

**Model 2**
1. A literature review and interviews are used to determine the quantities of materials and these quantities are related to the capacities of transportation modes. This results in the number of construction logistics flows.
2. The configuration of the construction phases leads to a planning.
3. The number of transportation flows for materials and labour are calculated for each construction phase.
4. Transportation flows are related to time periods 15:00 and 16:00 and 16:00 and 17:00 and PAEs.

Table 45: Structure model 2.

**Model 3**
1. The model is structured on four scenarios, plus an upscale to three comparable projects.
2. The results of the calculations are structured on the total number of transportation flows, the number of transportation flows to the construction site, NOx, PM10 and logistics costs.

Table 46: Structure model 3.

**Model 4**
1. From the construction documents, a bill of quantity and a budget is produced.
2. The budget is translated into a number for man-hours and a number for materials.
3. These are translated into a planning.
4. Norms are formulated to determine the average driving distance regarding materials and labour.
5. The number of flows is multiplied by the average distance.
6. The results are multiplied with an emission norm, which is found in literature.
7. The emissions are calculated per construction phase.

Table 47: Structure model 4.

**Model 5**
1. The model is structured on transportation, warehousing and productivity processes.
   Information regarding the analysis of the measured data is not available.

Table 48: Structure model 5.
Research question 3
Which input is necessary to develop a construction logistics calculation model?

A small change in the purpose of a model will have a major impact on data that are required. A detailed consideration of processes, activities, cost objects, resources and resource drivers is necessary to determine the data and application of sensors. TMS and ERS are needed to develop a realistic construction logistics calculation model. The results are presented in the tables below.

Model 1

| 1. The volume of the project in m² or m³. |
| 2. The budget.                         |
| 3. The planning.                      |
| 4. Information about alternative routes. |

Table 49: Requirements model 1.

Model 2

| 1. The planning of the construction phases in weeks. |
| 2. The construction method.                        |
| 3. The function of the building.                    |
| 4. Number of layers below ground and the amount of excavated soil. |

Table 50: Requirements model 2.

Model 3

| 1. Information regarding containers and pallets per type of truck. |
| 2. Costs of transportation per transportation mode.                |
| 3. Parking costs.                                                  |
| 4. Emissions regarding transportation per transportation mode.     |
| 5. Costs of companies that are involved (transportation, labour, activities etc.). |
| 6. Distances between the CCC and the construction site (water and road). |
| 8. Data regarding loading, bundling and unloading.                |
| 9. Driving speed and driving time.                                |
| 10. Percentage FTL.                                               |

Table 51: Requirements model 3.

Model 4

| 1. The construction plan / project scheme. |
| 2. The bill of quantities.                 |
| 3. The planning.                          |
| 5. Emission norms.                        |

Table 52: Requirements model 4.

Model 5

| 1. TMS and ERS systems are needed to map the impact of a CCC. |
| 2. Labour productivity must be measured by using sensor technologies. |

Table 53: Requirements model 5.
Research question 4  
Are data measured, from expertise or from literature in currently used construction logistics calculation models?

The only construction logistics calculation model that is partly measured is model 5. Models 1, 2, 3 and 4 are based on data from the expertise of respondents or from literature. It is observed that in 2007 there were no data available. Not in literature and not in practice. In 2015 there was the start of data analysis regarding impacts of executed construction logistics measures. The process of transportation is easy to measure because data are available from TMS. The processes warehousing and processing are more difficult to measure because the authors did not obtain the necessary data registration systems, yet. The results are presented in the tables below.

<table>
<thead>
<tr>
<th>Model 1</th>
<th>Data are from the expertise of the respondents and literature. Minor empirical data and data from literature were available. This data were used to determine the first parameters. The model is not verified in practice.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Table 54: Data model 1.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model 2</th>
<th>Data are collected from construction documents and interviews. The model is not verified in practice.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Table 55: Data model 2.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model 3</th>
<th>The methods are not described explicitly in the research. The research suggests that data are collected through interviews, and thus expertise. To describe the scenarios, a couple of rules have been taken into account. This indicates that data are not measured, but that it is based on expertise. External companies have provided data regarding the %FTL. It is unknown if the model is verified in practice.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Table 56: Data model 3.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model 4</th>
<th>Data comes from expertise and literature. In a later stadium, seven projects were analysed and outcomes were reflected on the outcomes of the model.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Table 57: Data model 4.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model 5</th>
<th>The data that are presented in this deliverable are measured.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Table 58: Data model 5.</td>
</tr>
</tbody>
</table>
Research question 5
Which difficulties did the author of these construction logistics calculation models experience?

The progress of the development of the construction logistics calculation model is dependent on its purpose. Models that focus on predicting construction logistics flows and emissions are relatively easy to develop. Models that focus on predicting the impacts of construction logistics measures increase the necessary data enormously. A detailed consideration of processes, activities, cost objects, resources and resource drivers is necessary to determine the data and application of sensors. It is observed that the authors of the models were surprised by the complexity of the development of their models. The difficulties per model are presented below.

Model 1
The author indicates that this was the first model within the municipality of XXX. A difficulty was to find reliable data. The author indicates that its respondents did not have data and data in literature were not available. Subcontractors were at that time not aware of their logistics processes. The author was surprised that much data were needed to develop the model.

Model 2
The author indicates that the development of the research proposal was complex. The author did not face many difficulties during the execution of the research. A reason for this can be that model 2 is a follow-up from model 1. This means that the approach, structure, necessary data and barriers were already known. This awareness could prosper the progress.

Model 3
It was not possible to plan an interview with the author and therefore information about difficulties is not known. It is written that reliable data from subcontractors and suppliers were difficult to collect. Also, the translation from quantitative to qualitative data was difficult.

Model 4
The author of the construction logistics calculation model did not experience any difficulties.

Model 5
This analysis shows that it is very difficult to conduct a construction logistics calculation model, even when data analysts and logistics experts are involved. This analysis shows that the main contractor does not have IT systems available to map all the KPIs. The process transportation was easy to map. Warehousing and processing were difficult to map. The research indicates that an ERS is necessary.
Research question 6
Which factors of the ILC hinder the development of construction logistics calculation models?

| Corporate strategy. | • It is observed that main contractors are aware of the benefits of innovation in construction logistics. First, due to efficiencies in construction logistics costs can be reduced. Second, innovative solutions in construction logistics in the Netherlands are rewarded in tenders. Innovation in construction logistics results in a higher possibility to be awarded for projects. It is observed that the corporate strategy does not form a problem for the development of construction logistics calculation models.
  • Main contractors are always looking for new collaborations. But collaborations between contractors are not noticed. E.g. collaborations with IT companies are observed. The use of IT in the construction industry will stimulate the development of reliable construction logistics calculation models. |
| Personal organisation. | • It is observed that personal organisation structures differ per contractor. Each contractor has own work methods to determine construction logistics solutions. A lack in a universal approach to innovation in construction logistics can be seen, from one perspective, as a barrier to develop reliable construction logistics calculation models. From another perspective, this can contribute to the development of construction logistics calculations models because different approaches lead to different lessons learned.
  • It is observed that construction logistics measures are formulated on the tactical level. The strategic level focuses on long-term partnerships and process innovation to address construction logistics measures at potential projects.
  • It is observed that the director needs to inform the departments regarding new work processes regarding construction logistics. This indicates that innovation in construction logistics is a new phenomenon. This can be seen as a barrier.
  • It is observed that subcontractor and suppliers rapidly fall back to their own interest when problems in the logistics planning occur. |
| Supply chain strategy. | • It is observed that horizontal, vertical and longitudinal fragmentation is present in the construction industry and that this hinders the development of reliable construction logistics calculation models. There is mistrust among construction companies. Construction companies need to collaborate in an early stage to create innovation. This is not the case and can be seen as a barrier.
  • Construction logistics awareness is a new phenomenon. This can indicate that knowledge and experiences still need to be embraced by all employees and construction partners. This can be seen as a barrier because the development of reliable construction logistics calculation models requires new work ethics such as the willingness to share data.
  • It is observed that the procurement department in a construction company often focuses on price. Geographic locations are frequently not considered as important. Due to this, inefficient logistics processes often are created. The focus needs to be on partners who have the work ethic to contribute to optimize construction logistics processes. This can be seen as a barrier.
  • Subcontractors and suppliers frequently offer all-in prices for their services. This creates a barrier for innovation because cost prices are unknown. These cost prices are needed to formulate calculations regarding innovative logistics measures. This can be seen as an important barrier.
  • It is observed that KPIs are frequently focused on the construction supply chain. This stimulates the development of reliable construction logistics calculation models. |
| Building Information Modelling. | • IT is far from integrated in the construction industry. This can be seen as a barrier.
  • It is observed that IT problems arise on the tactical level. Problems are related to the supply of incomplete, unsuitable and unrealizable information. Coordination of
information is the biggest barrier for innovation in construction logistics.

- It is also observed that IT is not integrated on the operational level. Due to this, it is not possible to obtain necessary data. This can be seen as a barrier.

| Delivery patterns. | It is observed that materials and construction phases each have different characteristics. These characteristics result into different possibilities regarding innovative measures. This can be seen as a barrier because data are required for each type of construction material and phase. |

| Table 59: Answer RQ 6. |

**Reflection on SMARTSET barriers**

1. **Political support.** It is observed that construction logistics is an important subject in the municipality of XXX. Because several construction logistics calculations models are formalised by the municipality it can be stated that construction logistics is a relevant topic. These assumptions, however, contain too little information for this barrier. *More research is necessary. But for now, this does not forms a barrier.*

2. **Personnel and competence.** It is observed that construction logistics awareness is a new phenomenon. New processes need to be embraced by departments within main contractors and companies on the operational level. Geographic locations of suppliers and subcontractor are frequently not considered in the procurement department. This leads to inefficient logistics flows. It is also observed that companies on the operational level do not see the benefits of innovations in construction logistics. *This forms a barrier.*

3. **Network.** There is no trust between construction companies. To create innovation in construction logistics it is necessary that construction companies collaborate in an early moment in the process. It is observed that this is not the case. The thought is that an early involvement leads to unwanted price discussions. *This forms a barrier.*

4. **Identification of value.** It is observed that main contractors see the value of innovation in construction logistics. It is observed that not all companies see the value of these innovations. However, suppliers and subcontractor are not included in this deliverable. Information is missing. *For now, this does not form a barrier.*

5. **Invisible transport costs.** It is observed that services and products are offered based on all-in prices. This creates a barrier for innovation because cost prices are unknown. These cost prices are needed to formulate calculations for innovative logistics measures. *This forms a barrier.*

6. **Sharing information.** The problem here is *what* information do we need, *which* company has this information and *who* will edit this information. Due to horizontal, vertical and longitude fragmentations sharing *useful* information is difficult. *This forms a barrier.*

7. **Vehicles.** *No information obtained.*

8. **Location of terminal.** It is observed that main contractors are using CCC for their construction logistics processes. A location can be provided by a 3PL. *This does not form a barrier.*

9. **Enforcement regulations.** *No information obtained.*

10. **Critical mass.** It is observed that construction production determines when a CCC is cost beneficial. This determines the construction logistics solution. *This forms a barrier.*

| Table 60. Reflection on SMARTSET barriers. |
6. Literature list

- Clark, A., Mattisson, PH. (2016). *D6.5 Final results, conclusions and recommendations from SMARTSET*. Gothenburg: SMARTSET.


• Yuan, F. (2011). *A cost-based model for optimizing the construction logistic schedules*. Hong Kong: University of Hong Kong.
7. Appendix

7.1 Interview guide BIM and SCM

BIM

- What is in your eyes the definition of BIM?
- In literature, it stated that by using BIM, construction drawings could be transformed into bill of quantities. What are the major factors that hinder this function?
- Is it possible to connect BIM, GIS and logistics? What are the major factors that hinder this development?
- What possibilities does BIM have in a relation to managing construction logistics? What elements improved significantly in recent years? What elements are being improved nowadays?
- How do you see BIM in 5 – 10 years?
- Which private parties are leading regarding the use of BIM, GIS and logistics? Do you have any contacts?

BIM and SCM

- What is in your eyes the definition of BIM and SCM in the construction sector?
- What aspects have been improved significantly in recent years?
- To what extent has BIM been integrated with SCM at your construction company?
- What are other competing construction companies doing regarding BIM, GIS and SCM?
- What IT factors limit the usefulness of BIM with SCM in practice? What key factor needs to be improved?
- What market factors limit the usefulness of BIM with SCM in practice? What key factor needs to be improved?
- What process factors in the construction chain limit the usefulness of BIM with SCM in practice? What key factor needs to be improved?
- What are in your eyes the first steps that need to be taken to develop a fully integrated BIM/SCM model?
- What developments do you see within 5 years? And 10 years? When do you think a fully integrated system is available?
7.2 Interview guide Construction logistics and tendering

- Do you have quantitative data available regarding the construction production per sector in the municipality of Amsterdam?
- Do you have quantitative data available regarding construction logistics in the municipality of Amsterdam?
- To what extent does the municipality, in an early stage, have insight on the number of construction logistics flows per construction project? What is the source of this data and is it measured, expertise or from literature?
- How is public procurement within the municipality organised? How does it work and what is your opinion?
- To what extent is construction logistics integrated into public procurement regarding construction projects per sector?
- Do you have a reliable insight into the construction logistics processes when documents for the tender are submitted? Which documents do main contractors submit? What information do main contractors give?
- What is your opinion on the functioning of the MEAT/EMVI tender regarding controlling/managing construction logistics? How can it be improved?
- Which changes are needed to manage construction logistics in a better way by using a MEAT/EMVI tender?
- Which aspects of the construction supply chain need change in order to control construction logistics in a better way?

7.3 Interview guide Construction logistics calculation models

- What is the purpose of the model in relation to the corporate strategy of your company?
- On which process of construction logistics does the model focus? Transportation, warehousing or processing?
- Which activities have been examined? Did you experience any difficulties?
- How did you measure these activities? Is data from literature, expertise or measured?
- How did you determine the resources, cost objects and cost drivers?
- Which KPIs did you use?
- How is the model structured?
- Which difficulties did you experience when you were developing this model? What are the weak points of the model?
- How is the connection made between the logistics activities and the construction volume? How did you obtain data from subcontractors and suppliers? Did you experience any difficulties?
- Did you conduct any interviews at other construction partners? What were the lessons learned?
- Is the model verified in practice? What will be the next step regarding this model?

7.4 Interview guide Current state

This interview guide is formulated by Chalmers University of Technology.

Key actors
Who are the stakeholders and what professions do they represent?

What roles and responsibilities do different stakeholders have in the specific project?

Who decides and about what?

Who decides who is going to be responsible for governing and executing logistics in the specific project?

How do stakeholders interact?

Principles for information sharing

How is knowledge exchanged between actors?

What impact does national laws, regulations and traditions have on stakeholders?

What impact does the client have on stakeholders and responsibilities?

Would alternative governance of and by stakeholders be possible in this project?

What are the challenges with regards to stakeholders and governance?

Key resources

What key resources need to be governed?

How is use of resources planned?

How is use of resources organized?

Are there some constraints regarding use of resources?

What do these constraints mean for governing activities?

Would alternative governance of resources be possible in this project?

What are the challenges with regards to resources and governance?

Key activities

What key activities need to be governed?

How is the construction project planned?

How are activities planned?

Are there several planning phases?

Is planning top-down?

What risks are there and how are these managed?

What changes were made and how were these changes managed?

Is planning fragmented?

What planning is strategic?

How is planning standardized?

How are activities coordinated?

How is IT used to coordinate activities?

What impact does the surrounding societal conditions have on activities on-site?

What are the challenges with regards to performing activities and governance?

Describing governance

What type of contract is used and how is the contract set up?

How is tendering conducted?

What is the policy for rewards and penalties?

How is knowledge transferred between construction projects regarding (a) construction logistics and (b) governance?

What are the objectives of governance? What is important to achieve?

What are the challenges of governance? What makes it difficult?

Material flows

How much material enters the construction site?

What different types of materials enter the construction site?
• Are the different types managed differently?
• From how many suppliers is material ordered/delivered?
• Where are suppliers located?
• Are materials consolidated before entering the construction site?
• What requirements are set on delivery windows for material?
• How much time is there between ordering of material and expected delivery? Does this differ depending on the type of material?
• How large share of project turnover is material from suppliers?
• What are the challenges with regards to material flows and governance?

Context of the specific project

• Time frame.
• Client.
• Project size.
• Type of construction/project.
• Location of the construction.