Master Thesis

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Improving the cost efficiency in the supply chain of the Heijmans Woon Concept projects

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Management summary

The research was conducted at the headquarters of Heijmans and commissioned by the residential building department; Heijmans Housing (HH).

Situation and problem statement: In 2016, the Heijmans Woon Concept (HWC) team set the ambition to save up to 10% on the total cost of ownership (TCO) of a HWC house. Over the years they were able to incrementally improve the construction process of HWC projects and reduce the prices of a house, but many improvements have been implemented. To help to fulfil the team's ambition, the focus of this research is improving the first-tier physical distribution streams in the supply chain of HWC projects and to deliver an instantly implementable business case. The highly fragmented nature of the supply chain and the many Cooperating Companies (CCs) that take care for their own physical distribution streams makes it difficult to indicate inefficiencies and to improve the supply chain. The research consist of three phases:

- Phase 1: Mapping the current situation
- Phase 2: Search for optimisation scenarios
- Phase 3: Mapping the optimisation scenarios and comparing to Phase 1

Research question: How can the cost efficiency of the first-tier physical distribution streams in the supply chain of HWC projects be improved during the execution phase of the construction process?

Methodology: A theoretical process model is presented in which the steps made in this research are visualised to get from the current situation of the supply chain to the improved situation. To make a comparison between the current situation and the optimisation scenarios, an activity-based costing (ABC) model is presented in which both supply chains can be mapped. In Phase 1, 29 interviews were conducted to retrieve the required data in order to map the current situation of a case study project. In Phase 2, a literature review and business case meetings with Logistic-Providing Companies (LPCs) were conducted to find optimisation scenarios that improve the cost efficiency in the supply chain of the case study project. Three selected LPCs were invited to make an offer on specifications that fit to the proposed optimisation scenarios. In Phase 3, optimisation scenarios are mapped with the figures of the LPCs. On both mappings of the case study project and optimisation scenarios, ABC analyses were conducted in order to compare them.

Results: The ABC analysis conducted on the mapping of the case study project indicates that 6.64% of the total building sum is spend on logistics costs, with a total of €210,000. Five different physical distribution stream categories were identified. Three of these categories are selected, based on their fit, to go through the optimisation scenarios. The results of the ABC analyses on the optimisation scenarios, present the potential to improve the cost efficiency of the first-tier physical distribution streams in the supply chain of the HWC projects. The best optimisation scenario shows *a cost savings potential of €23,000, a logistic costs savings potential of around 10% and a profit increase* on the total project in comparison to the analysis conducted on the case study project. These results were attained in an analysis in which all cost parameters were overestimated and all cost saving parameters were underestimated. In practice, the scope of the cost savings could even be higher. The logistic hub proves to lower the logistic costs of the optimisation scenarios, but the costs of the logistic hub need to be compensated for by increased productivity. The increased productivity is hard to calculate and results from the carry-on approach that reduces the costs of the on-site

logistics activities: waiting, finding and transporting of goods. In the optimisation scenarios the transports of the waste streams are carried out by the LPC eliminating the corresponding transport costs. The waste stream transports are carried out With an expected 600 houses to be built in 2016, *the extrapolated cost savings potential per year is around €300,000*. The cost savings potential is not sufficient to help to fulfil the team's ambition to save up to 10% on the TCO of a HWC house, but could be implemented as part of the solution.

Next to the above financial considerations, the implementation of the optimisation scenarios results in the following:

- coordinated first-tier physical distribution streams;
- increased productivity;
- higher delivery accuracy.

Practical recommendations:

- Implement the logistic hub in the supply chain of the HWC projects:
    - outsource the logistic hub to a LPC;
    - the logistic hub should have a variable location to follow the projects locations.
- Continue to improve the physical distribution streams categories that do not go through the optimisation scenarios.
- Investigate in which other business areas a logistic hub is beneficial.

A plan of action is presented with the five steps required to implement the logistic hub for the HWC projects.

Preface

Dear reader,

This document is the end product of my study period at the University of Twente and seven months of hard work at the company Heijmans in Rosmalen, the Netherlands. After one and a half year of studying Civil Engineering and Management I changed my interest into the study International Business Administration. In the bachelor phase I got excited about logistics and supply chain Management due to the interesting courses on these topics. Also work that I did in a large warehouse triggered my interest into the logistics field. The warehouse was subject to a large improvement project that focused on various material handling disciplines inside the warehouse, as well as the supply chain to and from the warehouse. I joined the improvement team that was able to boost the production output while using less employees. Moreover, the employees that were able to stay could work more structured and were more pleased with their jobs. After a break of six months of working in and travelling through Asia, I started my Master Business Administration once again at the University of Twente. In the first and second quartiles courses were elected from the specialisation tracks 'Information Management' and 'Supply Chain Management and Purchasing'. I decided to start searching for a master's thesis project at a company in the subject supply chain Management and Purchasing. I successfully applied at Heijmans in Rosmalen, the Netherlands, and the research period started the 19th of October 2015. The proverbial circle was now complete. The knowledge attained at the Propaedeutic phase of the Civil Engineering and Management, together with the knowledge of the Bachelor and Master phase of the (International) Business Administration are all used in this master's thesis research project.

Special thanks goes out to my supervisors from Heijmans, that are Esther Donders, Pim Ketelaars and Theo van der Plas, for their support, advice, carpool sessions, conversations and guidance during the internship at Heijmans. Moreover, special thanks goes out to all the colleagues for their advice, listening ears, borrowing of lease cars and filling them up with fuel such that I was able to travel the country by car instead of train saving many of time. Also special thanks to all the CCs and employees that freed up time and were open to share the data necessary for this master's thesis research. Lastly special thanks goes out to my supervisors from the University of Twente that are Dr. Peter Schuur and Dr. Hans Voordijk for their guidance, support, conversations and time.

I wish you the greatest of pleasure with the reading of my master's thesis.

If there are any question or remarks, please feel free to contact me.

With kind regards,

R.M. Bloemheuvel

Definitions

There is no definition of 'supply chain' in literature that fits one to one to the scope of this research and therefor a combined definition is proposed [25, p. 450]; [90, p. 338]; [16, p. 403]. The definition of supply chain used to express what is to be optimised in this research is:

The total physical distribution streams of goods and employees from the first-tier suppliers to the construction site and vice versa.

Other definitions in this research:

Cooperating Company: *all the companies that carry out a construction activity in the construction process of the HWC projects.*

Logistics: *the movement of the forward as well as backwards physical distribution of goods and transport of employees.*

Optimisation Scenario: *a scenario being able to improve the physical distribution streams in the supply chain as well as its ability to incorporate other optimisation possibilities.*

Physical Distribution: *the streams of construction materials from the initial manufacturer up to the construction site* [16, p. 403]; [21, p. 325]; [108, p. 458].

Supply Chain Management: *the organisation, management and control of the supply chain* [25, p. 450]; [69, p. 420]; [4, p. 160].

List of abbreviations

3PL	3rd Party Logistics
4PL	4th Party Logistics
ABC	Activity-Based Costing
APS	Advanced Planning System
BIM	Building Information Model
CC	Cooperating Company
EDI	Electronic Data Interchange
ERP	Enterprise Resource Planning
ESI	External Systems Integration
FLTR	From Left To Right
FTL	Full Truck Loads
HH	Heijmans Housing
HWC	Heijmans Woon Concept
ISI	Internal Systems Integration
IT	Information Technology
K	1.000
KM	Kilometre
LP	Lean Production
LPC	Logistics-Providing Company
M	1.000.000
MEAT	Most Economically Advantageous Tender
TCO	Total Cost of Ownership
VCA	Safety, Health and Environment

List of figures

List of tables

Table of content

1 Introduction

In this chapter, the introduction and the setup of the research are elaborated upon, followed by the motivation and methodology of the research. The chapter ends with a reading guide that visualises the overall setup of this master's thesis.

The structure of Chapter 1 is as follows:

- 1.1 Heijmans company;
- 1.2 Motivation for the research;
- 1.3 Problem statement;
- 1.4 Research scope;
- 1.5 Research goals and objectives;
- 1.6 Research questions;
- 1.7 Methodology;
- 1.8 Reading guide.

To complete the Master's in Business Administration at the University of Twente, I conducted my master's thesis at the headquarters of the company Heijmans in Rosmalen. The research was commissioned by and carried out for the Heijmans Housing (HH) department, under guidance of the procurement department. HH is responsible for the Heijmans Woon Concept (HWC) house-building projects that follow a concept-based approach. The ambition is set by the HWC team to save 10% on the total cost of ownership (TCO) for a HWC house [48, p. 9]. To achieve its ambition, HH can choose to focus on incremental product improvements or it can change the daily routine of the construction process radically. One of the areas to look for relevant cost savings is the optimisation of the supply chain. The goal of the research is to improve the first-tier physical distribution streams in the supply chain of HWC house-building projects and to reduce the TCO of the HWC houses.

A theoretical process model is presented in Chapter 2 in which the ten steps made in this research, to get from the current situation of the supply chain to the improved situation, are visualised. To make a comparison between the current situation the case study project supply chain in Chapter 4 and the improved supply chain of the optimisation scenarios in Chapter 6, an ABC model is presented in Chapter 3, in which both supply chains are mapped.

The research has three phases, which correspond to the following chapters:

Phase 1	Chapter 4	*Mapping the case study project with the use of the activity-based costing (ABC) approach.*
Phase 2	Chapter 5	*Literature review and business case meetings on (construction) Supply Chain optimisation possibilities.*
Phase 3	Chapter 6	*Mapping the optimisation scenarios with the use of the ABC approach.*

In this first section the company Heijmans and HH are briefly elaborated upon.

1.1 Heijmans company

Heijmans is a stock-market-listed international construction and service company that combines activities in real estate, housing, non-residential and infrastructure in the working areas, for living, working and connecting [47, p. 1]. It focusses on continuous quality improvement, innovation and integrity, whereby added value is realised for its customers. Heijmans had six thousand eight hundred employees and a turnover of nearly two billion euro in 2015 [47, p. 12]. The history of Heijmans begins in 1923 as a paving company in Rosmalen. After the second world war, there were ample opportunities for growth in the post-war reconstruction period, with restoration and the construction of roads and airports [44, p. 12]. In 1993, Heijmans obtained a listing on the Amsterdam Exchanges, which gave the company a new source of capital and enabled further growth and acquisitions [44, p. 12]. Heijmans is active in the Netherlands, Germany and Belgium [44, p. 12]. The performance of the infrastructure department still effects the overall results of Heijmans due to loss-making projects, disputes and the general market situation [44, p. 6]. After years of disappointing results, the figures for 2015 demonstrate recovery based on the outcomes of the hard work of Heijmans to generate profit once again [46, p. 36]. The turnover illustrates an increase of 6% and a net result of 27 million negative. The shareholders reacted positive with an increase of the shares quotation of 40% in the time period the 8th of February 2016 to the 8th of March 2016.

The business areas Heijmans is active in are [44, p. 12]:

- *Residential building:* The core of this business area is to build different types of houses and restorations (hereafter referred to as Heijmans Housing (HH).
- *Property development:* The core of this business area is development of both large and smaller-scale projects on mainly residential properties.
- *Non-residential building:* The core of this business area is to realise complex, large-scale buildings in the customer and market segments of health care, government and the semi-public sector.
- *Infra:* The core of this business area are road and civil activities that are focusing on the building, maintenance and improvement of infrastructure and on location-linked infrastructure above and below ground, such as viaducts, tunnels, pipelines, sluices, etc.

1.1.1 Heijmans Housing

As stated in the previous section, the core business of HH is to build different types of residential buildings such as houses. HH had a net result of €15M and a turnover of €295M in 2015, and an increase of 33% in sold houses in comparison to 2014 [46, p. 48]. HH has branches in the regions Rosmalen, Rotterdam, Amersfoort, and Huizen, by which it covers the Netherlands as a whole. HH offers an integrated proposition to customers, from idea to realisation, maintenance and service [44, p. 11]. HH changed its strategy radically when the crisis hit in 2008 and started to focus on adding value based on the integration of its business units. By improving its processes, efficiency and funding relationships, HH created the space in which it launched innovative ideas and differentiated itself in the market [44, p. 12]. An example of such innovative ideas are the HWC and the Heijmans One. €102M is generated by land-based houses from which €48M is HWC related. After years of disappointing results the housing market is showing signs of recovery [44, p. 12]. During the housing crisis in the Netherlands HH developed the HWC in 2013. In the next section the motivation for the research is set out.

1.2 Motivation for the research

HH needs to offer low prices and prime quality to win tenders and to secure new house-building projects from its competition [63, p. 16]; [112, p. 108]. The current target of the HWC is to save 10% on the total cost of ownership (TCO) of a HWC house as visualised in Figure 1 [48, p. 9]. The upper green line is the price level for which HH was able to build the HWC house type; the B01. This type of HWC house is built in 90% of the time. During the years, they were able to incrementally improve the construction process and lower the price of a house. The red area indicates the unforeseeable price risings due to extra governmental regulations. The HWC team recognised that, on the short-term, not that many costs advantages are to be expected. In order to make up for the unforeseeable costs and to meet the ambition the costs to manufacture a house need to be reduced. HH recognises that many large and small improvements and cost savings possibilities at the HWC have been implemented [45, p. 100]; [87, p. 76]. To meet the ambition it requires innovations that change the daily routine of the construction process radically. One of the areas to look for relevant cost savings is the optimisation of the supply chain [73, p. 795].

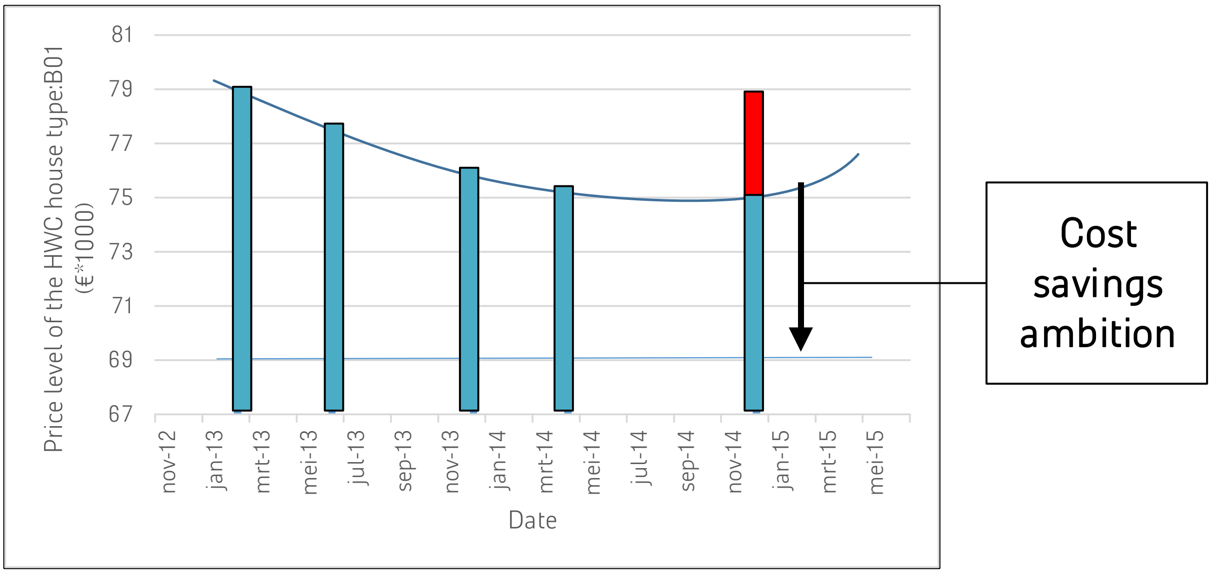

FIGURE 1: PRICE LEVEL OF THE HWC HOUSE TYPE; THE B01.

In the long-term sustainability strategy '*the outlines of tomorrow*', Heijmans recognises that the world is changing fast. The construction industry has the chance to incorporate sustainable designs in the constructed surroundings of the world [44, p. 24]. On short-term and as part of this strategy, the procurement department works continually to raise awareness for reducing the number of transports. The possibilities for logistical cooperation on projects are investigated in practical terms [45, p. 217]. The number of transports required in the construction process are being limited by Heijmans but also by its clients. At the same time, the timely availability of products is improved [45, p. 217]. At the HWC the costs of transport may be as high as 10% of the total construction costs, and around 75% of the turnover is being purchased, indicating the many physical distribution streams to and from construction sites [15, p. 33]; [92. p. 73].

A thorough understanding of the physical distribution streams in the supply chain of the HWC projects contributes to effectively analyse and improve the physical distribution streams. In its turn, this contributes to indicate optimisation possibilities that fit to the HWC projects that lead to cost savings. Moreover, low house prices can increase the number of HWC projects HH incorporates in the future [110, p. 136]; [73, p. 795]. In the next section, the problem statement is elaborated upon,

1.3 Problem statement

A normal construction supply chain is complex and highly fragmented making it difficult to indicate inefficiencies and to improve the supply chain [99, p. 6]. This results in many different physical distribution streams, as visualised in Figure 2 on the next page in a simplification of the general construction supply chain [31].

The blue arrows in Figure 2 are the second-tier transports of goods from the factories of the manufacturers to the Cooperating Companies (CCs). The green arrows are the first-tier transports of goods from the factories of the manufacturers directly to the construction site. Both have a capacity usage percentage of around 45%. The red arrows are the first-tier transports from the CCs to the construction site with a capacity usage percentage of around 30%, resulting in an average percentage of capacity usage of 40% for the physical distribution streams in the supply chain of a construction project [68, p. 1].

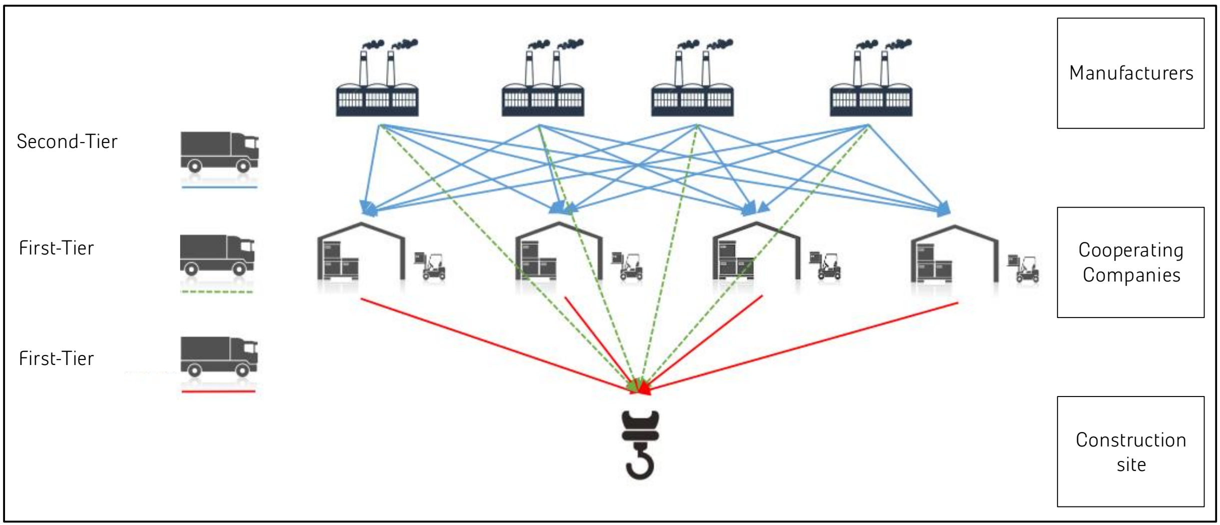

FIGURE 2: SIMPLIFICATION OF THE PHYSICAL DISTRIBUTION STREAMS IN THE SUPPLY CHAIN OF A NORMAL CONSTRUCTION PROJECT.

At the HWC projects, the supply chain is even more complex due to the various different construction sites. In the construction process of the HWC, many CCs take care of their own physical distribution. The CCs are all the companies that carry out a construction activity in the construction process of the HWC projects. Stock is kept by nearly all CCs separately, and no synchronisation of physical distribution streams take place between them. At this moment, it is nearly impossible for the HWC team to optimise the physical distribution streams in the supply chain of the HWC due to complexity and the fragmented nature. In Figure 3 a simplification of the HWC projects supply chain and the physical distribution streams is presented.

Below the problem statement and the two hypotheses of this research are presented.

The problem statement:

'Highly fragmented nature of the physical distribution streams in the supply chain of the HWC projects that are carried out by (too) many, and with little synchronisation between, the Cooperating Companies'.

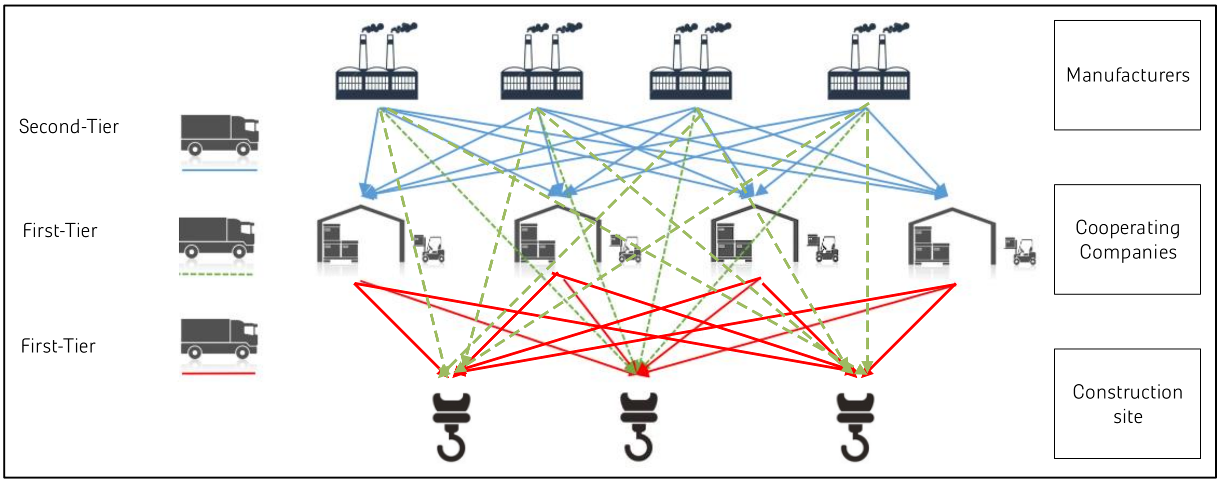

FIGURE 3: SIMPLIFICATION OF THE PHYSICAL DISTRIBUTION STREAMS IN THE SUPPLY CHAIN OF THE HWC PROJECTS.

Hypothesis 1:

The highly fragmented nature of the physical distribution streams in the supply chain of the HWC projects that are carried out by (too) many Cooperating Companies results in an inefficient supply chain with high costs.

Hypothesis 2:

The highly fragmented nature of the physical distribution streams in the supply chain of the HWC projects that are carried out with little synchronisation between the Cooperating Companies results in an inefficient supply chain with high costs.

In the next section the research scope is presented.

1.4 Research scope

The scope of the research is:

- The first-tier physical distribution streams in the supply chain of the HWC projects as stated in Step 1 of section 2.1 [10, p. 14]. The first-tier physical distribution streams are visualised as the red and green lines in Figure 3. That are:
  - materials and products;
  - equipment;
  - transport of employees.

  The research does not focus on the less obvious non-physical logistics cost elements such as risk costs, administration costs, information sharing costs, etc.
- The cost elements of the physical distribution streams in the supply chain of the HWC projects as set out in Step 2 of section 2.1:
  - transport;
  - handling;
  - inventory and warehousing;
  - on-site logistics.

  In the interviews with the CCs, the cost elements inventory and warehousing were not present in any of the CCs' data. The information of these costs is hidden in the overhead and not directly passed on to the buyer and thus not available.
- The supply and on-site logistics as set out in Step 3 of section 2.1 [87, p. 76].
- The construction phase of the construction process of the HWC projects [32, p. 145].

Now that the research scope is presented, the goals, general and chapter specific objectives and the deliverable of the research are set out.

1.5 Research goals and objectives

The goal of this research is to improve the first-tier physical distribution streams in the current supply chain of the HWC projects and to deliver an instant implementable business case. The results should lower costs and increase the margins on the houses.

The objectives of the research are:

General objective:

- To propose an ABC model in which the first-tier physical distribution streams of a construction supply chain can be mapped.

Phase 1: Mapping the case study project with the use of the ABC approach;

- To map the case study project with the ABC approach.

Phase 2: Literature review and business case meetings on (construction) supply chain optimisation possibilities.

- To perform an extended research in literature on supply chain optimisation possibilities;
- To discuss the problem statement in the form of business case meetings with selected LPCs active on the Dutch market;
- To propose optimisation scenarios based on the literature research and business case meetings.

Phase 3: Mapping the optimisation scenarios with the use of the ABC approach.

- To map the optimisation scenarios with the ABC approach;
- To compare the results of the ABC analysis conducted on the mapping of the supply chain of the optimisation scenarios to the results of the ABC analysis conducted on the mapping of the case study project.

1.5.1 Deliverable

Deliverable: An ABC model in which the ABC analysis can be mapped for the HWC projects.

In the next section, the research questions are presented.

1.6 Research questions

This research has one central research question, three main questions and thirteen sub-questions as presented in the same sequence below.

Research question:

How can the cost efficiency of the first-tier physical distribution streams in the supply chain of the Heijmans Woon Concept projects be improved during the execution phase of the construction process?

The research question is derived from the goal and objectives presented in section 1.5. In order to answer the research question it is split down into three Main Questions that each are divided into multiple sub-questions.

Phase 1: Mapping the case study project with the use of the ABC approach.
Main Question one:

1.0 How are the first-tier physical distribution streams in the supply chain of the case study project composed during the execution phase of the construction process?
   - *1.1 What are the characteristics of the HWC?*
   - *1.2 What are the characteristics of the case study project?*
   - *1.3 What are the characteristics of a construction supply chain?*
   - *1.4 What are the results of the ABC analysis conducted on the mapping of the case study project?*

Phase 2: Literature review and business case meetings on (construction) supply chain optimisation possibilities.
Main Question two:

2.0 Which supply chain optimisation possibilities can be transformed into optimisation scenarios that fit the case study project?
   - *2.1 Which construction supply chain optimisation possibilities can be derived from the literature research?*
   - *2.2 Which construction supply chain optimisation possibilities can be derived from the meetings conducted with the selected logistics-providing companies?*
   - *2.3 Which supply chain optimisation possibilities can be transformed into optimisation scenarios based on sub-question 2.1 and 2.2?*
   - *2.4 Which supply chain optimisation possibilities and optimisation scenarios fit to the physical distribution categories that resulted from the ABC analysis conducted on the case study project?*
   - *2.5 What are the characteristics of the selected supply chain optimisation scenarios?*

Phase 3: Mapping the optimisation scenarios with the use of the ABC approach.
Main Question three:

3.0 Which supply chain optimisation scenario has the highest potential to improve the cost efficiency of the first-tier physical distribution streams in the supply chain of the HWC projects?
   - *3.1 What are the figures of the offers from the logistics-providing companies?*
   - *3.2 What are the prerequisites of the optimisation scenarios to start the ABC analysis?*
   - *3.3 What are the results of the ABC analyses conducted on the mapping of the optimisation scenarios?*
   - *3.4 What are the benefits and challenges of the optimisation scenarios?*

In the next section, the corresponding mythology of the research question is elaborated upon.

1.7 Methodology

The purpose of this section is to elaborate on the methodologies used per main and sub-question. In total 29 interviews and 24 company visits were conducted. Some of the company visits took place on the location of the case study project in Waalwijk.

1.0 *How are the first-tier physical distribution streams in the supply chain of the case study project composed during the execution phase of the construction process?*

This first Main Question is divided into four sub-questions.

1.1 *What are the characteristics of the HWC?*
Methods:

- review on the data present at the Heijmans documents and Intranet;
- pre-structured open conversations conducted with employees of HH.

See Section 4.1.

1.2 *What are the characteristics of the case study project?*
Methods:

- review on the data present at Heijmans documents and Intranet;
- construction site visits;
- pre-structured open conversation with HH employees;
- study in the Kyp program;
- pre-structured open interviews with employees of the CCs.

See Section 4.2.

1.3 *What are the characteristics of a construction supply chain?*
Methods:

- literature review on the construction supply chain;
- observations on the construction sites of HWC projects;
- observations at the CCs' facilities.

See Section 4.3.

1.4 *What are the results of the ABC analysis conducted on the mapping of the case study project?*
Methods:

- pre-structured open interviews with employees of the CCs;
- pre-structured open conversations with the employees of HH;
- pre-structured conversations with the executor of the project from HH;
- e-mail conversations;
- telephone conversations;
- ABC analysis conducted on the mapping of the case study project.

See Section 4.4.

All the information retrieved from the interviews on the logistics activities, the links between the activities and the cost information of the first-tier physical distribution streams in the supply chain of the case study project, is inserted into the ABC model in Microsoft Excel. In section 3.2, the setup of the ABC model is presented.

2.0 *Which supply chain optimisation possibilities can be transformed into optimisation scenarios that fit the case study project?*

The second Main Question is divided into five sub-questions.

2.1 *Which construction supply chain optimisation possibilities can be derived from the literature research?*
Methods:
A literature review is conducted on finding possible supply chain optimisation possibilities in a general and construction supply chain context. The literature review is conducted in the library of the University of Twente, the University of Utrecht, study books and on Google Scholar. In order to increase the accuracy of the literature review synonym searches were performed, and the articles read were documented and categorized.
See Section 5.1.

2.2 *Which construction supply chain optimisation possibilities can be derived from the meetings conducted with the selected logistics-providing companies?*
Methods:
Business case meetings are conducted with LPCs to find construction supply chain optimisations possibilities in the context of the problem statement of this research. Quick scans are conducted on the Internet to find LPCs active in the Dutch logistics providing industry.
See Section 5.2.

2.3 *Which supply chain optimisation possibilities can be transformed into optimisation scenarios based on sub-question 2.1 and 2.2?*
Methods:
The outcomes of sub-question 2.1 and 2.2 are combined and transformed into optimisation scenarios. The optimisation scenarios are based on two aspects:

- analysis conducted on the optimisation possibilities from the literature review;
- analysis conducted on the optimisation possibilities of the business case meetings.

The optimisation scenarios are summarized and presented along with the insights that are gathered during the research [60, p. 2].
Method: The results of Main Question 1 and 2 are analysed and compared.
See Section 5.3.

2.4 *Which supply chain optimisation possibilities and optimisation scenarios fit to the physical distribution categories that resulted from the ABC analysis conducted on the case study project?*
Methods:
The optimisation possibilities and optimisation scenarios that results from section 5.3 are matched with the five physical distribution stream categories that resulted from the ABC analysis conducted on the mapping of the case study project in section 4.4.

See Section 5.4.

2.5 *What are the characteristics of the selected supply chain optimisation scenarios?*
Methods:
The supply chain Optimisations Scenarios are reflected against the theory that was retrieved from the literature review and visualisations of the optimisation scenarios are presented.
See Section 5.5.

The proposed optimisation scenarios are mapped and calculated with the use of another ABC analysis in order to answer Main Question 3.0.

3.0 *Which supply chain optimisation scenario has the highest potential to improve the cost efficiency of the first-tier physical distribution streams in the supply chain of the HWC projects?*

The third Main Question is divided into four sub-questions:

3.1 *What are the figures of the offers from the logistics-providing companies?*
Methods:
Three LPCs are invited to make an offer. The offers and specifications on the offers were communicated by telephone conversations, e-mails and the program 12build.nl, which is a cloud solution used by Heijmans, by which companies can easily ask other companies to make an offer [1].

See Section 6.1.

3.2 *What are the prerequisites of the optimisation scenarios to start the ABC analysis?*
Method:
For Optimisation Scenarios 1 and 2 an analysis is made on which physical distribution streams fit to go through a logistic hub and what prerequisites we need to understand to conduct the ABC analyses on the optimisation scenarios.
See Section 6.2.

3.3 *What are the results of the ABC analyses conducted on the mapping of the optimisation scenarios?*
Method:

- ABC analysis conducted on the mapping of the optimisation scenarios;
- spend analysis to find the labour costs;
- comparison between the results of the ABC analyses conducted on the mapping of the case study project and the mapping of the optimisation scenarios.

See Section 6.3.

3.4 *What are the benefits and challenges of the optimisation scenarios?*
Method:
The benefits of the optimisation scenarios are elaborated upon based on practice and literature. See Section 6.4.

In Appendix 9.1, the request for cooperation that was send to the CCs is presented. In the next section, the reading guide of the research is presented.

1.8 Reading guide

So far, the setup of the research is elaborated upon. This section visualises and describes the setup of the master's thesis.

Chapter 1: Introduction and methodology;
Chapter 2: The theoretical process model;
Chapter 3: The ABC model to map the supply chain;
Chapter 4: The case study project and the results of the ABC analysis;
Chapter 5: Supply Chain optimisation scenarios;
Chapter 6: ABC analysis of the three optimisation scenarios;
Chapter 7: Discussion;
Chapter 8: Conclusions and recommendations.

In Figure 4 a visualisation is presented on the structure of this master's thesis document.

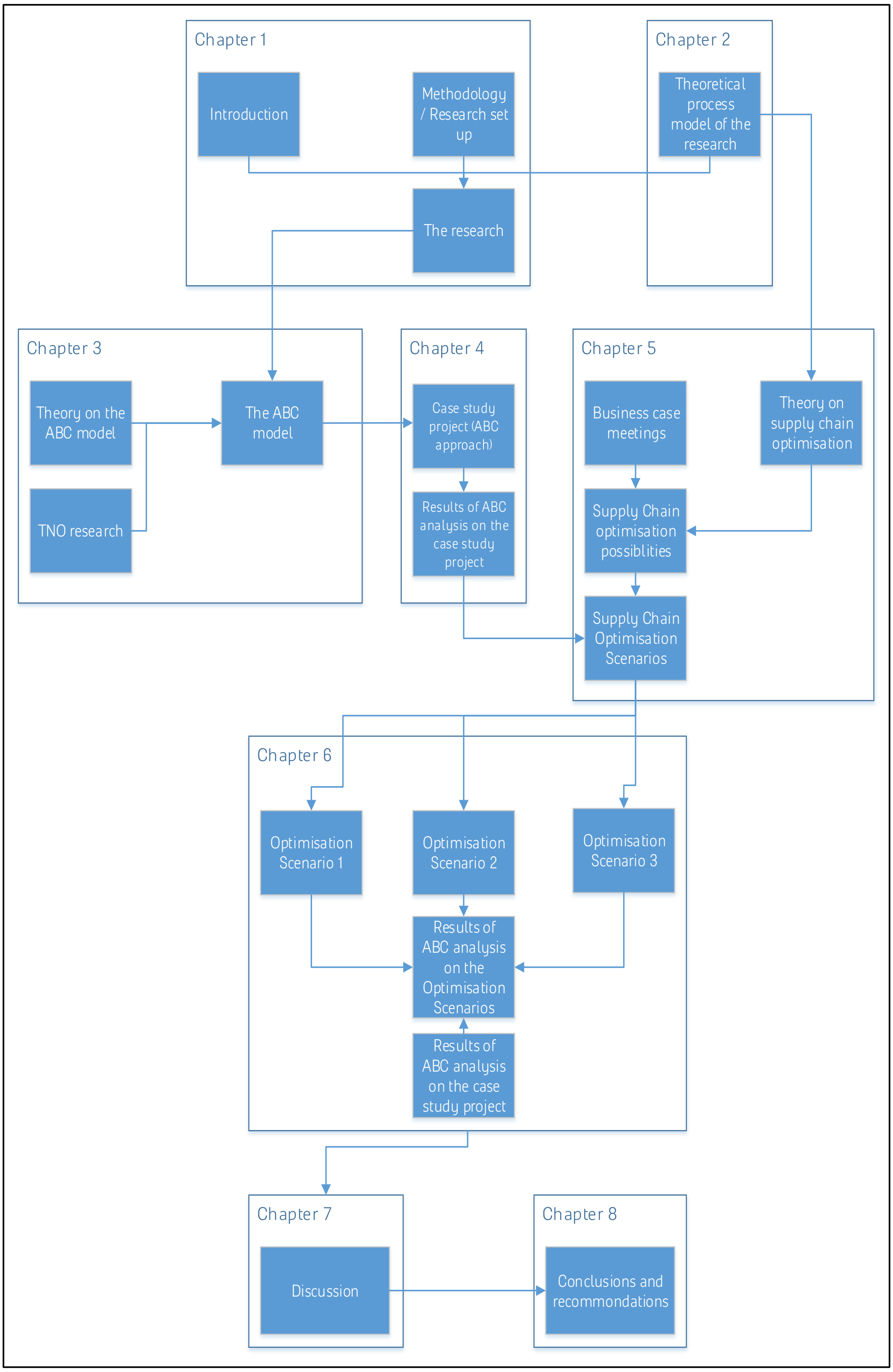

FIGURE 4: READING GUIDE.

This chapter elaborated upon the introduction, setup and methodology of the research. In the next chapter, the ten steps of the theoretical process model required to move from the current supply chain to the improved supply chain are set out.

2 The theoretical process model of the research

In this chapter we elaborate upon the theoretical process model of the research.

The structure of Chapter 2 is as follows:

2.1 The theoretical process model.

In Figure 5, the visualisation of the theoretical process model is presented. The numbers in Figure 5, are used to elaborate on the ten (theoretical) steps required to move from the current supply chain (ist-situation) to the optimised supply chain with improved cost efficiency for the first-tier physical distribution streams in the HWC projects (soll-situation). This research follow these steps.

2.1 The theoretical process model

The starting point of the theoretical process model is the supply chain that has been defined as:

The total physical distribution streams of goods and employees from the first-tier suppliers to the construction site and vice versa.

The ten steps presented in Figure 5 are:

Step 1:

In the supply chain of the HWC projects there are different physical distribution streams that are divided into four categories [97]:

- materials and products;
- equipment;
- transport of employees;
- a combination of these three.

A construction activity carried out by a CC can exist of multiple physical distribution streams and categories.

Step 2:

The physical distribution streams of Step 1 have different logistics cost elements [61, p. 2]; [92, p. 77]; [117, p. 318]. The cost elements are [10, p. 14]; [108, p. 460]; [95, p. 1]:

- transport;
- handling;
- inventory and warehousing;
- on-site logistics.

In this research we focus in Phase 1, *mapping the case study project with the use of the ABC approach*, on the supply logistics. In Phase 3, *mapping the optimisation scenarios with the use of the ABC approach*, the focus is extended with on-site logistics as stated in the research scope in section 1.4 [87, p. 76].

- *Supply logistics*: all the physical distribution streams to and from the construction site (external logistics).
- *On-site logistics*: all the physical distribution on the construction site itself (internal logistics).

Supply logistics:

Transport cost: The costs primarily depending on the type and number of goods carried from location to location, the mode of transport, the vehicle size, consignment size and the distance between locations [108, p. 461].

Handling costs: The costs associated with loading and unloading, internal transport, stocking up and stocking out, picking, assembling and packing [108, p. 460]; [16, p. 220].

Inventory costs: The costs that are determined by interest, obsolescence and spoilage based on the average quantity of stock held per year of a certain product expressed in euros per unit of stock [108, p. 460].

Warehousing costs: The costs associated with land, buildings and services such as electricity usage.

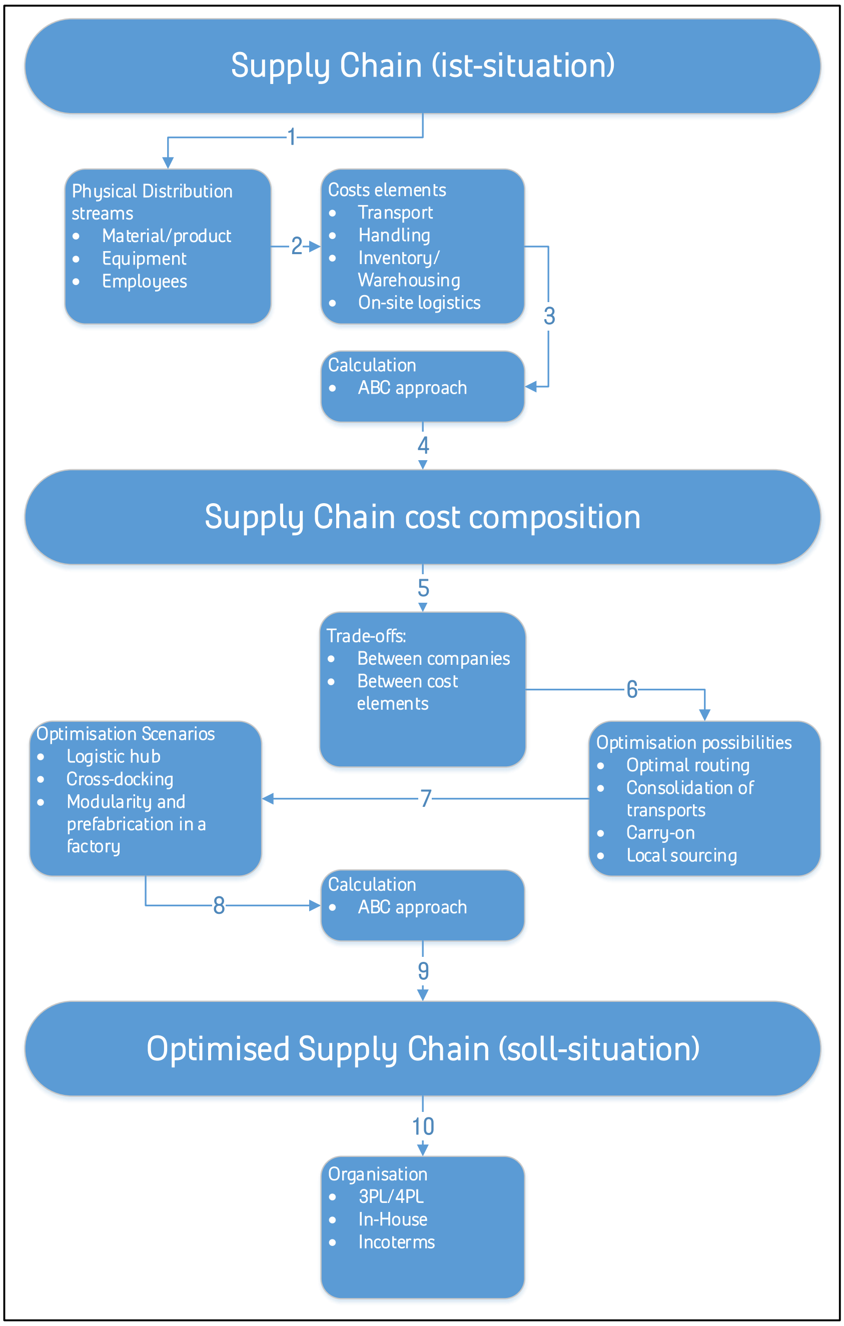

FIGURE 5: THE THEORETICAL PROCESS MODEL OF THE RESEARCH.

On-site logistics:

On-site logistics costs: The costs associated with waiting, finding and transport of goods on the construction site [102].

The on-site logistics costs result from a spend analysis that is conducted on the building sums of all the CCs of the case study project. Up to 50% of the construction costs can be labour related [31]. 6.25% of the productivity time of the construction employees is spend on waiting, finding and transporting of goods on the construction site [102]. To calculate the on-site logistics costs we need to make two steps.

Step 1: Calculate the labour costs of the construction activities;
Step 2: Calculate the on-site logistics costs. The on-site logistics costs result from taking 6.25% of the labour costs.

Improvements in the supply logistics offer improvement possibilities for the on-site logistics and vice versa.

Step 3:

The ABC approach has been used by many researchers for the identification of the cost composition of the physical distribution of goods in the (construction) supply chain [108, p. 459].

There are four steps in the ABC approach [36, p. 104]:

1. assigning and analysing the activities;
2. gathering the cost data and tracing the costs to activities;
3. establishing the output;
4. identifying activity drivers and analysing the costs.

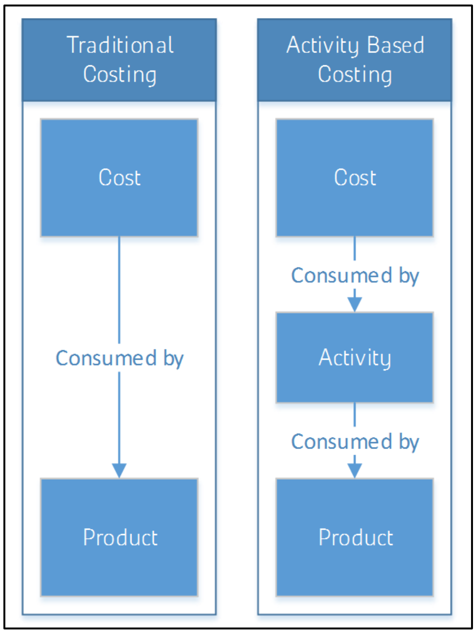

Figure 6: Difference between traditional costing (L) and Activity-Based Costing (R).

The CCs and the construction activities they carry out are the units of analysis of the ABC approach in Step 3. In the first-tier physical distribution streams of the construction activities in the supply chain of the HWC projects the logistics cost elements (Step 2) are found. The ABC approach states that all activities need to be understood in terms of how they affect and are affected by other elements and activities with which they interact [74, p. 93]. The ABC approach calculates the costs of individual activities and assigns those costs to cost objects, products and services on the basis of the activities undertaken to produce them as visualised in Figure 6 [52]. The ABC approach is used in this research due to its ability to allocate costs to individual construction activities and its ability to disclose hidden logistic costs in price formation of products [89, p. 566]. The costs of the first-tier physical distribution streams have to be summed up accurately in order to be able to lower logistics cost and improve efficiency. If not done correctly, it is difficult to take measures that lower logistics cost [89, p. 566].

Step 4:

The ABC approach is used to map the current composition of the first-tier physical distribution streams in the supply chain of the case study project (ist-situation). An ABC analysis is conducted on this mapping of the case study project to calculate the logistic (cost) composition.

Step 5:

To improve the cost efficiency of the first-tier physical distribution streams in the supply chain insights into the trade-offs of physical distribution cost patterns in the specific setting of construction supply chains are necessary [73, p. 795]; [108, p. 457]. The identification of cost trade-offs to optimise successfully is the crux of efficient management in a (construction) supply chain [74, p. 93]. There are two trade-off categories [10, p. 14]; [108, p. 460]; [95, p. 1]:

1. between CCs;
2. between cost elements.

An increase in one cost element might be necessary in order to decrease the cost of another cost element resulting in lower total costs [28, p. 28]. In this case, the company making higher costs should be compensated by the cost savings of the other companies. An example of a trade-off is found in direct delivery involving an increase in transport costs that should be sufficiently offset by a decrease in handling costs. If not, transport through intermediary companies are more beneficial. A second example are materials transported through an intermediary company that reveal an increase in handling costs, whereas transport costs and handling costs of the manufacturer and at the construction site decrease. This demonstrates the interdependence of the transport and handling costs elements [108, p. 467].

In a distribution centre, goods are first received and then stored. When there is a customer demand for an item, employees pick it from storage and ship it to the destination. The four major functions of warehousing are:

- receiving;
- storage;
- order picking;
- shipping.

The functions storage and order picking are typically costly, due to, respectively, the inventory holding costs and the labour time required.

Step 6

There are many optimisation possibilities to improve the physical distribution streams in the supply chain of the HWC projects as set out in Section 4.1 and Appendix 9.3:

- optimal routing;
- transport consolidation;
- carry-on approach;
- local sourcing;
- control tower;
- waste management;
- reverse logistics;
- modularity and prefabrication in a factory;
- logistic hub;
- cross-docking.

Step 7

In this step the optimisation possibilities are analysed resulting in supply chain optimisation scenarios in which the physical distribution streams of the construction activities are improved. The optimisation scenarios are selected on their fit with the results of the case study and their ability to be the change of the daily routine of the construction process to reduce the costs of the HWC houses.

Step 8

The changes that occur with the implementation of the optimisation scenarios are inserted in this mapping of the case study project from Step 4 to map the new first-tier physical distribution streams in the supply chain of the optimisation scenarios. An ABC analysis is conducted on this mapping to calculate the logistic (cost) composition of the optimisation scenarios.

Step 9

The outcomes of the ABC analysis from Step 8 result in an improved supply chain with improved physical distribution streams (soll situation). The logistics costs of the new improved construction supply chain of the HWC projects should demonstrate a drop in construction costs such that the logistic cost savings can help to meet the ambition of the HWC team to save up to 10% on the TCO of a HWC house as stated in section 1.2.

Step 10

The optimised supply chain is carried out and organised either in-house or is outsourced to a LPC. Many industries attempt to integrate physical distribution processes into the supply chains of suppliers and customers, starting with obtaining raw material, through manufacturing, distribution and final sale and service to the end-user [92, p. 73]. Physical distribution processes, being crucial for successful completion of the construction project are often entrusted to external professionals specialized in logistic services (3PL and 4PL) [92, p. 73]. Supply as in ordering, transport and storage, and production dominate the physical distribution processes [87, p. 2]. Due to organisational and technological reasons supply and production are often difficult to separate. At present, in a well-developed market for building materials and services, centralising and outsourcing the project supply chain physical distribution is considered to be an efficient solution facilitating higher project control [87, p. 2]. Two types of LPCs are:

3PL: 3rd Party Logistics is the supply chain practice where one or more logistic functions are outsourced to a 3PL provider. Services that a 3PL player can conduct are repackaging, assembling or prefabrication and return logistics by using its own assets and resources [23, p. 311].

4PL: 4th Party Logistics is the supply chain practice where a company manages resources, capabilities and technologies of their own company, and at the same time, complements it with services of multiple logistic operators such as transport companies and storage agents [23, p. 317].

Incoterms can help to regulate and uniform the supply chain and the physical distribution of goods as set out in Appendix 9.3.12.

Summary Chapter 2

In this chapter we presented the theoretical process model that is used in this research. The process model starts with the current situation of the first-tier physical distribution streams in the supply chain of the case study project and sets out the steps that lead to the improved situation of the first-tier physical distribution streams in the supply chain of the case study project. In the next chapter, (theory on) the ABC model, Step 3 of the process model, is elaborated upon.

3 The ABC model to map the supply chain

So far, the introduction and the setup of the research have been elaborated upon in Chapter 1, followed by the theoretical process model in Chapter 2. This chapter presents the ABC model used for the mapping and analysis of the case study project in Chapter 4 and the mapping and analysis conducted on the optimisation scenarios in Chapter 6.

The structure of Chapter 3 is as follows:

3.1 The ABC model formation;
3.2 Layout of the ABC model;
3.3 Explanation on the ABC model.

The first section elaborates upon the ABC model formation.

3.1 The ABC model formation

The ABC model used for this research is based on a research of TNO (2013) [97]. The focus of the TNO research was to calculate the benefits of transport over waterways in Amsterdam in comparison to normal over-land transport routes. The framework used in the TNO model is adjusted and extended to the specifications of this research. The ABC model is made in Microsoft Excel and has 36 columns, as visualised in Section 3.2. In the ABC model calculations are made, presented and visualised in the Appendices:

Appendix 9.6: The variables of the calculation formulas;
Appendix 9.7: The calculation formulas.

The next section focusses on the differences between the models.

3.1.1 Differences between the proposed ABC model and the TNO research

In this section, we elaborate on the five differences between the proposed ABC model in this research and the TNO model [97]. In the proposed ABC model:

1. The focus is on all first-tier physical distribution stream categories, as mentioned in Section 2.1.
2. The transport and handling costs are calculated corresponding to the CCs' accounting methods.
3. The costs elements are calculated per activity and first-tier physical distribution stream.
4. Inventory and warehousing costs are added in the optimisation scenarios.
5. On-site logistics costs are added in the optimisation scenarios.

Further elaboration:

1. The combined first-tier physical distribution streams and heavy equipment are added.
2. The calculations of the transport and handling costs in the model of TNO (2013) for their case study project are based on summed up generalised data and standard parameters. For example, to calculate the transport costs, the total kilometres travelled are summed and multiplied by the costs of transport per kilometre, based on one parameter. In the ABC model the transport and handling costs are calculated with the exact data per CC and with the parameters corresponding to the CCs.

3. In the ABC model, the costs are calculated for all CCs separately, as presented in Difference 2, based on the cost compositions of their corresponding logistics activities. This method of calculation enables a comparison between the different CCs, as mentioned in the trade-offs in Step 5 of Chapter 2.
4. In the ABC model, the inventory and warehousing costs are added in order to calculate the logistics costs in the optimisation scenarios.
5. In the ABC model, the on-site logistics costs are calculated in the optimisation scenarios in order to compare the productivity gains in the optimisation scenarios with the case study project.

Now that the main differences between the models have been elaborated upon the ABC model formation is set out in the next section.

3.1.2 Gaining understanding in the ABC model formation

In this section, we elaborate on characteristics of the ABC model that require extra explanation, beginning with three columns of the ABC model:

- Column 4, 'type of construction phase', is divided into the carcassing (outdoor) phase and finishing (indoor) phase. Usually the finishing phase starts when the house is waterproof.
- Column 7, 'type of transport', corresponds to Step 1 of the theoretical process model and is divided into the following categories:
    - materials and products;
    - equipment;
    - transport of employees;
    - a combination of these three.

  The (finished) products, or modules, such as the prefab roofs, are incorporated into the material and products category. It is possible that for one activity multiple transports occur. For example, for a certain activity, a crane is required to unload a truck as well as a telescopic handler in order to receive the materials at the right place on the construction site.
- Column 10, 'type of vehicle', is divided into the following categories:
    - cars;
    - delivery vans;
    - delivery vans with trailer;
    - trucks.

The next characteristics that requires extra elaboration are the cost streams and calculations steps in the ABC model. Figure 7 presents a visualisation of these cost streams in the ABC model. To calculate the logistics costs (Step 5) per construction activity (Step 1), the first-tier physical distribution streams (Step 3) are divided into four categories (Step 2), as stated in the theoretical process model presented in Section 2.1. The four cost elements (Step 4) together result in the logistics costs of the corresponding activity [10, p. 14]; [108, p. 460]; [95, p. 1]. These steps are followed for all construction activities that have first-tier physical distribution streams in the supply chain to find the total logistics costs of the supply chain mapped in the model.

All the calculation steps to find the cost elements in Step 4 of Figure 7 are presented in Figure 8, by which the logistic costs per construction activity are calculated. In Appendix 9.7, the 12 calculation steps made in Figure 8 are presented in a clear visualisation per calculation. Google Maps is used to find the distance of a one-way and round trip with the information of the address of origin and the optimal route to the address of destination. The total kilometres travelled inside and outside built-up areas can be measured in the same way. All roads that do not allow a speed higher than fifty kilometres per hour are, for the purpose of this research, qualified as kilometres inside built-up areas.

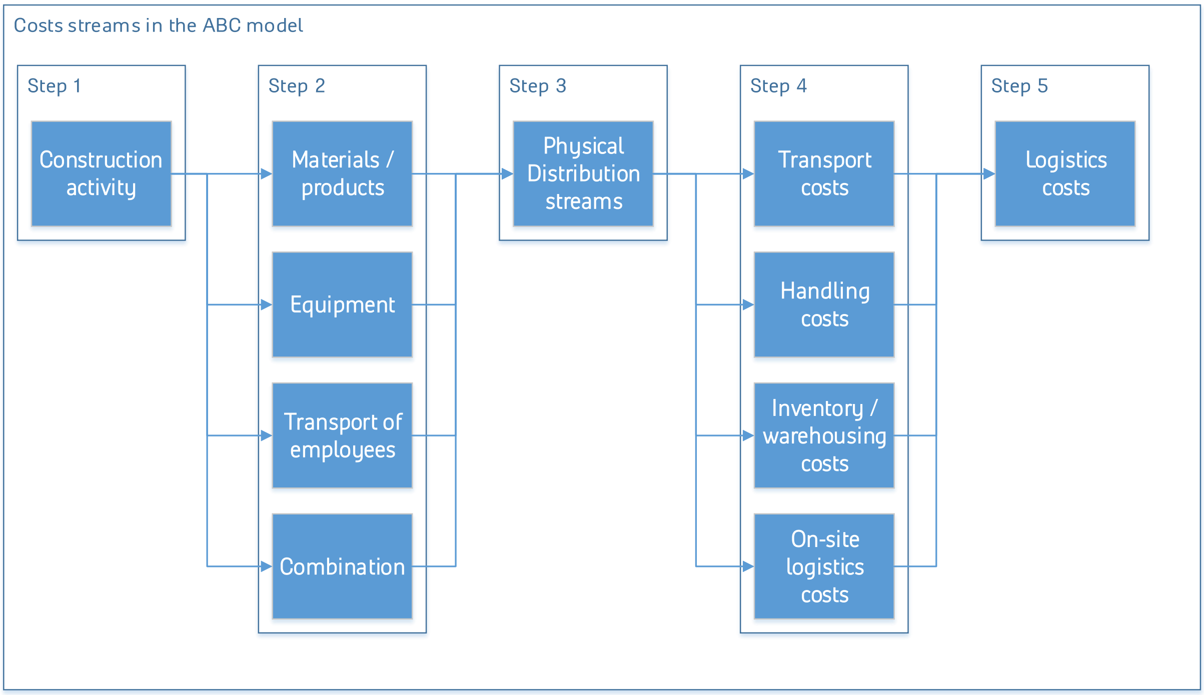

FIGURE 7: VISUALISATION OF THE COSTS STREAMS IN THE ABC MODEL.

In order to calculate the total driving time of the transports, in column 23 of the ABC model, for the total distance travelled from the point of origin to the point of destination, the total kilometres within and outside of built-up areas have to be divided by the average speed of the type of vehicle for those areas. The average speed within and outside of built-up areas per type of vehicle, as presented in Table 1, is based on TNO research (2013) and Riguelle (2012) [97, p. 51]; [83, p. 21]. To correct for the delay of traffic jams, a discount factor is used for driving time outside of built-up areas. In the TNO research, a discount factor of 1.3 is used for the areas of Amsterdam which are highly sensitive to traffic jams. In the mapping of the case study project, we adjusted this discount factor to 1.1 due to the lower traffic density in the mid-south of the Netherlands. The corrected outcome is averaged up to a round number.

Type of transport vehicle	Average speed within built-up areas in kilometres per hour	Average speed outside built-up areas in kilometres per hour
Car	25	80
Delivery van	25	80
Delivery van with trailer	20	75
Truck	16	67
Traffic jam delay factor		1.1

TABLE 1: AVERAGE SPEED BY TYPE OF TRANSPORT VEHICLE IN AND OUTSIDE BUILT-UP AREAS.

To calculate the CO_2, NO_x and fine particulates emissions, parameters based on the TNO (2013) research are used, which are in turn based on the figures of the CBS and a report of stream international freight (2011) [14, p. 22]; [97, p. 51]. The parameters are outside the scope of the research and are, as such, not presented.

The next section presents the layout of the ABC model, and in Section 3.3, we provide an example of how the ABC model works to clarify the characteristics, cost streams and calculations steps of the ABC model elaborated upon in this section.

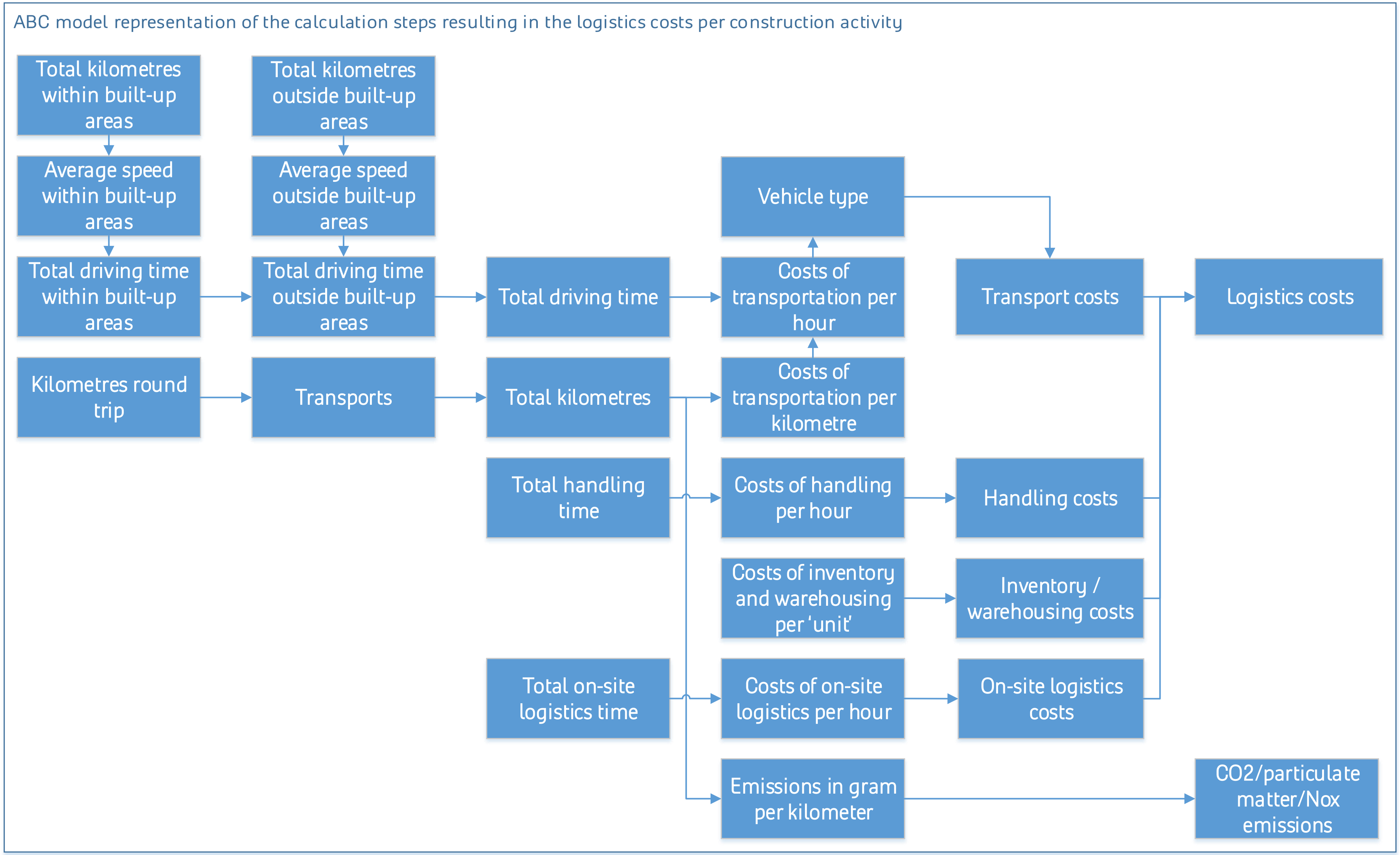

FIGURE 8: VISUALISATION OF THE CALCULATION STEPS IN THE ABC MODEL.

3.2 Layout of the ABC model

The layout of the ABC model is presented in Table 2. The reading order starts at the left top and continues to the right following the rising numbers of the columns. To gain better understanding of the ABC model the layout is filled in with data of the first two activities of the selected case study project supply chain elaborated upon in Chapter 4. In section 3.3, we elaborate on the 12 calculation steps as presented in Appendix 9.7 of the second construction activity 'construction of pile foundations'.

1. Name of activity	2. Activity number	3. Starting week of activity	4. Type of construction phase	5. Name CC	6. Address of origin	7. Type of transport
Digging excavation pit	1	1	Carcassing	Company A	Confidential	Equipment
Construction of pile foundation	2	1	Carcassing	Company B	Confidential	Employees
						Material and equipment

8. Address of destination	9. Optimal route	10. Type of vehicle	11. Supplier of the CC	12. What is transported	13. Kilometres one-way trip (#)	14. Kilometres round trip (#)
Toon Kortoomsstraat, Waalwijk	A59	Truck	None	Loader	42.3	84.6
Toon Kortoomsstraat, Waalwijk	A27	Delivery van	None	Employees	177	354
Toon Kortoomsstraat, Waalwijk	A27	Truck	None	Concrete and concrete pump	177	354

15. Number of transports (#)	16. Total kilometres travelled (#)	17. Kilometres within built-up areas one-way trip (#)	18. Kilometres outside built-up areas round trip (#)	19. Total number of kilometres within built-up areas (#)	20. Total number of kilometres outside built-up areas (#)	21. Driving time within built-up areas inclusive one hour (un)loading (hours)
2	169	15.5	26.8	62	107.2	5
1	354	3.8	173.2	7.6	346.4	2
2	708	3.8	173.2	15.2	692.8	2

22. Driving time outside built-up areas (hours)	23. Total driving time (hours)	24. CO2 emission (grams)	25. Fine particulates emission (grams)	26. NOx emission (grams)	27.Transport form	28. Costs of transport per hour (€)
2	8	Confidential	Confidential	Confidential	In the truck	Confidential
5	8	Confidential	Confidential	Confidential	In the delivery van	Confidential
11	15	Confidential	Confidential	Confidential	In the truck	Confidential

29. Costs of transport per kilometre (€)	30. Total transport costs (€)	31. Costs of handling per hour (€)	32. Total number of handling hours (#)	33. Total handling costs (€)	34. Total inventory and warehousing costs (€)	35. Total costs of logistic per activity (€)
Confidential	Confidenti al	Confidential	Confidential	Confidential	Confidential	Confidential
Confidential	Confidenti al	Confidential	Confidential	Confidential	Confidential	Confidential
Confidential	Confidenti al	Confidential	Confidential	Confidential	Confidential	Confidential

36. Percentage capacity usage (%)
N/A
10
>90

TABLE 2: VISUALISATION OF THE SETUP OF THE MICROSOFT EXCEL ABC MODEL (FLTR).

3.3 Explanation on the ABC model

The purpose of this section is to elaborate on how the ABC model works by using the second construction activity 'construction of pile foundations' as presented in Table 2, as subject for this explanation. Again, in Appendix 9.6 and 9.7 the variables and calculation formulas used in this explanation are presented and visualised. This explanation corresponds with Figure 8.

To perform the activity 'construction of pile foundation' (column 1) the responsible company, Company B (column 5), sends material and equipment (column 7) from the address of origin (column 6) to the address of destination (column 8) in Waalwijk combined in one truck movement. To calculate the costs of the activity the total number of kilometres travelled inside and outside built-up areas needs to be known. The optimal route (column 9) travelled proposed by Google Maps is by the A27. A one-way trip is 177 kilometres (column 13) making a round trip 354 kilometres (column 14). Two trips (column 15) are sufficient to perform this activity resulting in a total of 708 kilometres (calculation 1 from Appendix 9.7; column 16). A one-way trip is 171.5 kilometres on outside built-up area roads (column 18) and 5.5 kilometres within built-up area roads (column 17). This brings the total distance travelled kilometres outside built-up areas on 686 (column 20) and within built-up areas on 22 (column 19; calculations 2 and 3 from Appendix 9.7).

With the information of the total distance of kilometres travelled the driving time within and outside built-up areas is calculated. Within built-up areas the driver needs to travel 22 kilometres divided by the average speed of a truck of 16 kilometres per hour, as presented in Table 1, resulting in two hours of driving time (calculation 4 from Appendix 9.7). The driver needs to travel 686 kilometres outside built-up areas divided by the average speed of 67 kilometres per hour, as presented in Table 1, results in eleven hours of driving time (column 22). In this calculation the delay of a transport stuck in a traffic jam is neglected. Therefore a discount factor of 1.1 is used [82, p. 51]. Discounting the eleven hours results in a total of (averaged up) thirteen hours of driving time (calculation 5 from Appendix 9.7). It takes on average one hour to unload on the construction site. All results in a total of fifteen hours driving time (calculation 6 from Appendix 9.7).

To calculate the emissions of the transports the total distance travelled is multiplied by the emission factors (calculation 7, 8 and 9 from Appendix 9.7).

Transport costs are divided into the wage of the driver per hour and costs of the vehicles per kilometre (depreciation and fuel). Multiplying the total driving time (column 23) with the cost of transport per hour (column 28) and the total number of kilometres travelled with the costs of transport per kilometres (column 29) results in a total transport costs (column 30) when added up (calculation 10 from Appendix 9.7).

Handling costs are divided into costs of handling per hour (wages, column 31) and the total number of handling hours (column 33). Multiplying both results in the total handling costs (column 33, calculation 11 from Appendix 9.7).

The total logistics costs per activity (column 35) result from adding up the transport costs, handling costs and warehousing and inventory costs (column 34, calculation 12 from Appendix 9.7). The inventory and warehousing costs were not available from the collected data. In the next part the summary of Chapter 3 is presented.

Summary Chapter 3

This chapter has elaborated upon the ABC model formulated and used in this research to map and calculate the logistics costs of the first-tier physical distribution streams in the supply chain of the case study project, in Chapter 4, and to map the optimisation scenarios, in Chapter 6. At the end of Chapter 6, a comparison is made between the results of the ABC analyses to see whether the optimisation scenarios were able to improve the cost efficiency of the first-tier physical distribution streams in the supply chain of the case study project.

In the next chapter, the characteristics of the case study project and the results of the ABC analysis conducted on the mapping of the first-tier physical distribution streams in the supply chain of the case study project are set out.

4 The case study project

In this chapter, Phase 1 of the research is set out:

Phase 1: Mapping the case study project with the use of the ABC approach.

Chapter 1 elaborated upon the setup of the research. Chapter 2 presented the theoretical steps of the research in the form of a process model, and Chapter 3 presented the ABC model used for the mapping the first-tier physical distribution streams in the supply chain of the HWC case study project which is presented in this chapter and the optimisation scenarios presented in Chapter 6.

The objective of Phase 1 is *to map the case study project with an ABC analysis.*

This chapter focusses on the characteristics of the case study project and the ABC analysis to provide an understanding of the current situation of the (cost) composition of the first-tier physical distribution streams in the supply chain of the case study project. The Main Question for Phase 1 is as follows:

1.0 How are the first-tier physical distribution streams in the supply chain of the case study project composed during the execution phase of the construction process?

This Main Question is divided into four sub-questions, as set out in Section 1.6.

The structure of Chapter 4 is structured as follows:

Section 4.1 The characteristics of the Heijmans Woon Concept;
Section 4.2 The characteristic of the case study project;
Section 4.3 The characteristics of a construction supply chain;
Section 4.4 The results of the ABC analysis conducted on the case study project.

At the end of Section 4.4, a summary is presented which gives the answer to Question 1.0. The first section of this chapter elaborates on the characteristics of the HWC.

4.1 The characteristics of the Heijmans Woon Concept

In this section, the first sub-question of Phase 1 is answered:

1.1 What are the characteristics of the HWC?

As seen in Section 1.1.1, the turnover of the HWC projects in 2015 was €48M, 16% of the total turnover of HH. The HWC is part of the category land-based houses, which is accountable for 35% of the total turnover of HH. The goal for 2016 is to build all the land-based houses following the HWC approach. This goal results in a projected turnover of the HWC projects of around €100M in 2016. HH needs to save €10M in total to meet the ambition of a 10% reduction of the TCO of a HWC house, as presented in Section 1.2.

The HWC consists of the Heijmans Wenswonen and Heijmans Huismerk. Both aim at two different markets, each with its own commercial approximation, as visualised in Figure 9 [44, p. 11].

The *Heijmans Wenswonen* aims for private house owners. The focus is on comfort, sustainability and safety, together with optimal counselling in the total process from choices to completion of the projects [44, p. 12].The *Heijmans Huismerk* aims at the housing corporations. The role of HH is to be the professional partner for investors and corporations. HH offers customization options to its customers and guides them in this process to ensure they make the right choices.

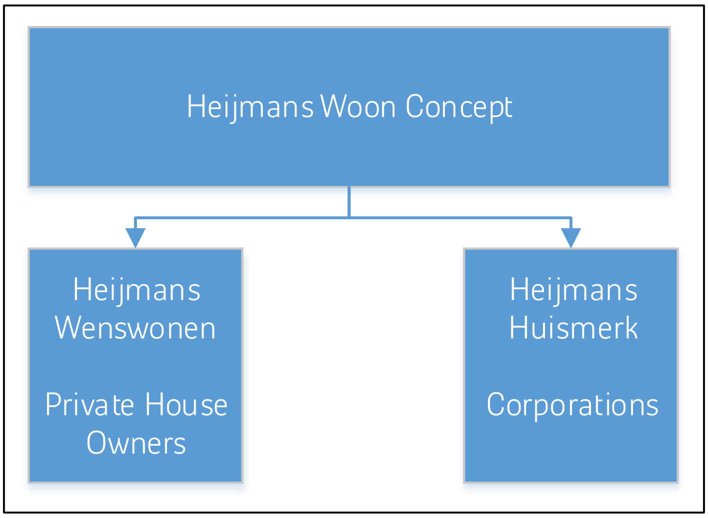

FIGURE 9: THE COMMERCIAL APPROXIMATIONS OF THE HEIJMANS WOON CONCEPT.

By capturing both products into the HWC, Heijmans internally ensures cost savings and efficiency. Externally, it brings out one clear story to the outside world and ensures less errors due to less delivery points.

The HWC breaks with the traditional way of building and uses a concept-based approach where a fixed team builds houses better, cheaper and more customer-oriented, resulting in a less complex organisation of the building process [48]. The variety in the number of houses that is built per project runs between eight and more than a hundred with an average number of houses per project of around twenty. Heijmans is the main contractor that cooperates with suppliers and sub-contractors, and guides the sales process of the houses to the buyers. The HWC characterises itself by fast development and a short building time. The average time to build a house is sixty days. Within the HWC construction process there is a nationwide improvement register in order to incrementally improve the construction process, as well as the on-site logistics of the construction site, as seen in Step 2 of section 2.1.

The HWC is executed nationwide in the same way and with the same CCs. This approach has several advantages [19, p. 15]; [20, p. 183]; [106, p. 168]. For example, by implementing co-design between the designers and material suppliers early in the design phase, errors in the construction phase could be prevented. In Appendix 9.4 the different relationship types and their characteristics that Heijmans differentiates are elaborated upon. The scope of the working relationship can vary from short-term to long-term in the following order as visualised in Figure 10 on the next page:

1. supplier;
2. preferred supplier;
3. co-maker;
4. partner.

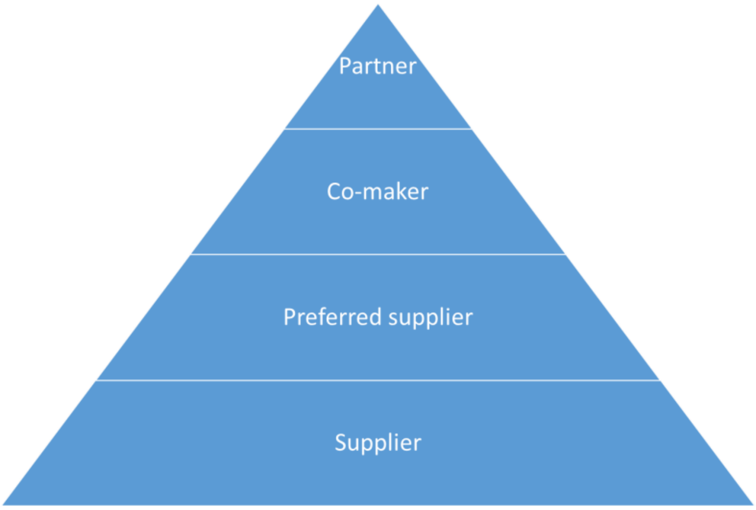

FIGURE 10: THE DIFFERENT TYPES OF COOPERATING COMPANIES AT HEIJMANS AND THE HWC PROJECTS.

Heijmans incorporated the concept-based product development to manage the complexity of offering more product variety which is one of the goals of the HWC [58, p. 52]. There is a library with eight types of houses. In 90% of the cases the BO1 type is build. The houses are 80% fixed and 20% open for variation, especially in the outside look [44, p. 28]. An illustration of this 80/20 rule is that all the prefab walls are made with six sockets in exactly the same place in the wall. The buyer can choose whether or not to install them. Moreover, the buyer may want to have a building extension to the house, but can only choose between a small, average or large building extension and these sizes are fixed. This results in a high predictability of demand for goods at the HWC projects.

In Figure 11, the construction site of the case study project as set out in section 4.2 is presented in an advanced stage. The activities carried out by the CCs in the construction process of the HWC houses start at the first house and are repeated for all houses that are part of the project, known as phasing of the construction process. When the HWC houses are constructed, the destination of the physical distributions streams of goods and transport of employees changes with the different locations of the projects. The construction sites can be seen as temporary 'factories' that move from project to project. The phasing of the construction process is similar to the 'assembly line' as seen in the automotive industry. In the construction case the assemble line moves from parcel to parcel over time. The output of the construction assembly line are the individual HWC houses.

FIGURE 11: CONSTRUCTION SITE OF THE CASE STUDY PROJECT IN AN ADVANCED STAGE.

Although HH and all CCs are cooperating on many disciplines, there is still an area where they have not found each other yet. All CCs so far take care of their own logistics and physical distribution streams that in many cases are outsourced to their own LPCs.

In this section we gained an understanding of the characteristics of the HWC projects. In the next section the characteristics of the case study project are elaborated upon. In section 4.4, the results of the ABC analysis conducted on the mapping of the case study project are presented.

4.2 The characteristics of the case study project

In this section the second sub-question of Phase 1 is answered:

1.2 What are the characteristics of the case study project?

The case study project is the HWC project the 'Leeswand' in the Netherlands in Waalwijk at the Toon Kortoomsstraat referred to as the 'Leeswand'. The Leeswand consist of two phases of respectively twelve and seventeen houses making a total of 29. The commercial approximation of the houses is Heijmans Wenswonen and they are built for private house-owners [49]. There are two views in the construction industry to manage a construction project [87, p. 75]:

- Conversion view — Each stage of production is controlled independently;
- Flow view — The focus is on the control of the total flow of the production.

The flow view is recognized by the managers of the HWC projects however not all aspects of it are yet incorporated in the day-to-day management. As a consequence the projects are usually still performed following the conversion view of production.

The Leeswand consists of four blocks of houses and this division is used by some of the CCs to structure their deliveries. This means that the goods of the first block are delivered first, followed by the second block and so on, until the goods of all blocks are delivered. The CCs are subcontractors of Heijmans. Many of the CCs in turn have their own subcontractors. The subcontractor companies of the CCs each have their own suppliers making the total structure of the HWC supply chain complex. Nevertheless, this is a normal setup of a construction supply chain [87, p. 2]. The Leeswand was chosen as the case study project firstly due to the timing aspect. The construction period started ideally synchronised with the research period. Secondly, it was chosen due to the fact that the Leeswand was a pilot project for the software program Kyp [59]. Kyp is a web based online program that focusses on the communication between the CCs. At any moment in time all CCs have 24/7 access to information about the planning of when, what, from whom and where.

The Leeswand is directed from the Heijmans office in Rosmalen in the Netherlands which is the office from where the research was conducted. The case study project started, following the Kyp planning, at the 26th of October 2015 in week 44 with the excavation of the building pit and finished, according to the lean planning, at the fifth of May 2016 in week 15, when the last house was delivered. In the Christmas period from the 21st of December 2015 to the 3rd of January 2016 the construction was paused due to the holidays. This also happened in the period from the 8th of February to the 9th of February 2016, which was the carnival holiday in the south of the Netherlands. Unfortunately in the period from the 18th of January to the 20th of January 2016, the construction was paused due to freezing weather conditions, however this only applied to the outdoor activities. The indoor activities continued. No other major delays occurred during the construction period.

In total the Leeswand has 82 construction activities that result in 134 different first-tier physical distribution streams of goods and transports of employees. The first four houses were delivered at the 10th of March 2016 with zero delivery points meaning that after inspection of the houses there were no errors discovered and no rework was required [49].

In Appendix 9.5 the 29 CCs directly involved in the first-tier physical distribution in the supply chain of the Leeswand are presented with the activities they are responsible for and the internal links between the CCs. The same order as in the planning of Kyp is used to present the activities of the CCs following the timeline of the construction phase. There are 7 co-makers and 22 preferred suppliers directly and 20 suppliers indirectly involved in the first-tier physical distribution of goods and transport of employees during the construction process.

In this section we gained an understanding of the characteristics of the case study project; the Leeswand. The 82 construction activities and the 134 first-tier physical distribution streams are used to map and to calculate the logistics costs of the case study project. In the next section the characteristics of the construction supply chain are explained in order to gain an understanding on the specifications of a construction supply chain and by that of the supply chain in the case study project.

4.3 The characteristics of the construction supply chain

In this section the third sub-question of Phase 1 is answered:

1.3 *What are the characteristics of a construction supply chain?*

Supply chains can be found all around us and in various disciplines. The supply chains in the food industry are different from the supply chain of a mobile phone manufacturer and requires focus on different aspect. The same goes for the construction industry being different from others. The construction industry is viewed as a sector of the economy that transforms various resources into constructed facilities [72, p. 2]. One in three truck movement has a construction site as destination having a large impact on the total traffic congestion on the Dutch roads [51, p. 5]. Construction work starts early in the morning and the goods necessary have to be available at that time. This results in a convergence of transports in the morning and many transports stuck in traffic jams. The cost of materials in a typical construction project can take up to 60% of the total construction costs [98, p. 394]; [92, p. 73]. Material supply is an important process of construction companies and a factor affecting the quality of construction projects [94, p. 3]. In a general construction project the logistics costs may be as high as 10% of the total construction costs [15, p. 33].

In Figure 12 on the next page, the general construction supply chain setup is presented that consists of [16, p. 403]; [21, p. 325]; [108, p. 458]:

- the manufacturing of construction goods;
- the physical distribution of goods and transport of employees;
- the processing of goods on the construction site.

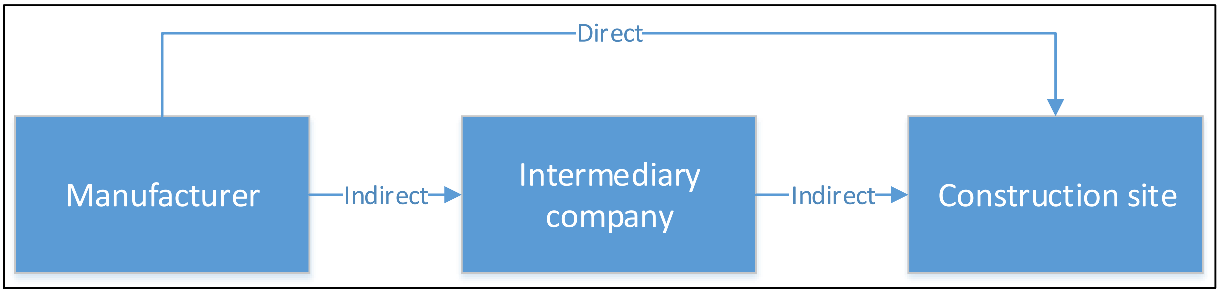

FIGURE 12: PHYSICAL DISTRIBUTION STREAMS IN THE SUPPLY CHAIN OF A CONSTRUCTION PROJECT.

The construction goods and transport of employees need to be distributed to the construction site. In Figure 12, the two basic distribution strategies are presented:

- direct distribution of materials from manufacturer to the construction site;
- indirect distribution through intermediary companies such as wholesalers and traders.

Direct distribution is mainly used when a customer requires a Full Truck Load (FTL) of materials requiring transports with high percentage of capacity usage. In case of indirect distribution finished goods are stocked at one or more points in the supply chain [108, p. 458]. The requirement for transport between facilities in the supply chain is determined by the inventory policy followed by the CCs in the network [16, p. 220].

Typical characteristics of the construction supply chain are [40, p. 287]: [107, p. 217]; [99, p. 6]:

1. Uniqueness of construction projects;
2. Realization on the location of use;
3. Fragmented character of the construction process.

Further elaborated:

1. Traditionally, each construction project is regarded more or less in isolation such that the physical distribution streams take place by a different coalition of CCs consisting of manufacturers, LPCs such as transport and warehousing companies and contractors making every construction project unique [107, p. 217]. While each project is different, all projects are approached conservatively in process terms due to the long and entrenched traditions [112, p. 108]. A general construction project starts with the planning phase, followed by the design, construction and operation phases [32, p. 145]. The CCs are involved in storing and moving both goods and transport of employees to the construction site [40, p. 287].

2. In the automotive industry a car is constructed in a factory however the usage of the car is outside the factory. The first-tier physical distribution of goods and transport of employees have the same destination, the factory, over and over again. In the construction industry the construction site and the different routes that are used by the various CCs for the first-tier physical distribution streams, from the place of origin to the construction site, change with each new project due to the realization of the construction projects on the location of use. Contractors taking part in a construction project are responsible for their individual supply chains to provide goods and transport of employees required within their scope of work [87, p. 2]. The usage of the constructed project is on the place of realization.

3. The construction industry is highly fragmented which can have a significant negative impact, such as low productivity, cost and time overrun, conflicts and disputes resulting in claims and time consuming litigation [99, p. 6]. There is evidence, that up to 40% of the overall project duration from the inception to completion is spend on non-value-adding activities such as waiting, ordering and delivery of materials [73, p. 380]. Because they add no value to the final product and are time consuming and expensive, these non-value adding activities should be reduced to a minimum [87, p. 75]. The activities in the supply chain for the physical distribution streams of goods and transport of employees are an example of such non-value-adding activities that should be optimised to minimise the costs.

These typical characteristics of a construction project supply chain and the traditional relationships in supply and demand have undergone a variety of radical changes in recent years [24, p. 96]. There are two views in the construction industry to manage a construction project [87, p. 75]:

- Conversion view. Each stage of production is controlled independently.
- Flow view. The focus is on the control of the total flow of the production.

The traditional view is based on a conversion view on production, however, more and more, the flow view is implemented in the day to day management of construction projects. Each phase of construction involves a variety of suppliers and subcontractors who contribute to the production with a possible multiplicity of goods delivered and transports of employees. Construction activities, in general, are divided into sequential activities, which are given to different specialists for execution, putting unnecessary constraints on the work flow, increasing the possibility of conflicts and consequently leading to time waste and rework [57].

During construction important actors are [33, p. 157]:

- main contractor;
- subcontractors;
- purchasers;
- project manager;
- material suppliers;
- equipment suppliers;
- designers;
- financial institutions;
- insurance agencies;
- regulatory bodies.

The construction procurement system evolves and traditional systems such as general contracting in which subcontractors are hired to perform activities in the construction process are often replaced by Performance Management (PM) systems, where the manager acting on behalf of the employer decides on designer, contractor and supplier selection. The choice of materials, their manufacturers or even supplier belongs no longer to the designer or the contractor, but to the employer or his consultant or project manager [96, p. 151]. All having their effects on the physical distribution streams in the supply chain of construction projects. Challenges in the construction industry are [34, p. 587]:

1. The difficulty of capturing, structuring, prioritizing and implementing client's needs.
2. The dispersed design, fabrication and construction data making it difficult to convey the data to the downstream.
3. The lack of integration, co-ordination and collaboration between various disciplines during the life-cycle of a product.

4. The poor communication of design intention and rationale resulting in unwarranted design changes, inadequate design specifications, unnecessary liability claims, and the increase of project time and costs.

These challenges should be at the core of attention of managers that are optimising supply chains in the construction industry. Dissatisfaction with the fragmented and temporary organisation of the construction supply chain has led several companies to offer a total construction package from design to delivery of a construction project including maintenance and exploitation. This reduced project uncertainty, by systemisation and integration of the different stages of the building process [108, p. 457].

In this section the setup and characteristics of a construction supply chain were set out in order to gain a better understanding of the supply chain in the HWC projects. In the next section the results of the ABC analysis conducted on the mapping of the case study project are elaborated upon.

4.4 The results of the ABC analysis conducted on the mapping of the case study project

In this section the fourth sub-question of Phase 1 is answered:

> *1.4 What are the results of the ABC analysis conducted on the mapping of the case study project?*

We mapped all the first-tier physical distribution streams in the supply chain of the case study project in the ABC model. The data was retrieved through company visits, telephone conversations and e-mails. We conducted an ABC analysis conducted on the mapping of the case study project in the ABC model when it was complete. In this section the results of this ABC analysis are presented on the following aspects:

1. The composition of the case study project supply chain;
2. The cost composition of the logistics cost elements of the case study project supply chain;
3. The different first-tier physical distribution stream categories.

The next part starts with the composition of the case study project supply chain.

1. The composition of the case study project supply chain

In order to build the houses all vehicles together travelled a total of 130 kilometres, which is the equivalent of 3.3 times around the world. Table 3 and Table 4 show that it took nearly 1500 transports to carry out the 134 first-tier physical distribution streams for the 82 construction activities. Figure 13 on the next page indicates that the truck transports account for nearly half of the total distance travelled in the supply chain of the case study project. This indicates that the trucks need to cover longer distances to deliver their goods from the point of origin to the point of destination. This can be explained by the specialist nature of many of the CCs involved in these transports. They are based on central point's in the Netherlands and need to travel far to reach their destinations. In Figure 14 on the next page, it becomes clear that the different type of vehicles have nearly the same share in the total required transports.

Composition of the case study project supply chain	(#)
Construction activities	82
Physical distribution streams	134

TABLE 3: COMPOSITION OF THE CASE STUDY PROJECT SUPPLY CHAIN.

Characteristic	Total at case study project (*1000)	Total per house (*1000)
Kilometres travelled	131	4.5
Transports	1477	51

TABLE 4: CHARACTERISTICS OF THE CASE STUDY PROJECT SUPPLY CHAIN.

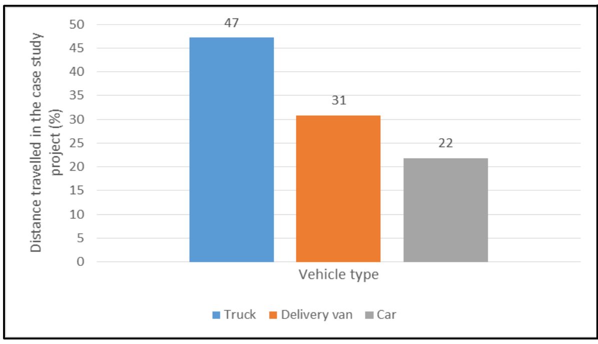

FIGURE 13: DISTANCE TRAVELLED PER VEHICLE TYPE.

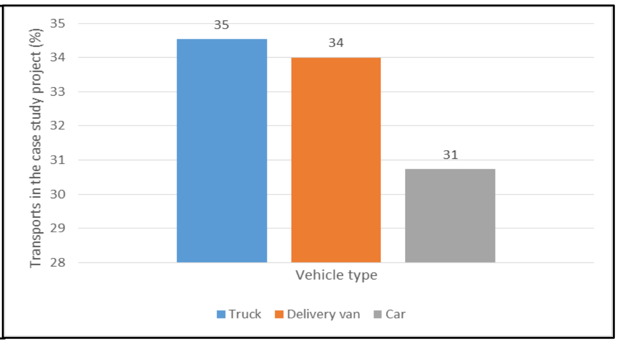

FIGURE 14: NUMBER OF TRANSPORTS PER VEHICLE TYPE.

The composition of the case study project supply chain is set out in this part. In the next part the cost composition of the case study project supply chain is elaborated upon.

2. The cost composition of the logistics cost elements of the case study project supply chain

The four steps of the ABC approach mentioned in section 2.1 are used to map the first-tier physical distribution streams in the supply chain of the case study project in the ABC model, as set out in Chapter 3. The CCs provided the requested data in different ways. The transport costs were, for example, calculated by tonnage transported, by number of transports or per products distributed depending on the type of agreements the CCs have with their own LPCs and with HH.

In Table 5 the results of the ABC analysis conducted on the mapping of the case study project point out that 6.44% of the total building sum of the case study project consists of logistics costs. The total logistic costs in the case study project is €210K.

Type of costs	Total costs (€*1000)	Percentage logistics costs over the total project building sum (%)
Logistics costs	210	6.44

TABLE 5: LOGISTIC COSTS COMPOSITION OF THE CASE STUDY PROJECT SUPPLY CHAIN.

6.44% is lower than the, in section 1.3 stated, 10% logistic costs for a general construction project [92, p. 73]. An explanation for the remainder 3% can be:

1. the warehousing and inventory costs;
2. the logistics costs beyond the first-tier suppliers.

Further elaboration:

1. We were not able to capture the warehousing and inventory costs because the required data was not available in the data of the CCs.
2. The logistics costs to transport the goods to the first-tier suppliers from the second-tier suppliers, from the third-tier to the second-tier, etc. are not incorporated in the 6.44%.

In Appendix 9.8, Table 25, the extended results of the ABC analysis conducted on the case study project are presented per CC on various characteristics according to the explanation of the ABC model in Section 3.3. In Table 6, the cost composition of the logistics cost elements of the case study project is presented. The majority of the logistics costs consists of transport costs, followed by on-site logistics and handling costs. Moreover, the costs per house per cost element are presented.

Type of costs	Total costs (€*1000)	Percentage of the total logistics costs (%)	Total costs per house (€*1000)
Transport	180	86	6.2
On-site	24	11	0.8
Handling	6	3	0.2

TABLE 6: LOGISTIC COSTS COMPOSITION OF THE CASE STUDY PROJECT SUPPLY CHAIN.

In Figure 15, the percentages of logistic costs, calculated by accumulating only the transport and handling costs, over the total building sum per CC, are presented. This presents an understanding on the spend of the CCs on their logistic activities.

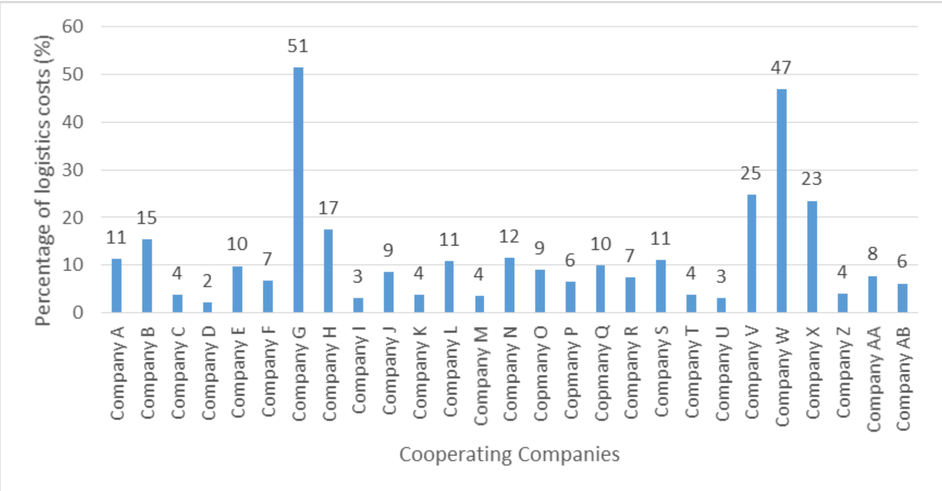

FIGURE 15: PERCENTAGE OF LOGISTICS COSTS OVER BUILDING SUM OF THE COOPERATING COMPANIES.

In Table 7, the total logistics costs, total logistics costs per house and the profit per house of the case study project are presented. These numbers are used as a benchmark for the optimisation scenarios in Chapter 6.

	Total logistics costs (€*1000)	Total logistics costs per house (€*1000)	Profit per house (€*1000)
Case study project	210	7.2	CONFIDENTIAL

TABLE 7: RESULTS OF THE ABC ANALYSIS CONDUCTED ON THE CASE STUDY PROJECT SUPPLY CHAIN.

The percentages of the logistics cost of the case study project per CC are presented in Figure 16. It points out which CCs have the highest impact on the total logistics costs of the case study project.

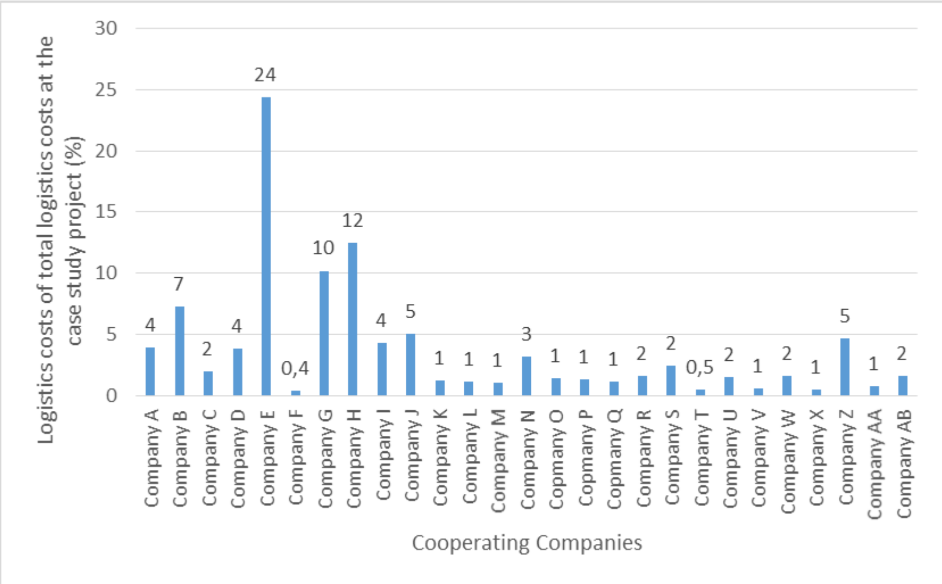

FIGURE 16: PERCENTAGE OF LOGISTICS COST PER COOPERATING COMPANY OF THE TOTAL LOGISTIC COSTS IN THE CASE STUDY PROJECT.

Now that we gained an understanding of the (cost) composition of the case study project supply chain present the five physical distribution stream categories are presented that were indicated after the analysis conducted on the mapping of the case study project in the ABC model.

3. The five physical distribution stream categories

After analysing the first-tier physical distribution streams of the case study project we identified five physical distribution stream categories that differ from the four categories mentioned in the theoretical process model presented in Section 2.1, Step 1:

1. *Direct heavy distribution:* The heavy specialised transports with high percentage of capacity usage carried out by trucks for the transport of, for example the carcasses, roofs and window frames. The direct heavy distribution transport visualised in Figure 18 are sometimes equipped with a transport carrier to protect the goods transported as presented in Figure 17.

FIGURE 18: DIRECT HEAVY TRANSPORT (HEAVY TRUCKS).

FIGURE 17: HEAVY TRANSPORT CARRIER.

2. *Direct light distribution:* The light non-specialised transports carried out by trucks for the transport of, for example the electra materials, wall tiles and the staircases. The direct light distribution is visualised in Figure 20.

FIGURE 20: DIRECT LIGHT TRANSPORTS (LIGHT TRUCKS).

3. *Employees:* The transports of employees with cars and or delivery vans as visualised in Figure 19.

FIGURE 19: TRANSPORT OF EMPLOYEES

4. *Employees with small materials and standard tools:* The transport of employees in delivery vans together with their small materials and standard tools required to carry out their activities as visualised in Figure 21.

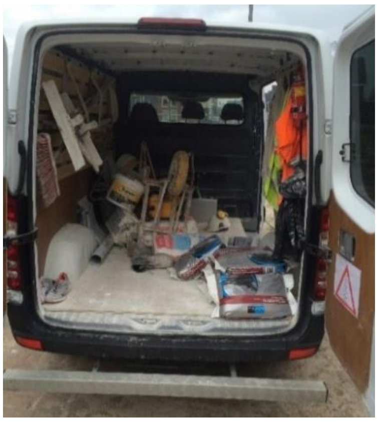

FIGURE 21: TRUCKLOAD OF DELIVERY VAN WITH SMALL MATERIALS AND STANDARD TOOLS.

5. *Equipment:* The transport of heavy equipment such as shovels, loaders and cranes as visualised in Figure 22.

FIGURE 22: TRANSPORT OF (HEAVY) EQUIPMENT.

In Figure 23, the percentages of logistics costs per physical distribution category are presented. The highest cost intensive distribution stream is the heavy distribution followed closely by transport of employees and employees with small material and standard tools. The light distribution streams account for nearly 1/8 of the total distribution costs. The equipment category transports only account for a small part of the total logistics costs of the case study project.

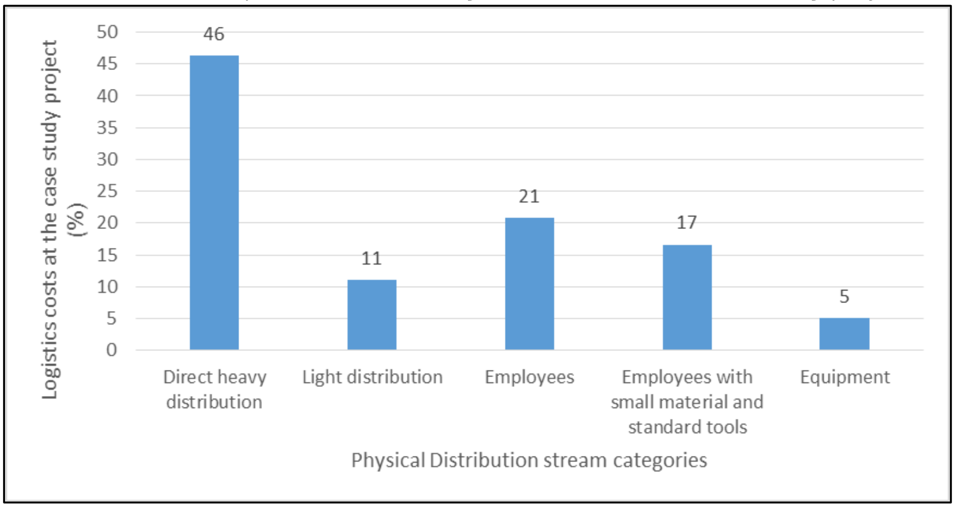

Figure 23: Percentage of total logistic costs per physical distribution category.

In this last section of Chapter 4 we gained an understanding of the (cost) composition of the current situation of the first-tier physical distribution streams in the supply chain of the case study project that resulted from the ABC analysis.

Summary Chapter 4:

In this chapter, Phase 1 of the research, *mapping the case study project with the use of the ABC approach*, is elaborated upon. The four sections and corresponding sub-questions have each contributed to answering the Main Question, which is as follows:

1.0 *How are the first-tier physical distribution streams in the supply chain of the case study project composed during the execution phase of the construction process?*

The objective of Phase 1 was *to map the case study project with an ABC analysis'*. This chapter's tables furnish the overall results of the ABC analysis conducted on the mapping the case study project in the ABC model, along with the answer to Main Question 1.0. The key findings of this chapter are set out below.

The composition of the first-tier physical distribution streams in the supply chain of the case study project consist of 29 CCs and 20 suppliers, resulting in a total of nearly 50 companies responsible for construction activities in order to build the 29 houses in the Leeswand project. These 50 companies perform 82 construction activities, for which they require 134 different physical distribution streams divided over nearly 1500 transports. The supply chain of the case study project is highly fragmented, and there are nearly no transport synchronisations between the CCs identified.

The costs of the first-tier physical distribution streams in the supply chain of the case study project are €210.000. This costs consists of 86% for transport, 11% for on-site logistics and 3% for handling costs. The potential for the improvement of cost efficiency for first-tier physical distribution streams is the highest for the transport and on-site logistics elements.

Five physical distribution stream categories have been identified after analysing the mapping of the case study project supply chain in the ABC model. These physical distribution stream categories require different optimisations to improve their cost efficiency:

1. direct heavy distribution;
2. direct light distribution;
3. employees;
4. employees with small materials and standard tools;
5. equipment.

The five physical distribution streams and their cost-element handling and on-site logistics require different optimisations to improve cost efficiency in the supply chain of the case study project. This improved efficiency is the starting point of the next chapter, in which Phase 2 of the research, *literature review and business case meetings on (construction of) supply chain optimisation possibilities*, is elaborated upon. The goal of Chapter 5 is to find optimisation possibilities and optimisation scenarios to move from the current situation to the improved situation of the supply chain of the case study project in Chapter 6.

5 Supply Chain optimisation scenarios

In Chapter 4, Phase 1 of the research, *mapping the case study project with the use of the ABC approach*, has been elaborated upon. The results presented in the summary of Chapter 4 are the starting point for this chapter, in which Phase 2 of the research is set out:

> *Phase 2:* *literature review and business case meetings on (construction) supply chain optimisation possibilities.*

Chapter 4 gave an understanding of the characteristics of the current situation of the first-tier physical distribution streams in the supply chain of the case study project. This chapter focusses on finding optimisation possibilities within the literature and within practice to improve the cost efficiency of the current situation. The Main Question of Phase 2 is as follows:

> 2.0 Which supply chain optimisation possibilities can be transformed into optimisation scenarios that fit the case study project?

The answer to this question is optimisation scenarios that improve the cost efficiency of the first-tier physical distribution streams in the supply chain of the case study project: the 'soll-situations'. In Phase 3 of the research, *mapping the optimisation scenarios with the use of the ABC approach,* ABC analyses are conducted on the optimisation scenarios, as presented in Chapter 6.

The structure of Chapter 5 is as follows:

Section 5.1	Literature review on supply chain optimisation possibilities;
Section 5.2	Business case meeting on supply chain optimisation possibilities;
Section 5.3	Matching the literature review with the business case meetings;
Section 5.4	Matching the optimisation possibilities and optimisation scenarios to the five physical distribution stream categories;
Section 5.5	Visualisation of the three proposed optimisation scenarios.

The first section elaborates on the supply chain optimisation possibilities resulting from the literature review. Together with the optimisation possibilities from the business case meeting, as presented in Section 5.2, the optimisation possibilities in the first section are used to propose optimisation scenarios that improve the cost efficiency of the current situation of the supply chain of the case study project, as elaborated upon in Chapter 4.

5.1 Literature review on supply chain optimisation possibilities

In this section, the first sub-question of Phase 2 is answered:

> *2.1 Which construction supply chain optimisation possibilities can be derived from the literature research?*

The objective of this section is *to perform an extended review of the literature on supply chain optimisation possibilities*. The optimisation possibilities, as presented below along with the number of the appendices that further elaborate upon them, were selected due to their ability to improve the first-tier physical distribution streams in a supply chain of construction projects:

- 9.3.1 Logistic hub [91, p. 1];
- 9.3.2 Cross-docking [17, p. 414];

- 9.3.3 Control tower [88, p. 8489];
- 9.3.4 Modularity and prefabrication in a factory [101, p. 422];
- 9.3.5 Reverse logistics [84, p. 2];
- 9.3.6 Waste management [80, p. 5];
- 9.3.7 Transport consolidation [90, p. 31];
- 9.3.8 Optimal routing [90, p. 90];
- 9.3.9 Carry-on approach [80];
- 9.3.10 Local sourcing [100, p. 1012];
- 9.3.11 Carpooling [39, p. 83].

In Appendix 9.3, the optimisation possibilities are further elaborated upon. We defined an optimisation scenario as a scenario that is able to improve the first-tier physical distribution streams in the supply chain, as well as to incorporate other optimisation possibilities. In Table 8, the optimisation possibilities are plotted against each other. The green cells indicate that the optimisation possibilities presented in the row can incorporate the optimisation possibility presented in the column, or vice versa. The red cells indicate an incompatibility due to mismatches between the two. In total, six mismatches are presented:

1. Principles:
   This mismatch occurs when the principles of one optimisation possibility exclude the principles of the other optimisation possibility: for example, the principle of cross-docking state that it transfers incoming shipments directly to outgoing vehicles without storing them in between. In the logistic hub there is more attention to repacking and even prefabrication, which requires more time between the incoming and outgoing transports.
2. Focus on the transport of employees:
   This mismatch occurs between the carpooling optimisation that focusses on the transport and pooling of employees and other optimisation possibilities: for example, carpooling and the logistic hub have a mismatch because in the logistic hub the focus is on the consolidation of goods and not on the pooling of the transports of employees.
3. Focus on on-site logistics:
   This mismatch occurs between the carry-on optimisation that focusses on the on-site logistics and other optimisation possibilities. The carry-on approach focusses on transporting goods from where they are dropped on the construction site to the place of processing on the construction site. One example of a mismatch is between the carry-on approach and optimal routing, since optimal routing has no focus on the on-site logistics.
4. Focus on prefabrication:
   This mismatch occurs between the modularity and prefabrication in a factory optimisation and other optimisation possibilities. Modularity and prefabrication in a factory focusses on prefabricating modules that can be easily assembled at the construction site. An example of a mismatch here is between modularity and prefabrication in a factory, on the one hand, and local sourcing, on the other. In case of local sourcing, the focus is on ordering goods from suppliers as close as possible to the construction site and not on modularity and prefabrication in a factory.
5. Focus on reverse logistics:
   This mismatch occurs between reverse logistics optimisation and other optimisation possibilities. Reverse logistics focusses on the extraction of goods from the obsolete building

and the reuse of materials. An example of a mismatch is between reverse logistics and the logistic hub. In the logistic hub, the focus is on optimising the first-tier physical distribution streams that go through the logistic hub and on the forward logistics. The focus of the reverse logistics is on backward logistics.

6. Focus on waste management:
   This mismatch occurs between the waste management optimisation and other optimisation possibilities. Waste management focusses on the backward physical distribution waste streams from the construction site. An example of a mismatch is between waste management and cross-docking, as in the case of the cross-docking optimisation, there are no backward physical distribution streams.

The abovementioned number of the mismatches are inserted in the red cells in Table 8 to indicate which mismatch occurs between the two optimisation possibilities. Per cell, only one number is inserted, however more mismatches could occur between the two plotted optimisation possibilities. A red cell does not mean that the two optimisation possibilities could not be implemented in parallel.

In this section, the ten supply chain optimisation possibilities from the literature review are presented and plotted against each other in Table 8. This comparison yields an understanding of which optimisation possibilities have the ability to incorporate other optimisation possibilities. In Section 2.1, the optimisation possibilities resulting from the business case meetings conducted with LPCs are set out.

	Control Tower	Logistic hub	Modular-ity and prefabri-cation in a factory	Cross-docking	Reverse logistics	Waste management	Transport consolidation	Optimal routing	Carry-on approach	Local sourcing	Carpooling
Control tower											
Logistic hub											
Modularity and prefabrication in a factory											
Cross-docking		1	4								
Reverse logistics		5	5	5							
Waste management				6							
Transport consolidation											
Optimal routing					5						
Carry-on approach			3		5			3			
Local sourcing			4		5				3		
Carpooling		2	2	2	2	2			2		

TABLE 8: SUPPLY CHAIN OPTIMISATION POSSIBILITIES FROM THE LITERATURE REVIEW PLOTTED AGAINST EACH OTHER.

1. adverse principles;
2. mismatch in focus on the transport of employees;
3. mismatch in focus on on-site logistics;
4. mismatch in focus on prefabrication;
5. mismatch in focus on reverse logistics;
6. mismatch in focus on waste management.

5.2 Business case meeting on supply chain optimisation possibilities

In this section the second sub-question of Phase 2 is answered:

> *2.2 Which construction supply chain optimisation possibilities can be derived from the meetings conducted with the selected logistics-providing companies?*

The objective in this section is *to discuss the problem statement in the form of a business case with selected LPCs active on the Dutch market.* In order to find LPCs that are active in the Dutch market two quick scans were carried out. Both 3PL and 4PL companies were approached as elaborated upon in Step 10 of section 2.1. Previous to the quick scans, three companies were already selected because of existing business relations with Heijmans. Out of the quick scans eight other companies resulted that after further investigation did not make the cut. Three other LPCs did demonstrate potential, however, they had no interest. The business case provided to and discussed with these LPCs is the same as the problem statement and Main Question of this research. The goal was to find supply chain optimisation possibilities from practice that are directly implementable. The LPCs were invited to the head office of Heijmans in Rosmalen to discuss the business case without influencing the LPCs up front.

With the selected LPCs one, two or three meetings were conducted depending on the developments. First meetings had the purpose to explain the business case more thoroughly and to provide an opportunity for the LPCs to demonstrate their expertise in the field of supply chain management. Moreover, to demonstrate successes from the past based on real cases. For the LPCs, the latter was difficult to do. Second meetings were conducted with those LPCs that had a successful first meeting and a further investigation on the problem statement was desirable. Third meetings had the purpose to offer the LPCs that past the first round(s) the opportunity to do a business proposition on the problem statement. The six selected LPCs are:

- LPC 1;
- LPC 2;
- LPC 3;
- LPC 4;
- LPC 5;
- LPC 6.

LPC 1 is the biggest technical wholesaler in the Netherlands with nearly 300K articles from more than 700 suppliers on stock and is specialised in installation materials in the field of electronics, light, equipment, sanitary, heating and climate control. It is capable of the organisation, transport and distribution of light materials and standard tools. From previous experiences it is known that the LPC is capable of tackling, solving and executing supply chain challenges. LPC 1 offers just-in-time and just-in-place deliveries and is capable of taking care of temporary storage of materials, transports consolidation, delivery on height, carry-on and waste retour practices.

LPC 2 is a wholesaler specialised in building materials that also offer, supply chain, online business and sustainability services. The supply chain services LPC 2 offers are similar to those presented at LPC 1. The LPC is strongly involved in the development of the software program Kyp and is co-developing an Advanced Planning System (APS) that in the future is coupled to a Transport Management System (TMS). LPC 2 sees itself as the totally exonerating service provider that sits down in the control room.

LPC 3 is a wholesaler specialised in electronics, sanitary, heating, industrial materials, security systems, light, fire detection and LPC 3 power. Its core business are the mechanical and electronical installation materials. The LPC uses its own software and outsources many of its transports. On their website they claim to have six logistic services to offer and are able to offer just-in-time and just-in-place deliveries 24/7, on-site logistics and assemble kits in which product are packed together. It can offer the same logistic services as LPC 1 but has less experience.

LPC 4 is a new LPC facilitating fast building time in busy built-up areas by means of analysis, coordination, stock control and transport. With these activities the construction process can be made more 'lean'. It sees itself as a market developer and hires only employees that come from the construction industry and understand the construction building context. The LPC offers free integrated logistic advice and makes logistic programmes for its clients. It uses its own logistic hubs or those of other companies closest to the construction site. It can offer the same logistic services as LPC 1 and has the similar experience.

LPC 5 is a LPC with a specialisation in construction that offers transports from light to heavy and is familiar with the construction process. Its expertise lays in the heavy transports and construction site formations. The LPC sees great opportunities in further implementing modularity and prefabrication in the HWC. CCs arrange the transports to the factory. From the factory a LPC transports the prefab structures to the construction site. These heavy transport movements are the expertise of LPC 5. LPC 5 states that Heijmans should be the organising company. LPC 5 is able to handle the retour waste streams. LPC 5 is not able to offer the same logistic services as LPC 1.

LPC 6 is part of the biggest collaboration of independent transport and distribution companies in the Netherlands and Belgium with more than five hundred trucks on the road and is specialised in the light distribution of materials. It is able to handle the retour waste streams. For the heavy transports the company is able to dive into its network. The IT systems of the participating companies in the network are not standardised nor connected. It was part of a construction logistic cluster in Amsterdam in cooperation with the municipality Amsterdam, a research company and a few wholesalers to discuss the constructions logistics challenges. It can offer the same logistic services as LPC 1 but has less experience.

In order to make an evaluation the LPCs are scored against the following characteristics:

- core business;
- experience in construction logistics;
- professionalism at meeting;
- enthusiasm at meetings;
- innovativeness;
- VCA certificate;
- type of transports;
- optimisation proposition;
- software package.

A VCA is a certificate that a CC can acquire that stands for Safety, Health and Environment issues. The goal is to reduce accidents on the construction site and to make it safer. In Table 9 on the next page, the rankings and the overall scores of the LPCs are presented. These represent an average of the scores of the Heijmans team members involved in this research. The possible score allocations per characteristic were -2, -1, 0, 1, and 2. LPC 2 and LPC 4 had the highest scores followed by LPC 1, LPC 3, LPC 5 and LPC 6. In Table 10, the score allocation on the tested characteristics is presented per LPC.

Ranking	LPC	Score	Optimisation possibilities
1	LPC 2	7.7	Logistic hub
1	LPC 4	7.7	Logistic hub
3	LPC 5	1.7	Modularity and prefabrication in a factory
4	LPC 6	-0.3	Logistic hub
5	LPC 1	-1.3	Digital library
6	LPC 3	-3.3	Logistic hub

Table 9: Ranking of the logistics-providing companies in the business case meetings.

The optimisation possibilities that resulted from the business case meetings, as presented in Table 9, are further elaborated upon in:

Appendix 9.3.1 Logistic hub;
Appendix 9.3.4 Modularity and prefabrication in a factory.

The digital library is an idea of LPC 1 that had no match with the scope of this research.

The next step in the business case meetings was to set out requests for a concept non-binding offer on the problem statement and optimisations possibilities discussed. The LPCs invited to make an offer were:

- LPC 1;
- LPC 2;
- LPC 4.

LPC 1 is asked to make an offer due to the history the LPC has with Heijmans. LPC 3 was not yet ready to make an offer and is, together with LPC 5 and LPC 6, no longer part of the group of potential LPCs for this research. The offers of LPC 2 and LPC 4 resulted in sufficient information to use for the mapping of the ABC analysis conducted on the optimisation scenarios presented in Chapter 6. The offer of TU had sufficient information to calculate the transport cost element however it lacked information to calculate the handling and inventory and warehousing costs. The figures of the offers are presented in Section 6.1.

In this section the supply chain optimisation possibilities that resulted from the business case meetings with the selected LPCs are elaborated upon. Together with the supply chain optimisation possibilities that resulted from the literature review in Section 5.1, they are used to propose optimisation scenarios in the next section.

LPC	Construction logistics core-business	Experience	Professionalism	Enthusiasm	Innovativeness	Feeling with the company	Procession of VCA	Type of direct transports	Ideal optimisation proposition	Software package used
LPC 1	0.7	1.3	-1.3	-.3	-0.7	-1	Yes	Light	Digital library	Self-developed, SAP
LPC 2	1.7	1.7	2.0	1.3	0	1	Yes	Light and heave	Logistic hub	Self-developed, SAP
LPC 3	-1	-0.7	-0.3	0.3	-.7	-1	Yes	Light	Logistic hub	Self-developed, SAP
LPC 4	2	1.7	1.7	1.3	0.3	0.7	Yes	Light and heavy (control tower)	Logistic hub	Self-developed, SAP
LPC 5	1.0	0.7	0	0.7	0.3	-1	Yes	Heavy	Modularity and prefabrication in a factory	Bought, SAP
LPC 6	0.3	0.3	0.7	0.3	-0.3	-0.7	No, but open to get it	Light and heavy in network	Logistic hub	Self-developed, SAP

TABLE 10: AVERAGED SCORES OF THE LOGISTIC PROVDING COMPANIES (SCORING RANGE FROM -2 TO 2).

5.3 Matching the literature review with the business case meetings

In this section the third sub-question of Phase 2 is answered:

> *2.3 Which supply chain optimisation possibilities can be transformed into optimisation scenarios based on sub-question 2.1 and 2.2?*

The objective of this section is *to propose optimisation scenarios based on the literature research and business case meetings.* As stated before an optimisation scenario is a scenario that is able to improve the first-tier physical distribution streams in the supply chain as well as to incorporate other optimisation possibilities [111].

In this section the optimisation possibilities from the literature review in Section 5.1 and business case meetings in section 5.2, are matched. In this research we are looking for supply chain optimisation scenarios in which the cost efficiency of the first-tier physical distribution streams is improved.

Optimisation possibility	Green cells in Table 8 (%)	Suggested as optimisation possibility in the business case meetings	Having its own physical location
Control tower	100	Yes	No
Transport consolidation	100	Yes	No
Optimal Routing	80	No	No
Waste Management	80	No	No
Logistic hub	70	Yes	Yes
Local sourcing	70	No	No
Modularity and prefabrication in a factory	50	Yes	Yes
Cross-docking	50	No	Yes
Carry-on	50	Yes	No
Carpooling	40	No	No
Reverse logistics	30	No	No

TABLE 11: OPTIMISATION POSSIBILITIES AND THEIR ABILITY TO BECOME AN OPTIMISATION SCENARIO.

In Table 11, the optimisation possibilities are presented based on the following characteristics:

- ability to incorporate other optimisation possibilities as visualised in the percentage of green cells in Table 8, column 2, from Section 5.1.
- suggested in the business case meetings in Table 9, column 3, from Section 5.2, and implementable by the LPCs.
- whether or not the optimisation possibility has its own physical location.

The third characteristic indicates whether a physical location is required. If so, it has consequences for the implementation and outsourcing option.

The optimisation possibilities that fit to the abovementioned characteristics are:

1. control tower;
2. logistic hub and cross-docking
3. modularity and prefabrication in a factory.

Abovementioned optimisation possibilities and their fit to the HWC projects are further explained below.

1. Control tower

The control tower, see Appendix 9.3.3, is implemented to sustain competitive advantage by improving the operation of the entire supply chain efficiency and benefits [88]. The approach provides a company the control and looks at the total demand of transports in order to optimise the physical distribution streams of goods for a given time period. The control tower itself is not an improvement of the physical distribution streams in a supply chain but a way to organise and implement the other optimisation possibilities. This explains the fit to the other optimisation possibilities. As stated all CCs at the HWC are responsible for their own physical distribution of goods in their activities. In order to implement other optimisations proposed the principles of the control tower demonstrate potential. If one company has the overall control and view of the supply chain it is able to predict the demand of transports and look for possible implementations of other optimisations in the supply chain of the HWC projects.

2. Logistic hub and cross-docking

A logistic hub, see Appendix 9.3.1, and cross-docking, see Appendix 9.3.2, are two supply chain optimisation possibilities that involve activities relating to transport, logistics and the physical distribution of goods [5, p. 4]; [91, p. 85]. The HWC projects have a relatively high predictability of demand for goods making both approaches implementable. The focus in cross-docking is mainly on receiving, storing, order picking and shipping in order to make the goods as quickly as possible ready for outbound transport. In a logistic hub the focus is on reloading, warehousing, separation, assemblage and prefabrication, packaging and transport. In Figure 24, an example of packaging is presented and in Figure 25, an example of prefabrication. The logistic hub and cross-docking optimisations have the ability to incorporate other optimisation possibilities. The underlying assumptions of a logistic hub fit better to the supply chain of the case study project. The logistic hub is a solution for the problem statement of this research due to its applicability of consolidation of transports together with the packaging and prefabrication practices. The control tower entity could be the LPC that organises and implements the logistic hub together with other optimisation possibilities.

FIGURE 24: PACKAGING OF GOODS AT A COOPERATING COMPANY.

FIGURE 25: PREFABRICATION AT A COOPERATING COMPANY.

3. Modularity and prefabrication in a factory

Modularity and prefabrication in a factory, see Appendix 9.3.4, has a large impact on the setup of the supply chain of the HWC projects. Transports of goods are carried out from the suppliers with high capacity usage percentages to the factory and from the factory the modules can be transported to the construction site in FTLs. The factory can be seen as a logistic hub in which even higher percentages of capacity usage percentages can be achieved.

The principles of modularity and prefabrication of elements and/or modules of the houses have huge potential and are already implemented in the HWC projects. There is room to further increase the level of modularity and prefabrication. The principles demonstrate potential to improve the cost efficiency of the supply chain. Bulk material can be purchased by the module suppliers resulting in savings on the costs of transports [26, p. 33].

In the next part the proposed optimisation scenarios of the research are presented.

The optimisation scenarios

From the four optimisation possibilities two are selected and proposed as optimisation scenarios in this research. The optimisation possibilities control tower and cross-docking do not fit to the objectives of the research. The logistic hub optimisation scenario is divided into two different optimisation scenarios resulting in three optimisation scenarios:

- Optimisation Scenario 1: Logistic hub, Type 1;
- Optimisation Scenario 2: Logistic hub, Type 2;
- Optimisation Scenario 3: Modularity and prefabrication in a factory.

Optimisation Scenarios 1 and 2 are in essence the same but the LPC exploiting the logistic hub carries out the direct heavy transports to the construction site as well as the transports from the CCs to the logistic hub that can be carried out against a lower price.

In the two logistic hub optimisation scenarios the following other optimisation possibilities can be incorporated as presented in Table 8:

- control tower;
- waste management;
- transport consolidation;
- optimal routing;
- carry-on approach;
- local sourcing.

For Optimisation Scenario 3, modularity and prefabrication in a factory, the same other optimisation possibilities can be incorporated except the carry-on approach and local sourcing optimisations.

In the next section the optimisation possibilities are matched to the five physical distribution stream categories.

5.4 Matching the optimisation possibilities and optimisation scenarios to the five physical distribution stream categories

In this section the fourth sub-question of Phase 2 is answered:

> *2.4 Which supply chain optimisation possibilities and optimisation scenarios fit to the physical distribution categories that resulted from the ABC analysis conducted on the case study project?*

In the previous section the selected optimisation scenarios and the optimisation possibilities that can be incorporated are presented. In this section the match between the optimisation scenarios and the optimisation possibilities, and the five physical distribution stream categories that resulted from the ABC analysis conducted on the case study project, is set out. This is done to gain an understanding of which first-tier physical distribution streams in the supply chain of the case study project change in the mapping of the optimisation scenarios conducted to an ABC analysis in Chapter 6.

Section 4.4 revealed the 82 construction activities of the case study project that have 134 different first-tier physical distribution streams requiring nearly 1500 transports to the construction site. Five different physical distribution stream categories were identified as mentioned in Section 4.4. These categories have different benefits from the optimisation possibilities and optimisation scenarios as presented in Section 5.1 and Section 5.2.

The five physical distribution stream categories and the fit to the optimisation possibilities are visualised in Table 12, and elaborated upon. A green cell in Table 12, indicates that the optimisation possibility is able to improve the (cost) efficiency of the physical distribution stream category. Only the optimisation possibilities that are able to directly influence the physical distribution stream categories are presented.

1. direct heavy physical distribution;
2. direct light physical distribution;
3. employees;
4. employees with small materials and standard tools;
5. heavy equipment.

1. *Direct heavy physical distribution:* The transport in this category have high loading usage percentages and are carried out by (heavy) trucks that departs from the factories of the manufacturers and/or suppliers. Many of these transports come from CCs that are in a co-makership relationship with HH. The transport planning is synchronised with the productivity and processing

time on the construction site. At the case study project new construction elements are called off if required which could occur multiple times a day. The use of a logistic hub for the first-tier physical distribution of the direct heavy distribution transports is not commonly efficient. The direct heavy physical distribution category is divided into two:

- Fast processing time: the direct heavy transports should go directly to the construction site to keep transport costs low. These goods are used and processed as quickly as possible.
- Slow processing time: a logistic hub could be beneficial for these direct heavy transports. From the logistic hub the goods can be delivered just-in-time and just-in-place. If these goods are delivered in FTL at the construction site they need to be stored resulting in a higher risk of damage and theft of the goods. In Figure 26 and Figure 27, this risk is visualised.

The FTLs, in many cases, have high percentages of capacity usage on their way to the construction site but are empty on their way back. The costs of these empty kilometres are hidden in the costs of the transports. If the planning of the trucks could be combined with transports to other nearby destinations the overall costs of the transports decrease due to less empty truck movements. At the HWC projects all CCs carry out their own logistics activities and are missing the economy of scale to optimise the transports for the case study project. A LPC could provide the required economy of scale and facilitate the transports consolidation. As a consequence efficiency increases resulting in lower costs. Moreover, the LPC has its own rates that, in some cases, are lower than the rates of the CCs. In these cases the LPC should take over the transports of the CCs.

FIGURE 26: HIGH RISK OF DAMAGE AND THEFT OF GOODS STORED AT THE CONSTRUCTION SITE.

FIGURE 27: DELIVERY OF GOODS FAR AWAY FROM THE PLACE OF PROCESSING.

2. *Direct light physical distribution:* The transports of the category have lower percentages of capacity usage and are carried out by (light) trucks that depart from the factories or warehouses of the suppliers. The transport planning is usually set up in an optimal route from the address of origin to multiple construction sites; drop off points.

The use of a logistic hub could be beneficial for the direct light transports due to the possibilities of:

- transport consolidation;
    - deliver goods just-in-time and just-in-place.
- achieving higher percentages of capacity usage of the transports to the logistic hub and from the logistic hub to the construction site;
- optimal routing.

3. *Employees:* The transports of this category are carried out by the employees themselves. They use their own delivery vans or cars or those of the CCs they work for. The vehicles are used for nothing else then the transport of the employees. The transports of employees can benefit from:

- carpooling;
- local sourcing.

For large projects, bus transports for groups of employees could be organised from a central location to the construction site to reduce the number of transports and costs.

4. *Employees with small materials and standard tools:* The transport of category are carried out by the delivery vans of the CCs. The transports consist of three different physical distribution streams that are: employees, small materials and standard tools. These three streams could be separated. A logistic hub could be beneficial for the physical distribution of the small materials and standard tools. Carpooling could be beneficial for the transport of employees.

5. *Heavy equipment:* The transports of this category are carried out by:

- the heavy equipment itself, for example self-driving cranes, shovels and loaders;
- heavy trucks.

The heavy equipment is specialised and not widely available in the market. Local sourcing is the ideal way to optimise the transport costs of this distribution stream.

In this section the five physical distribution stream categories were analysed on their fit to the optimisation possibilities and optimisation scenarios. The physical distribution stream categories that can improve the cost efficiency of the supply chain in the logistic hub optimisation scenarios are:

1. direct heavy physical distribution with slow processing time;
2. direct light physical distribution;
4. employees with small materials and standard tools
   - with the small materials.

In Optimisation Scenario 3, modularity and prefabrication in a factory, the factory is seen as a logistic hub in which the houses are produced. The same first-tier physical distribution stream categories as with the logistic hub can improve the supply chain of optimisation scenario modularity and prefabrication in a factory.

In the next and final section of Chapter 5, the three proposed optimisation scenarios are visualised and elaborated upon.

Physical distribution stream category	Control tower and, modularity and prefabrication in a factory	Logistic hub and cross docking	Transport consolidation	Optimal routing, reverse logistics and waste management	Carry-on approach	Local sourcing	Carpooling
Direct heavy physical distribution (Fast processing time)							
Direct heavy physical distribution (Slow processing time)							
Direct light physical distribution							
Employees							
Employees with small materials and standard tools							
Heavy equipment							

TABLE 12: THE FIVE PHYSICAL DISTRIBUTION STREAMS AND THEIR FIT TO THE OPTIMISATION SCENARIOS AND POSSIBILITIES.

5.5 Visualisation of the three proposed optimisation scenarios

In this section the fifth sub-question of Phase 2 is answered:

2.5 *What are the characteristics of the selected supply chain optimisation scenarios?*

In this section the optimisation scenarios that were selected in Section 5.3 are presented and visualised. In Figure 28, Figure 29 and Figure 30 the optimisation scenarios are presented. The physical distribution streams arranged to the logistic hub (blue lines) and from the logistic hub to the construction site (green lines) have higher percentages of capacity usage in the optimisation scenarios than the physical distribution streams in the case study project [15]; [68]. Optimisation Scenarios 1 and 2 are in essence the same but the LPC exploiting the logistic hub carries out the direct heavy transports to the construction site as well as the transports from the CCs to the logistic hub that can be carried out against a lower price.

Optimisation Scenario 1: Logistic hub, Type 1

Suitable physical distribution streams go through a logistic hub. CCs arrange the transport to the logistic hub and from there the LPC exploiting the logistic hub arranges the transport to the construction site. This is visualised in Figure 28.

Blue line: Second-tier transports carried out by the CCs to the factory.
Green line: First-tier transport carried out by the CCs directly to the construction site.
Red line: First-tier transport carried out by the LPC from the factory to the construction site.

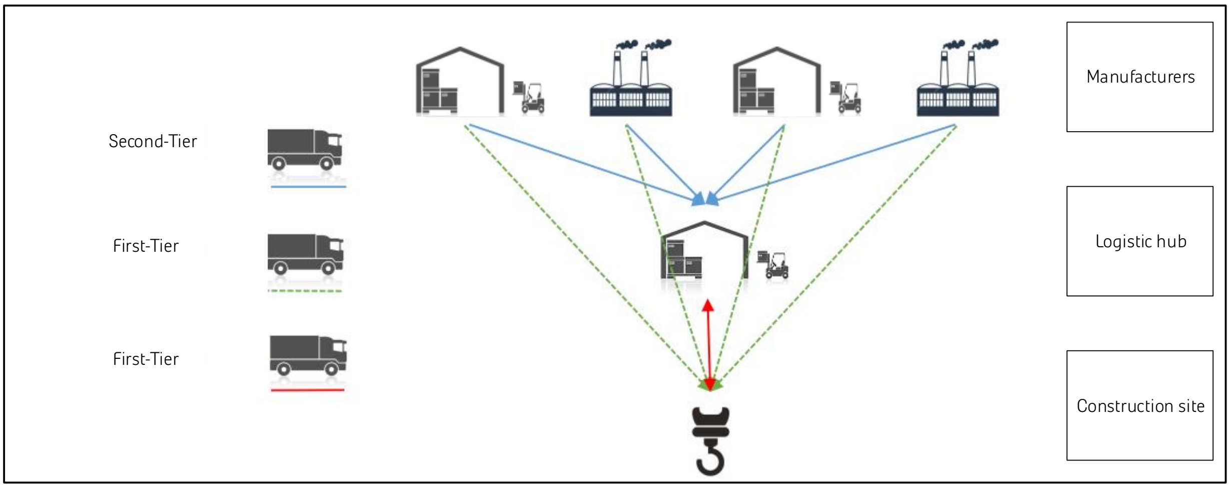

FIGURE 28: VISUALISATION OPTIMISATION SCENARIO 1, LOGISTIC HUB, TYPE 1.

Optimisation Scenario 2: Logistic hub, Type 2

Same flow as scenario 1, but the LPC exploiting the logistic hub carries out the direct heavy transports to the construction site as well as the transports from the CCs to the logistic hub which can be carried out against a lower price. This is visualised in Figure 29.

Blue line: Second-tier transports of the CCs to the logistic hub. Some of these transports are carried out by the LPC.
Green line: First-tier transport carried out by the CCs directly to the construction site.

Red line: First-tier transport carried out by the LPC of the logistic hub to the construction site.

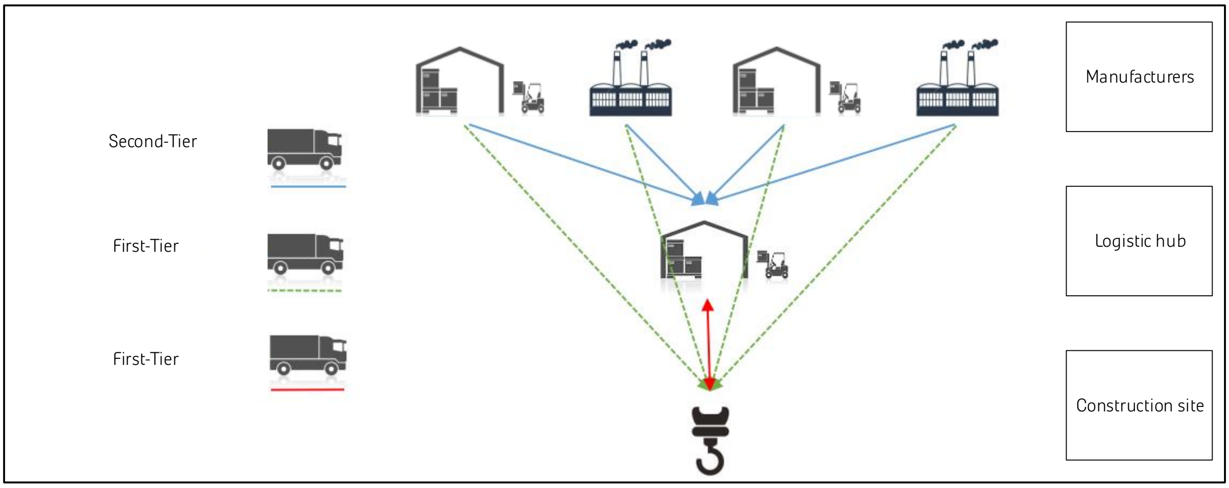

FIGURE 29: VISUALISATION OPTIMISATION SCENARIO 2, LOGISTIC HUB, TYPE 2.

Optimisation Scenario 3: Modularity and prefabrication in a factory

A factory is built in which prefabbed modules are manufactured. From the factory the modules are transported to the construction site. CCs arrange the transports to the logistic hub and from there a LPC arranges the transports of the prefabbed modules to the construction site. This is visualised in Figure 30.

Blue line: Second-tier transports carried out by the CCs to the factory.
Green line: First-tier transport carried out by the CCs directly to the construction site.
Red line: First-tier transport carried out by the LPC from the factory to the construction site.

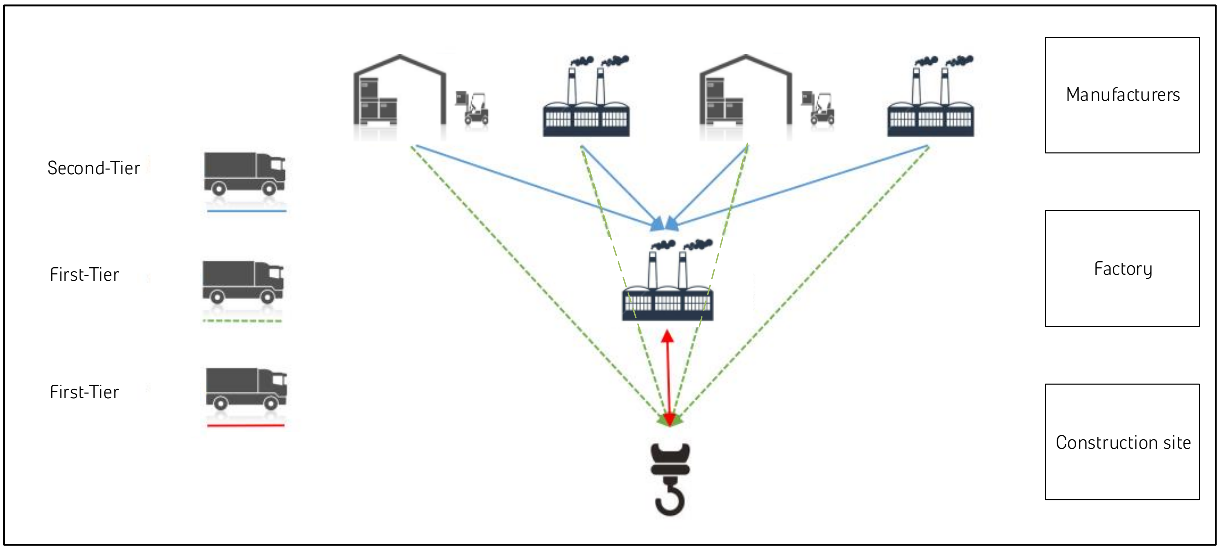

FIGURE 30: VISUALISATION OPTIMISATION SCENARIO 3, MODULARITY AND PREFABRICATION IN A FACTORY.

Optimisation Scenario 3 is added to the optimisation scenarios to get a feeling of its logistics cost savings potential. This optimisation scenario has not been discussed with the LPCs so no LPCs were invited to make an offer. In the next part the summary of Chapter 5 is presented.

Summary Chapter 5

In this chapter, Phase 2 of the research, *literature review and business case meetings on (construction) supply chain optimisation possibilities*, is elaborated upon. The five sections and corresponding sub-questions each contribute to answering the Main Question:

2.0 *Which supply chain optimisation possibilities can be transformed into optimisation scenarios that fit the case study project?*

The main objective of Chapter 5 is to *propose optimisation scenarios based on the literature review and business case meetings.* Three optimisation scenarios gleaned from the resulting optimisation possibilities are proposed based on the following selection criteria:

- ability to incorporate other optimisation possibilities;
- suggested in the business case meetings and implementable by the LPCs;
- whether or not the optimisation possibility has its own physical location.

The three proposed optimisation scenarios are the answer to Main Question 2.0:

- *Scenario 1: Logistic hub, Type 1*: Suitable physical distribution streams go through a logistic hub. CCs arrange the transport to the logistic hub, and from there the LPC exploiting the logistic hub arranges the transport to the construction site.
- *Scenario 2: Logistic hub, Type 2*: Same flow as Scenario 1, but the LPC exploiting the logistic hub carries out the direct heavy transports to the construction site as well as the transports from the CCs to the logistic hub, which can be carried out against a lower price.
- *Scenario 3: Modularity and prefabrication in a factory*: A factory is used in which prefabbed modules are manufactured. From the factory the modules are transported to the construction site. CCs arrange the transports to the logistic hub, and from there a LPC arranges the transports of the prefab modules to the construction site.

The five physical distribution stream categories, identified in Chapter 4, have different benefits from the various optimisation possibilities. Three of the five physical distribution stream categories are selected according to their fit within the optimisation scenarios:

1. direct heavy physical distribution with
    - slow processing time;
2. direct light physical distribution;
4. employees with small materials and standard tools;
    - with the small materials.

The two physical distribution streams that do not go through the optimisation scenarios can be improved parallel to the optimisation scenarios, by improving their cost efficiency by implementing other optimisation possibilities.

The three optimisation scenarios and the physical distribution stream categories selected for their fit with the optimisation scenarios are the starting point of Chapter 6. In this next chapter, Phase 3 of this research, *mapping the optimisation scenarios with the use of the ABC approach,* is set out. The optimisation scenarios are the improved situations of the first-tier physical distribution streams in the supply chain of the case study project.

6 ABC analysis conducted on the three optimisation scenarios

In Chapter 4, Phase 1 of the research, *mapping the case study project with the use of the ABC approach*, has been detailed, while Chapter 5 has explained Phase 2 of the research, *literature review and business case meetings on (construction) supply chain optimisation possibilities*. The results of Chapter 5 form the starting point of this chapter, in which Phase 3 of the research is set out:

Phase 3: Mapping the optimisation scenarios with the use of the ABC approach.

The ABC analysis conducted in Chapter 4 on the mapping of the case study project supply chain elucidated the characteristics of the current (cost) composition of the first-tier physical distribution streams. The optimisation scenarios that are able to improve the current situation were presented in Chapter 5:

1. Logistic hub, Type 1;
2. Logistic hub, Type 2;
3. Modularity and prefabrication in a factory.

This chapter examines the ABC analyses conducted on the mapping of the three optimisation scenarios in the ABC model. This examination results in an understanding of the (cost) composition of the first-tier physical distribution streams in the supply chain of the optimisation scenarios. The same construction activities as with the case study project and the changes that occur in the first-tier physical distribution streams with the implementation of the optimisation scenarios are inserted into the ABC model. The Main Question of Phase 3 as follows:

3.0 Which supply chain optimisation scenario has the highest potential to improve the cost efficiency of the first-tier physical distribution streams in the supply chain of the HWC projects?

The answer to this question enables an answer to the research question in Chapter 8, which concerns conclusion and recommendations.

The present chapter has two objectives:

- *to map the optimisation scenarios with an ABC analysis;*
- *to compare the results of the ABC analysis conducted on the mapping of the supply chain of the optimisation scenarios to the results of the ABC analysis conducted on the mapping of the case study project.*

To achieve these objectives and answer Main Question 3.0, the chapter covers the following sections:

6.1 The offers of the logistics-providing companies;
6.2 Extra calculation steps for the optimisation scenario ABC analysis;
6.3 The results of the ABC analyses conducted on the mapping of the optimisation scenarios;
6.4 Benefits and challenges of the Optimisation Scenarios 1 and 2.

The first section of this chapter presents the figures that resulted from the offers of the LPCs.

6.1 The offers of the logistics-providing companies

In this section the first sub-question of Phase 3 is answered:

3.1 What are the figures of the offers from the logistics-providing companies?

In Phase 2 the three selected LPCs, LPC 1, LPC 2 and LPC 4, were invited to make an offer in which they presented their cost composition figures of the logistics cost elements transport, handling and inventory and warehousing as stated in the theoretical process model in section 2.1. The figures are used to calculate the logistics costs in the ABC analysis conducted on the mapping of the supply chain of the optimisation scenarios.

For Optimisation Scenarios 1 and 2, the total logistics costs and logistics costs savings of the implementation of a logistic hub are calculated for all three selected LPCs. The logistic hub costs figures of LPC 2, presented in Table 13, are used to calculate the costs of the logistic hub for LPC 1 as well as for LPC 2 who was not able to come up with its own logistic hub costs composition. LPC 2 calculates the costs of the logistic hub per pallet and presented three cost levels. They expect that the costs in practice lay somewhere in this scope. In the price per pallet the transport, handling, inventory, warehousing, carry-on and organisational costs elements are all included.

Logistic hub cost levels	Low logistic hub costs (€)	Average logistic hub costs (€)	High logistic hub costs (€)
Cost per pallet	CONFIDENTIAL	CONFIDENTIAL	CONFIDENTIAL

TABLE 13: LOGISTICS COST FIGURES OF LPC 2.

In Table 14, the number of pallets that fit in a truck of LPC 2 is presented. In the next section is explained how this is used in the calculation steps of the ABC analysis conducted on the optimisation scenarios.

Characteristic	(#)
Pallets per truck	22

TABLE 14: NUMBER OF PALLETS PER TRUCK.

In Optimisation Scenario 2, the transport costs to arrange the selected transports from the CCs to the logistic hub are calculated with the figures of LPC 1 and LPC 2. The figures of the transport cost elements from the offers of LPC 1 and LPC 2 are presented in Table 15.

LPCs	LPC 1	LPC 1	LPC 2
	Per hour (€)	Per hour (€)	Per kilometre (€)
Heavy transport costs	CONFIDENTIAL	CONFIDENTIAL	CONFIDENTIAL
Light transport costs	CONFIDENTIAL	CONFIDENTIAL	CONFIDENTIAL

TABLE 15: TRANSPORT COSTS OUT OF THE OFFERS OF LPC 1 AND LPC 2.

The figures of LPC 4 are based on subcontracting and the cost composition of the logistic hub for one project is presented in Table 16 on the next page. The discount is based on contributions (subsidy) from the government for logistics optimising initiatives in the construction industry. LPC 1 and LPC 2 were asked whether they are open for subcontracting. Their answer was that on the short-term they see too much risks and they are not open for subcontracting.

Type of costs	Costs (€*1000)
Advise	CONFIDENTIAL
Logistic hub	CONFIDENTIAL
CONFIDENTIAL	CONFIDENTIAL
Discount	CONFIDENTIAL
Total logistic hub costs	CONFIDENTIAL

TABLE 16: COSTS COMPOSITION FROM THE OFFER OF LPC 4.

Before these figures can be used to calculate the logistics costs of the first-tier physical distribution streams in the supply chain of the optimisation scenarios an understanding is required of the calculation steps in the ABC analysis conducted on the mapping of the supply chain in the optimisation scenarios. This is set out in the next section.

6.2 Extra calculation steps for the optimisation scenario ABC analysis

In this section the second sub-question of Phase 3 is answered:

3.2 What are the prerequisites of the optimisation scenarios to start the ABC analysis?

Now that the figures of the LPCs are known the logistics costs of the first-tier physical distribution streams in the supply chain of the optimisation scenarios are calculated. The calculation steps are different from the calculations of the logistics costs of the case study project in Chapter 4. For the optimisation scenarios there are four calculation steps:

Step 1: Mapping the new first-tier physical distribution streams of the supply chain in the optimisation scenarios;
Step 2: Calculation of the extra logistic hub costs;
Step 3: Calculation of the improved productivity;
Step 4: Calculation of the logistics costs of the optimisation scenarios.

Step 1: Mapping the new first-tier physical distribution streams in the supply chain in the optimisation scenarios

The same approach is used as applied to the case study project, but to map the new first-tier physical distribution streams in the supply chain of the optimisation scenarios for the different LPCs, the locations of the facilities of the LPCs are inserted in the ABC model. In Optimisation Scenarios 1 and 2, the facility is a logistic hub, and in Optimisation Scenario 3, the facility is a factory. The physical distribution streams are redirected if required and the new costs per construction activity are calculated. When added up, this results in the new logistics costs in the supply chain of the optimisation scenarios. In order to redirect the physical distribution streams the locations need to be known to insert them into the ABC model.

Optimisation Scenario 1 and 2: Logistic hub, Type 1 and 2

The locations of the logistic hubs in scenario 1 and 2 of LPC 1 and LPC 2 are as visualised in Figure 31:

1. LPC 2 CONFIDENTIAL
2. LPC 1 CONFIDENTIAL

The locations were selected in accordance with the LPCs and are existing facilities based on:

- the location of the logistic hub facility in the Netherlands;
- the position to the case study project;
- the closeness to a highway to reduce the distance travelled inside built-up areas.

FIGURE 31: LOCATION OF THE LOGISTIC HUBS OF LPC 1 AND LPC 2.

FIGURE 32: LAND POSITIONS OF HEIJMANS FOR A MODULARITY AND PREFABRICATION FACTORY.

Optimisation Scenario 3: Modularity and prefabrication in a factory

The location of the factory is based on a study of existing land positions of Heijmans. The following criteria were used:

- central in the Netherlands;
- close to the highway;
- open for development.

The three possible land position of Heijmans as visualised in Figure 32 are:

1. Labradoriet 330 3316 KE Dordrecht
2. Roosendaalsebaan 41 4751 XX Oud Gastel
3. Hurksestraat 19 5652 AH Eindhoven

Land position 1 is the ideal option to the criteria and is used in the ABC model of Optimisation Scenario 3.

Step 2: Calculation of the extra logistic hub costs;

The calculation of the extra logistic costs of the optimisation scenarios was only possible for scenario 1 and 2 due to missing figures to calculate the costs of Optimisation Scenario 3. To calculate the costs of the logistic hubs for LPC 1 and LPC 2 the number of pallets that go through the logistic hub need to be known.

Optimisation Scenario 1 and 2

In order to establish the number of pallets the results of the ABC analysis conducted on the mapping of the supply chain of the case study project are analysed. This based on the match between the optimisation possibilities and the five physical distribution stream categories presented in Section 5.4. This resulted in 37 first-tier physical distribution streams with 184 transports that were selected to go through the logistic hub. This is 12.4% of the total transports. The maximum load of a LPC 2 truck is 22 pallets. The selected first-tier physical distribution streams are analysed and if a transport had formerly 50% capacity usage in the case study project we took 50% of 22 pallets resulting in 11 pallets for that particular physical distribution stream. The capacity usage data results from the 36th column of the ABC model as presented in Section 3.2. The calculations for the other type of transport vehicles are pro rata in comparison to the maximum truckload of 22 pallets to calculate the number of pallets. The analysis of all 37 selected first-tier physical distribution streams resulted in nearly 36 FTL transports that are required to arrange the transports of the pallets from the logistic hub to the construction site presented in Table 17 with a total of 832 pallets. This results in an approximation based on capacity usage data retrieved from the interviews. The actual number of pallets could be higher or lower. Instead of using the 832 pallets to calculate the logistic hub costs, a safety factor of 1.2 is applied to make up for the possible different numbers of pallets in practice, resulting in a roundup of 1000 pallets. This is done to correct for the approximations made.

Characteristic	(#)
Number of pallets required	832
Number of FTL transports at least required from the logistic hub to the construction site	36
Total number of safety pallets	1000

TABLE 17: NUMBER OF TRANSPORTS AND PALLETS IN ORDER TO CARRY OUT OPTIMISATION SCENARIO 1 AND 2.

LPC 2 gave a scope of low, average and high costs per pallet. The actual costs per pallet and the costs of the logistic hub lay somewhere in the scope that is presented in Table 18. The cost levels are used to calculate the logistic hub costs in Optimisation Scenarios 1 and 2.

Logistic hub cost levels	Logistic hub costs (€)	Logistic hub costs 1000 pallets (€*1000)
Low logistic hub costs	CONFIDENTIAL	CONFIDENTIAL
Average logistic hub costs	CONFIDENTIAL	CONFIDENTIAL
High logistic hub costs	CONFIDENTIAL	CONFIDENTIAL

Table 18: Logistic hub cost levels of LPC 1 and LPC 2.

In Figure 33, the percentages of the physical distribution streams categories, as mentioned in Section 4.4, are presented of the 37 selected physical distribution streams. The five physical distribution steams are:

1. direct heavy first-tier physical distribution;
2. direct light first-tier physical distribution;
3. employees;
4. employees with small materials and standard tools;
5. heavy equipment.

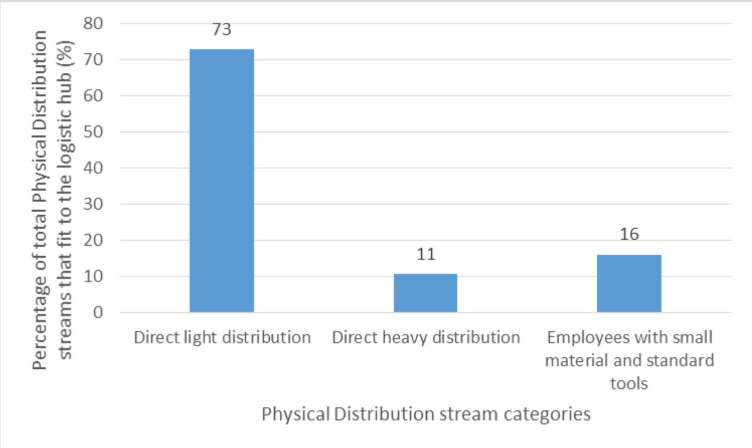

FIGURE 33: PERCENTAGES OF THE TYPE OF PHYSICAL DISTRIBUTION STREAMS THAT FIT TO THE LOGISTIC HUB OPTIMISATION SCENARIOS.

As expected in Section 5.4, the light direct distribution category has the highest potential from the logistic hub optimisation scenarios. In Figure 34, the percentages of the physical distribution streams per CC are presented.

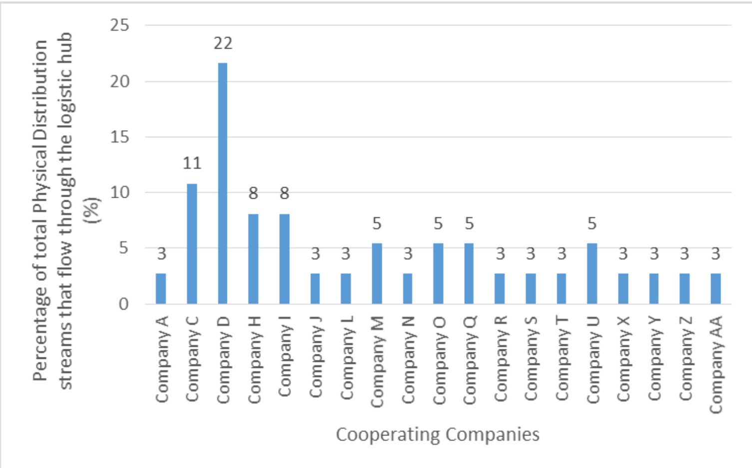

FIGURE 34: PERCENTAGE OF PHYSICAL DISTRIBUTION STREAMS THAT FLOW THROUGH THE LOGISTIC HUB PER COOPERATING COMPANY.

The first-tier physical distribution streams of Figure 34 are summed up to calculate the total logistics costs and logistics cost savings of the supply chain in Optimisation Scenarios 1 and 2.

Step 3: Calculation of the improved productivity.

For Optimisation Scenarios 1 and 2, the implementation of a logistic hub results in an increased productivity of the employees. From literature a productivity increase of 6.25% is expected [31, p. 3]. To calculate the on-site logistics costs two calculation steps are made:

Step 1: Calculate the labour costs of the construction activities that go through the logistic hub. The labour costs are calculated by taking 25% of the total building sums per CC. The exact labour costs of the HWC projects are unknown. By taking half of the usual construction labour costs (50%) fluctuations in the actual unknown labour costs of the CCs in the construction activities they carry out are taken into account in the calculation [31].

Step 2: Calculate the on-site logistics costs. In this research the on-site logistics costs are calculated by taking 5, 6.25 and 10% of the labour costs as presented in Table 19.

Productivity level	Cost savings due to increased productivity (€*1000)
Increased productivity 5%	19
Increased productivity 6.25%	24
Increased productivity 10%	38

TABLE 19: COST SAVINGS DUE TO INCREASED PRODUCTIVITY.

The expected increased productivity cost savings with 6.25% is €24K and is thus based on an underestimation of the expected cost savings.

Step 4: Calculation of the logistics costs of the optimisation scenarios

To calculate the logistics costs of the optimisation scenarios per LPC the logistic hub costs of Step 2 are subtracted from the results of the mapping of the optimisation scenario in Step 1. At last the increased productivity of Step 3 is added.

In this section the calculation steps of the logistics costs of the first-tier physical distribution streams in the optimisation scenarios are presented. Together with the figures from the offers of the LPCs, the ABC analyses can now be conducted. The results of the ABC analyses are presented in the next section.

6.3 The results of the ABC analyses conducted on the mapping of the optimisation scenarios

In this section the third sub-question of Phase 3 is answered:

3.3 What are the results of the ABC analyses conducted on the mapping of the optimisation scenarios?

The objectives of Phase 3 and this section are:

- *To map the optimisation scenarios with an ABC analysis.*
- *To compare the results of the ABC analysis of the supply chain optimisation scenarios to the results of the ABC analysis of the case study project.*

The results of the ABC analysis conducted on the mapping of the first-tier physical distribution streams in the supply chain of Optimisation Scenarios 1 and 2 are set out in the next two sections. Optimisation Scenario 3 is set out in chapter 7; the discussion. In Section 6.3.1 the logistic costs and logistic cost savings are presented for Optimisation Scenario 1 and the LPCs. In Section 6.3.2 for Optimisation Scenario 2.

6.3.1 Optimisation Scenario 1: Logistic hub, Type 1

For a review on Optimisation Scenario 1 go to section 5.5. The results of the ABC analyses are presented for LPC 1, LPC 2 and LPC 4 in Figure 36 and Figure 35. The results are based on the average logistic hub cost level of € CONFIDENTIAL per pallet, as presented in Table 18, and a productivity increase of 6.25%, as presented in Table 19. In Appendix 9.9, page 119, the results of the other productivity and pallet cost levels are presented in figures as well as in a table form.

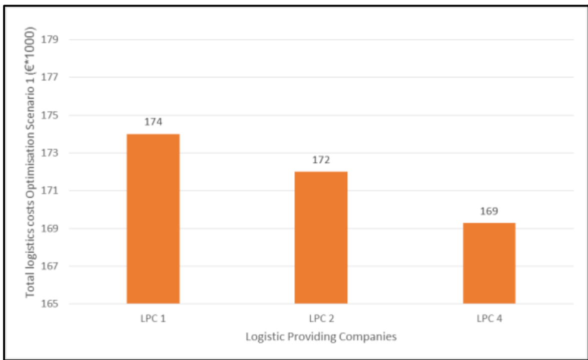

FIGURE 36: TOTAL LOGISTICS COSTS OPTIMISATION SCENARIO 1 PER LOGISTICS-PROVIDING COMPANY.

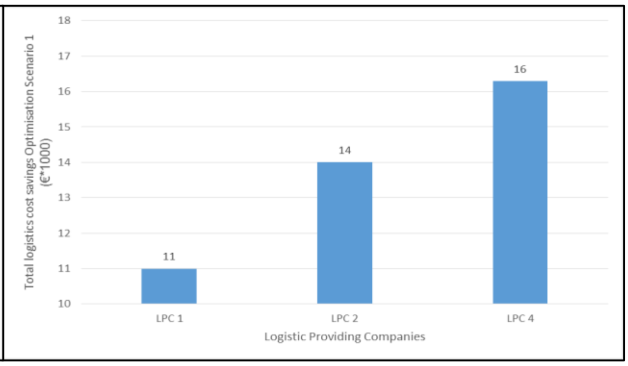

FIGURE 35: TOTAL LOGISTICS COST SAVINGS OPTIMISATION SCENARIO 1 PER LOGISTICS-PROVIDING COMPANY.

For LPC 4 the figures of the cost composition were provided too late to redirect the transports to a location of LPC 4 in the ABC model. The assumption is made that the costs do not show significant differences from LPC 2 due to the extended network of locations of LPC 4 and the probability that it has a logistic hub location close to the location of the case study project. Therefore, the results of the ABC mapping of the LPC 2 facility are used to calculate the logistics costs of LPC 4 together with the figures of LPC 4.

The results of the ABC analysis, as presented in Table 20, conducted on the mapping of the supply chain of Optimisation Scenario 1 reveal a significant cost savings potential for all three LPCs in comparison to the logistic costs of the case study project presented in Chapter 4. The LPCs show a logistics cost savings potential in the range of 5-10% in Optimisation Scenario 1.

LPCs	Total logistics costs (€*1000)	Cost savings (€*1000)	Logistics cost savings (%)	Costs savings per house (€)	Project profit increase (%)
LPC 1	174	11	5	389	CONFIDENTIAL
LPC 2	172	14	7	479	CONFIDENTIAL
LPC 4	169	16	8	562	CONFIDENTIAL

TABLE 20: RESULTS OF THE ABC ANALYSES CONDUCTED ON OPTIMISATION SCENARIO 1.

In the next part the changes in transports in Optimisation Scenario 1 and 2 are presented.

Number of transports in the supply chain

The number of trips required to arrange the transports to the logistic hub and directly to the construction site is reduced with 42 and the total kilometres by 1182 in optimisation scenario 1 and 2. From the logistic hub at least 36 transports are necessary from the logistic hub to the construction site. These 36 transports are a consolidation of 56 transports that have the logistic hub as their destination. The difference results from the CCs that require more than one FTL for their first-tier physical distribution to the logistic hub that have non optimal percentage of capacity usage on their last transport. In the case study project this required 183 transports which is a reduction of 128. Added to the 36 transports that are minimally required to arrange the transports to the construction site the reduction of trips is undone. This can be explained by the separation of transports of the fourth physical distribution stream category 'employees with small materials and standard tools' as well by the transports that have to be carried out twice. One time from the CC to the logistic hub, and one time from the logistic hub to the construction site.

In the next section the results of the ABC analyses conducted on Optimisation Scenarios 2 for the LPCs is elaborated upon.

6.3.2 Optimisation Scenario 2: Logistic hub, Type 2

For a review on Optimisation Scenario 2 go to section 5.5. The results of the ABC analyses are presented for LPC 1 and LPC 2 in Figure 38 and Figure 37. LPC 4 is not open to arrange the transports to the logistic hub. Optimisation Scenario 2 is exactly the same as Optimisation Scenario 1, but the LPC exploiting the logistic hub carries out the direct heavy transports to the construction site as well as the transports from the CCs to the logistic hub which can be carried out for a lower price. In the calculations of the new transport costs to the logistic hub a response time of 30 minutes per transport is added to incorporate the driving time to the facilities of the CCs by the LPCs. The handling time at the CCs is only incorporated in the calculations of the physical distribution streams when this was done in the mapping of the case study project in Chapter 4.

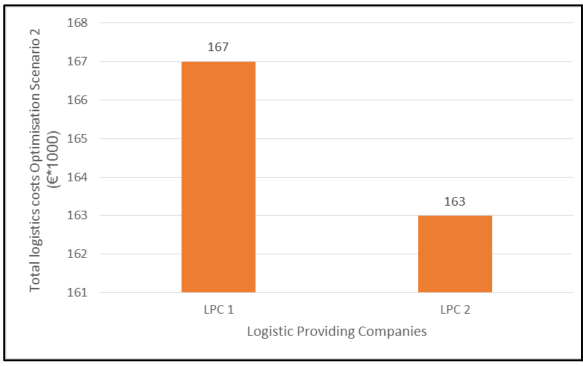

FIGURE 38: TOTAL LOGISTICS COSTS OPTIMISATION SCENARIO 2 PER LOGISTICS-PROVIDING COMPANY.

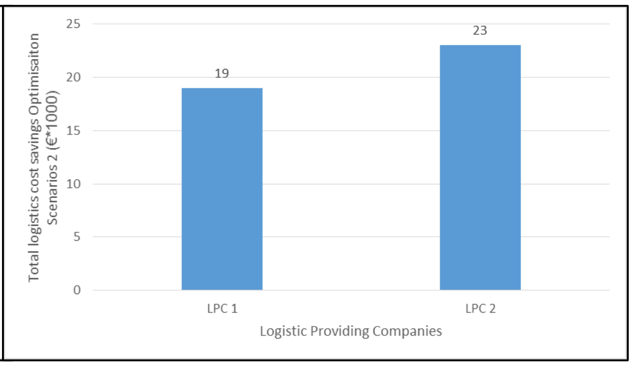

FIGURE 37: TOTAL LOGISTICS COST SAVINGS OPTIMISATION SCENARIO 2 PER LOGISTICS-PROVIDING COMPANY.

In Table 21 the number of first-tier physical distribution streams that are carried out by the LPCs in Optimisation Scenario 2 are presented together with the extra logistics costs savings potential. Table 21 reveals that LPC 1 is able to carry out more transport against a lower, however LPC 2 shows higher cost savings potential for those transports.

LPCs	Number of physical distribution streams taken over (#)	Extra logistics cost savings potential (€*1000)
LPC 1	8	CONFIDENTIAL
LPC 2	7	CONFIDENTIAL

TABLE 21: CHANGES IN OPTIMISATION SCENARIO 2; TRANSPORTS TAKEN OVER AND EXTRA LOGISTICS COST SAVINGS POTENTIAL.

The results of the ABC analyses as presented in Table 22 conducted on the mapping of the supply chain in Optimisation Scenario 2, reveal a significant cost savings potential for all LPCs in comparison to the logistic costs of the case study project presented in Chapter 4. Around 10% logistic cost savings could be established for both LPCs in Optimisation Scenario 2.

LPCs	Total logistics costs (€*1000)	Cost savings (€*1000)	Logistics cost savings (%)	Cost savings per house (€)	Project profit increase (%)
LPC 1	166	19	9	793	CONFIDENTIAL
LPC 2	163	23	11	655	CONFIDENTIAL

TABLE 22: RESULTS OF THE ABC ANALYSES CONDUCTED ON OPTIMISATION SCENARIO 2.

In Table 23, the expected cost savings per year based on 600 houses that are built in 2016 is presented under linear cost savings conditions. This indicates the scope of the cost savings for the HWC projects per year.

LPCs	LPC 1	LPC 2	LPC 4
Characteristic	Cost savings (€*1000)	Cost savings (€*1000)	Cost Savings (€*1000)
Optimisation Scenario 1	232	287	337
Optimisation Scenario 2	393	467	N/A

TABLE 23: EXPECTED COST SAVING PER YEAR BASED ON 600 HOUSES.

In this section, the results of the ABC analysis conducted on the mapping of the supply chain of the Optimisation Scenario 1 and 2 are presented, including their benefits and challenges. Again, Optimisation Scenario 3 is elaborated upon in Chapter 7, the discussion. In the next section the benefits and challenges of Optimisation Scenarios 1 and 2 are set out.

6.4 Benefits and challenges of the Optimisation Scenarios 1 and 2

This section begins to answer the fourth sub-question of Phase 3:

3.4 *What are the benefits and challenges of the optimisation scenarios?*

Section 6.3 has outlined the financial results of the ABC analysis conducted on Optimisation Scenarios 1 and 2. Aside from their financial advantages, the optimisation scenarios have other benefits. The benefits and challenges of Optimisation Scenario 3 are presented in Chapter 7, the discussion.

First, the general benefits of Optimisation Scenarios 1 and 2, the logistic hub, Types 1 and 2, that apply to all LPCs are set out. This explanation is followed by the specific benefits of the LPCs LPC 2 and LPC 4. At the end of this section, the challenges of a logistic hub are elaborated upon.

General benefits

1. Logistics costs are reduced [47, p. 26]
   - based upon the implementation of the logistic hub and the optimisation of the first-tier physical distribution streams in the supply chain,
   - based upon increased productivity;
   - waste stream is carried by LPC.
2. Scaling up increases the cost savings potential per house [79, p. 68]. A larger number of houses and projects incorporated through the logistic hub result in a higher cost savings potential per house due to economies of scale, as visualised with the blue line in Figure 39:
   - the scope of transport consolidation increases;
   - the scope of optimisation beyond one project.

Figure 39 presents an illustrative example of the cost behaviour of the cost savings potential in the optimisation scenarios. The orange line in the figure represents the linear relationship when the number of houses increases or decreases based on the cost savings potential that occurs with 29 houses. In practice, the cost savings potential per house increases if the scope of the number of houses increases, and it decreases if the number of houses decreases. Figure 40 shows the break-even point of a logistic hub. For a certain number of houses, the day-to-day costs of the logistic hub are lower than the cost savings, the break-even point visualised with the green line.

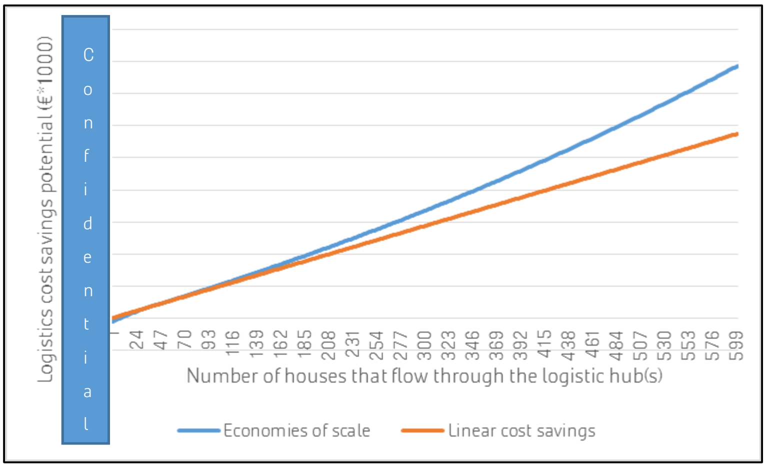

FIGURE 39: ECONOMIES OF SCALE, LINEAR COST SAVINGS AND THE LOGISTICS COST SAVINGS POTENTIAL IN A LOGISTIC HUB.

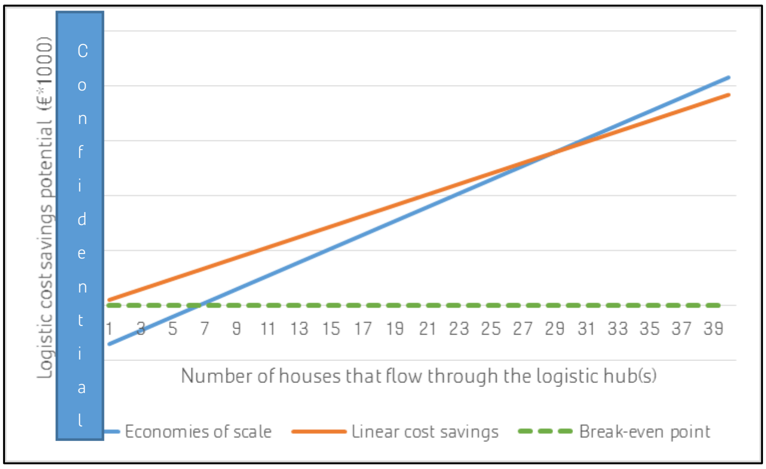

FIGURE 40: BREAK-EVEN POINT FOR THE IMPLEMENTATION OF A LOGISTIC HUB.

3. Increased productivity:
    - The logistic hub ensures that the goods are delivered just-in-time and just-in-place, such that the employees can focus on production instead of on the on-site logistical activities: waiting, finding and transporting goods. This carry-on approach increases productivity and reduces the labour costs of the CCs.
4. Coordinated first-tier physical distribution streams [71, p. 14]:
    - less fragmented organisation of the physical distribution streams in the supply chain [109, p. 1161];
    - less transports to the construction site required, meaning
        - less nuisance for the surroundings,
        - transport consolidation at the logistic hub,
        - more safety on the roads due to less truck movements,
        - higher percentages of capacity usage of the trucks;
    - The transports from the logistic hub arrive at the construction site at the end of the day instead of in the morning, meaning
        - at the end of the day the executor of Heijmans is less busy,
        - the transports are carried out outside the rush hours, reducing the driving time,
        - the executor can focus on the quality of construction work in the morning,
        - lower risk of damage and theft of the goods;
    - The transports from the logistic hub are conducted by the same LPC, so that
        - the drivers of the LPC know the construction site,
        - less unloading time is required at the construction site.
5. Potential to achieve higher scores on the 'most economically advantageous tender' (MEAT) criteria [62, p. 124]:
    - increases the possibility to win tenders.
6. Higher delivery accuracy, 95% (currently above 90) [102]:
    - extra checking moment at the logistic hub;
    - increased productivity.
7. Bulk purchasing:
    - goods can be purchased in bulk (higher quantities) and stored at the logistic hub. Purchasers are able to buy the light materials for more than one project at the time:
        - reducing of material costs.

In the next part the extra benefits for LPC 4 are presented.

Extra benefits for LPC 4

1. CONFIDENTIAL
    - CONFIDENTIAL is a cloud-solution developed by LPC 4 in order to improve the planning of transports and to visualise them in a display;
    - Construction site drawings can be sent to the CCs and LPCs indicating both driving routes to the construction site and drop-off points;
    - Safety instructions can be communicated to the drivers up-front.
2. Container delivery:
    - LPC 4 uses small containers to deliver the goods from the logistic hub at the construction site. Each container has two compartments for two different CCs, and the containers are placed as close as possible to the area of processing, resulting in

        - easy transport of the containers,
        - easy loading of the containers at the logistic hub,
        - easy unloading of the containers at the construction site,
        - reduction of on-site logistic costs.
3. Barcode scanning:
    - LPC 4 uses barcodes and packing lists are used to fill the containers such that the outbound transports depart only when all materials required at the construction site have been picked up.
4. Subcontracting:
    - LPC 4 is open to carry out the logistic hub as a subcontractor and is open to share the risks of the implementation;
    - fixed price per project instead of per pallet.

In the next part the extra benefits for LPC 2 are presented.

Extra benefits for LPC 2

1. Discounts on products of LPC 2;
    - LPC 2 is open to offer discounts on the products from their own product offering on the product prices and on the logistic costs.
2. Carry-on approach;
    - LPC 2 promises to deliver the goods to the place of processing, resulting in increased productivity in comparison to LPC 4, which delivers as close to the place of processing as possible.
3. Social return
    - LPC 2 deploys employees in its warehouses with poor job prospects.

General challenges

1. The ability of the supply chain network to quickly deploy process integration solutions while keeping the costs down [79, p. 68]:
    - Implementing the same IT systems in the supply chain network.
2. Institutional factors including intercompany power, trust, and relational embeddedness that determine the success of the logistic hub need to be overcome [24, p. 100].
3. The cost of adding an additional partner or good might be higher than the expected returns, making scaling up an advantage as well as a challenge [79].
4. Increased kilometres travelled in the supply chain:
    - As stated in Section 6.3.1, the implementation of a logistic hub can increase the number of kilometres and transports required;
        - From a sustainability point of view this is a negative outcome;
    - Increased emissions.
5. Establishing the break-even point of the logistic hub. Figure 41 exemplifies the break-even point of the logistic hub, represented by the green line. The blue line represents the cost savings that occur in the logistic hub with economies of scale. The point at which the blue and green line cross is the break-even point. This example indicates that it is profitable to implement the logistic hub with a minimum of seven houses. The yellow line represents the management choice that should indicate from which minimum number of houses the logistic hub is implemented.

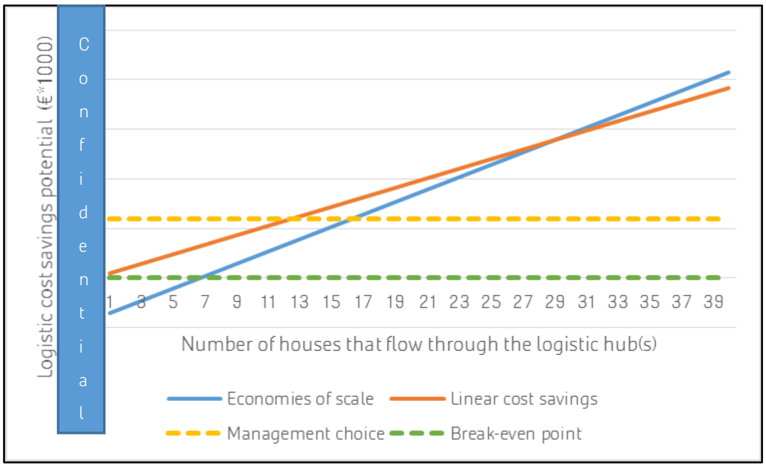

FIGURE 41: BREAK-EVEN POINT AND THE MANAGEMENT CHOICE FOR IMPLEMENTATION OF A LOGISTIC HUB.

In the next part the summary of Chapter 6 is set out.

Summary Chapter 6

In this chapter, Phase 3 of the research, *mapping the optimisation scenarios with the use of the ABC approach,* has been described. The four sections of Chapter 6 and the corresponding sub-questions have each contributed to answer the Main Question:

3.0 *Which supply chain optimisation scenario has the highest potential to improve the cost efficiency of the first-tier physical distribution streams in the supply chain of the HWC projects?*

The objectives of Phase 3 were as follows:

- *To map the optimisation scenarios with an ABC analysis;*
- *To compare the results of the ABC analysis of the supply chain optimisation scenarios to the results of the ABC analysis of the case study project.*

It was not possible to calculate the logistics costs and cost savings potential of Optimisation Scenario 3. The calculation steps for the ABC analysis conducted on the mapping of Optimisation Scenarios 1 and 2 were slightly different from the ABC analysis conducted on the case study project which took four steps:

1. The changes that occur in the supply chain are inserted in the mapping of the optimisation scenarios;
2. The logistic hub costs are calculated;
3. The increase in productivity is calculated;
4. The ABC analysis is conducted.

The results of all ABC analyses, conducted with the figures of the LPCs and on the selected optimisation scenarios, show the potential to improve the cost efficiency of the first-tier physical distribution streams in the supply chain of the HWC projects. The best optimisation scenario shows *a cost savings potential of €23,000, a logistic costs savings potential of around 10% and a profit increase* on the total project, as compared to the current situation of the case study project. These results were attained in an analysis which overestimated all cost parameters and underestimated the cost saving parameters. In practice, the scope of the cost savings potential could be even higher. The logistic hub proves to lower the logistic costs of the supply chain in the optimisation scenarios, but increased productivity need to compensate for the costs of the logistic hub. This increased productivity results from the carry-on approach, reducing the costs of the on-site logistics activities: waiting, finding and transporting goods. In the optimisation scenarios the transports of the waste streams are carried out by the LPC eliminating the corresponding transport costs in the case study project supply chain. With an expected 600 of houses to be built in 2016, *the extrapolated cost savings potential per year is around €300,000*.

Besides the financial benefits of Optimisation Scenarios 1 and 2, other general benefits and challenges have been set out. Moreover, the specific benefits for two LPCs are presented.

In Chapter 7, the limitations of the research are discussed.

7 Discussion

The previous three chapters set out the results of the two ABC analyses conducted on the case study project and the optimisation scenarios emerging from Chapter 5. This chapter renders the study's limitations, along with future research options and sets out the reliability and the validity of the results of this research. The focus is on reliability of the data retrieved from the conducted interviews, missing data, used calculations and subjective plotting of tables and figures. Moreover, the applicability of the ABC model for projects other than the HWC is elaborated upon. This chapter ends with directions of future research based on the limitation discussed in Section 7.1.

Chapter 7 proceeds as follows:

7.1 Limitations;
7.2 Applicability of the ABC model;
7.3 Future research (scientific recommendations).

7.1 Limitations

This sections elaborates on eight limitations of the research.

1. *Parameters used for part of the calculations in the ABC mapping of the case study project*

In Chapter 4's ABC analysis conducted on the case study project supply chain, the costs of transportation are calculated for some of the physical distribution streams in the construction activities, with parameters. These parameters are based on the average costs of transportation as found in the interviews with the CCs. The results of the costs of these physical distribution streams may be higher or lower in reality. The differences are, however, negligible. The reliability of the aggregated results of the ABC analysis are not negatively affected by the parameters used.

2. *Missing physical distribution streams*

It is possible that some physical distribution streams are missing in the mapping and ABC analysis conducted in Chapter 4. CCs that are not incorporated into the Kyp program beyond the scope of this research, meaning that the number of physical distribution streams that fit to go through the logistic hub may even be higher than found during this research, resulting in higher cost savings potential of the optimisation scenarios.

3. *Plotting of the optimisation possibilities*

In Table 8 in Chapter 5, the optimisation possibilities that resulted from the literature review are plotted against each other to show their ability to incorporate each other. If they cannot, this incompatibility is due to mismatches between the two. In total, six mismatches are presented:

1. adverse principles;
2. mismatch in focus on the transport of employees;
3. mismatch in focus on on-site logistics;
4. mismatch in focus on prefabrication;
5. mismatch in focus on reverse logistics;
6. mismatch in focus on waste management.

The mismatches assigned to the cells in the table are based on our judgement, and the results could differ slightly if plotted by others. The plotting of the optimisation scenarios and their ability to incorporate other optimisations is not the only characteristic on which the selection of the optimisation possibilities is based in this research, and therefore a (slightly) different plotting has no impact on the selection of the optimisation scenarios and results of this research.

Moreover, in Table 12 in Chapter 5, the optimisation possibilities and the five physical distribution stream categories that resulted from the ABC analysis conducted on the supply chain of the case study project in Chapter 4, are plotted against each other to show the ability of the optimisation possibilities to improve the (cost) efficiency of the five physical distribution stream categories. The plotting is based on our judgement, and the results could differ if plotted by others. Table 12 is precise enough to help to choose the correct optimisations for the right physical distribution stream category.

4. *Logistic hub costs*

In Chapter 6, the figures out of the offer of LPC 2 provided a scope of low, average and high prices per pallet to calculate the logistic hub costs. In this research, the average price per pallet is used to calculate the logistic hub costs in the ABC analyses conducted on the optimisation scenarios. Moreover, the number of pallets used in the calculations is based on the capacity usage percentages, from the mapping of the case study project, of the transport that were selected to go through the logistic hub. The result of this calculation is multiplied with a safety factor of 1.2 to make up for possible underestimations. Therefore, the cost savings potential of the logistic hub could even be higher in practice.

5. *Increased productivity*

The productivity increase is calculated in two steps:

Step 1: Calculate the labour costs of the construction activities that go through the logistic hub [31].
Step 2: Calculate the on-site logistics costs. In this research, the on-site logistics costs were calculated by taking 6.25% of the labour costs [31 ,p. 3].

Whether or not the 6.25% productivity increase is reachable in the case study project is not known. This unknown results in possible lower and higher increased productivity numbers and changes in the cost savings potential of the optimisation scenarios. The increased productivity cost savings potential is locked in the building sum of the CCs, but the labour costs of the construction activities that the CCs carry out are not all known by HH. This missing knowledge makes it hard to free up the increased productivity cost savings from the building sums of the CCs. It takes effort to discuss this issue with the involved CCs from which physical distribution streams go through the logistic hub.

6. *Numbers and characteristics of LPC 2 were used for LPC 1 and LPC 4*

In this research, the figures of LPC 2 were used to calculate the logistic hub costs of LPC 1. The location of LPC 2 was used to redirect the first-tier physical distribution streams for LPC 4. The results of the ABC analyses would have been more accurate if the data from LPC 1 and LPC 4 were available and used in the calculations. Due to the similarities between the three LPCs, the results of the ABC analyses conducted on the optimisation scenarios is not expected to differ much if calculated with the correct data of LPC 1 or LPC 4.

7. *Errors in the retrieved data*

Small errors in the retrieved data could have a significant effect on the outcomes of the research. For both the mapping of the case study project and the mapping of the optimisation scenarios, the same first-tier physical distribution streams are used that are double checked for potential insertion mistakes in the ABC model. Still, it is possible that errors in the data are inserted in both analyses having its effect on the logistics costs results of both analyses. This has no effect on the cost savings potential resulting from a comparison between the logistics costs of both analyses.

8. *Generalisability of cost savings results to all HWC projects*

As stated in Chapter 4, the HWC projects are executed nationwide in the same way and with the same CCs. The case study project used for the mapping of the current situation fits to all the characteristics of the HWC. The similarities in construction activities, materials, CCs and their physical distribution streams result in the generalisability of the cost savings potential that resulted from the optimisation scenarios in this research to all the HWC projects.

The expected cost savings potential presented in Chapter 6 is based on linear cost savings conditions. In reality the cost savings potential should not be extrapolated linear to smaller or bigger projects due to economy of scale issues and the day to day costs of a logistic hub. This result, therefore, should be used as an indication of the cost savings potential per year, not as the absolute truth.

In the next section a summary of the limitation is presented.

7.1.1 Summary limitations

The logistic cost savings, being the leading results of the research, face no significant negative effect from errors in the retrieved data as elaborated upon in Limitation 7, unlike for Limitations 4 and 5. If, in practice, the logistic hub costs and the productivity increase numbers differ much from the figures used in this research, the result is a significant effect on the outcomes of the ABC analyses. However, we used average numbers and safety factors, and therefore the outcomes are a good approximation of the expected cost savings in practice. Limitations 1, 2 and 6 all state issues with data that is less reliable. But, as stated, no significant differences in the outcomes of the research are expected if the correct data was used. The results could even show higher cost savings results with the correct and more accurate data. Limitation 3 has no effect on the results. Overall, the limitations do not negatively affect the reliability of the results in, nor the validity of, the research. The results are generalizable to all HWC projects, all being similar to each other, as elaborated upon in Limitation 8.

In the next section, Optimisation Scenario 3 is elaborated upon the assumptions that were required in the ABC mapping, the benefits and the challenges.

7.1.2 Optimisation Scenario 3: Modularity and prefabrication in a factory

During the ABC analysis conducted on the mapping of Optimisation Scenario 3, modularity and prefabrication in a factory in Chapter 6, too many assumptions needed to be made, and therefore the calculation of the logistics costs and logistics cost savings potential present no reliable results. For a review of Optimisation Scenario 3, see Section 5.5.

The general results of the mapping of Optimisation Scenario 3 reveal similarities to Optimisation Scenarios 1 and 2, with the redirection of the first-tier physical distribution streams to the location of the factory. In the ABC model, the same cost reductions occur due to transport consolidations to the factory. The number of physical distribution streams that go through the factory is higher.

Assumptions are made on the following aspects:

1. The factory:
   - the initial costs of the factory;
   - the daily costs of the factory;
   - which construction activities can and cannot be carried out in the factory;
     - which materials could experience damages from the transports of the modules from the factory to the construction site due to e.g. vibrations;
   - the sizes and number of modules required per house,
     - number of transports from the factory to the construction site to transport the modules.
2. Equipment:
   - equipment required or not in the factory;
   - equipment required or not at the construction site to assemble the modules;
3. Employees:
   - the number of transports of employees required at the construction site in order to assemble the modules;
   - the different construction activities required in the new building process;
   - local sourcing abilities of the construction activities in the factory.
4. Construction site activities:
   - which activities need to be carried out at the construction site.

The benefits and challenges of Optimisation Scenario 3 are as follows:

Benefits

Many of the benefits of Optimisation Scenarios 1 and 2 are applicable to Optimisation Scenario 3. Additional benefits include the below.

1. Construction of the houses in the factory is indoor, making construction 24/7 possible:
   - better work and weather conditions;
   - different modules of one house can be fabricated at the same time.
2. The preferred suppliers that are different for the region's HH is active in could be reduced:
   - standardising the quality of the houses;
   - easy information sharing in the supply chain of the projects.
3. The investment could be shared with a partnering company to split investments cost and risk.

Challenges

1. To calculate the break-even point of the initial investments and daily costs of the factory:
   - the number of houses required to reach this break-even point.
2. To calculate from which point the cost savings of Optimisation Scenario 3 are higher than those of the logistic hub optimisation scenarios.
3. To make sure that the number of houses to be built in the future is consistent:

- market and product changes could make the factory redundant or could increase the costs;
- Figure 41 presents an example of the point at which the cost savings of Optimisation Scenario 3, modularity and prefabrication in a factory, are higher than the cost savings of Optimisation Scenarios 1 and 2, the logistic hubs. This is the point at which the orange line crosses the blue line.

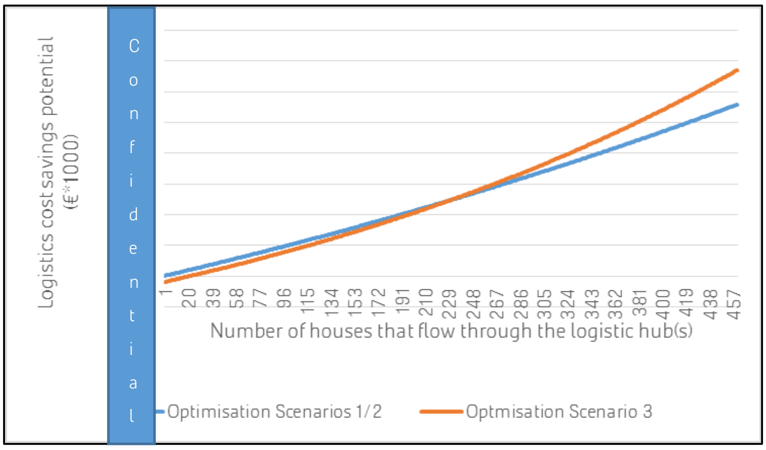

FIGURE 42: COST SAVINGS POTENTIAL OF THE OPTIMISATION SCENARIOS.

The elaboration of Optimisation Scenario 3, modularity and prefabrication in a factory, is used to propose the first future research area in Section 7.3.

So far, the limitations of the research have been set out, and Optimisation Scenario 3 has been further elaborated upon. In the next section, the applicability of the proposed ABC model to other construction projects is set out.

7.2 Applicability of the ABC model

The ABC model proposed is adjusted to the specific setting in this research and is based on Voordijk (2011), TNO research (2013) and practical experiences of this research [108]; [97]. As stated, in Limitation 8 in Section 2.1, the similarities in construction activities, materials, CCs and their physical distribution streams result in the applicability of the ABC model to other HWC projects. This wider applicability indicates that the results of the ABC analyses in this research are generalizable to and expected for all HWC projects.

Construction supply chains in the house-building industry are similar to each other, making the ABC model applicable to house-building projects other than HWC-related ones. Physical distribution streams, other than that occurred in this research, are easily inserted into the ABC model, but it takes much effort to do so. Moreover, adding of other characteristics than the 36 used in this research is possible, and other cost data could be incorporated into the calculations of the logistics costs. The ABC model is a good tool to map transport costs and, to a lesser degree, the handling costs of the physical distribution streams in a construction house-building supply chain. The applicability to other construction supply chains, such as non-residential or infrastructural projects, requires many changes in the ABC model, but is achievable. The cost data of the inventory and warehousing cost elements was not available in the data of the CCs approached in the research, but is still hidden in the overhead costs. The ABC model, the calculations formulas and the ABC approach are not sufficient to retrieve these hidden costs.

The same issues occur for the model proposed by Voordijk (2011). The data on the factors affecting the inventory and warehousing costs, like storage costs per m^2 or average days in stock, are hard to establish and calculate. In practice, the formulas proposed to calculate the inventory and warehousing costs in the model are not sufficient enough to retrieve these hidden costs elements from the overhead costs of the CCs' cost composition. The formulas proposed by Voordijk (2011) to calculate the transport and handling costs are sufficient, but too encompassing for the CCs. The CCs are not in the possession of data concerning equipment costs per hour or ordered quantity in m^3. Data accurate enough for improvement analysis is already achievable with the calculation formulas proposed in this research, but especially for the transport costs. The variables in the calculation formulas used in this research are more understandable for the CCs. The results of this research require changes in the ABC model used in this research and the model of Voordijk (2011) if the focus is on supply chain optimisation. In Section 7.3, this outcome is presented in the first future research possibilities.

7.3 Future research (scientific recommendations)

In this section, three future research areas are set out:

- Future research should investigate, for the characteristics presented in Table 24, which optimisation scenario, the logistic hub or modularity and prefabrication in a factory, has the highest potential to improve the cost efficiency of the first-tier physical distribution streams in the supply chain of the HWC and which is the ideal option to reduce the TCO of an HWC house.

Characteristic	Logistic hub	Modularity and prefabrication in a factory
1. Degree of standardisation	Low or average	High
2. Number of houses	Break-even point quickly established	Break-even point of the factory hard to establish
3. Certainty of future houses to be built	Short-term	Long-term
4. Relationship	Co-maker level	Strategic level
5. Initial investments	Low	High

TABLE 24: CHARACTERISTICS ON WHICH MANAGEMENT COULD BASE ITS CHOICE BETWEEN THE OPTIMISATION SCENARIOS.

  Optimisation Scenario 3, modularity and prefabrication in a factory, should be the starting point of future research in which the assumptions presented in this section are examined. The characteristics of Table 24 should be investigated, extended and compared to the results of this research.

- Neither the ABC model nor the model of Voordijk (2011) and the calculation formulas they presented were sufficient to retrieve the inventory and warehousing-costs elements data from the CCs. This insufficiency made improvement of these cost elements impossible. Future research could find out how the inventory and warehousing costs can be retrieved from the overhead costs of the CCs in an accessible way. This research could result in new calculation formulas with variables available in the data of the CCs.

- It requires effort to collect, insert and analyse the data in the ABC model. A decision-making model could be proposed in which characteristics of the implementation of a logistic hub are incorporated. Examples of such characteristics are as follows:
  - distance of construction site to a highway;
  - distance travelled within built-up areas;
  - type of construction project;
  - scope of the project.

  If the characteristics differ, the expected cost savings potential of a project change. For these characteristics, parameters could be established that indicate certain cost savings potential levels. If this decision-making model is established, it can be used by the HH team to decide whether or not the logistic hub is beneficial for a certain HWC project with less effort.
- The use of a building information model (BIM) could help to easily map the materials streams for all HWC projects [76, p. 21]. Future research could investigate the possibilities and benefits that BIM can offer in the optimisation of the supply chain of HWC projects.

While this chapter has set out the main study limitations and elaborated upon Optimisation Scenario 3, the next chapter sets out the conclusions and recommendations of this research. The plan of action is presented that has the highest costs savings potential, with the implementation steps of the logistic hub optimisation scenarios, as calculated in Chapter 6.

8 Conclusions and recommendations

In this chapter the conclusions and recommendations of this research are set out, and a plan of action is presented with the next steps that HH could follow to implement the optimisation scenarios.

The structure of Chapter 8 is as follows:

8.1 Conclusions;
8.2 Recommendations;
8.3 Plan of action

8.1 Conclusions

In 2016, the HWC team set the ambition to save up to 10% on the TCO of an HWC house. Over the years they were able to incrementally improve the construction process of the HWC projects and reduce the prices of a house, but many improvements have been implemented. To help to fulfil their ambition, the focus of this research is on improving the cost efficiency of the first-tier physical distribution streams in the supply chain of the HWC projects and to deliver an instant implementable business case. The highly fragmented nature of the supply chain and the many CCs that take care of their own physical distribution streams make it difficult to indicate inefficiencies and to improve the supply chain. The research consisted of three phases:

- Phase 1: Mapping the current situation
- Phase 2: Search for optimisation scenarios
- Phase 3: Mapping the optimisation scenarios and compare to Phase 1

The research question was, *how can the cost efficiency of the first-tier physical distribution streams in the supply chain of the HWC projects be improved during the execution phase of the construction process?*

A theoretical process model is presented in Chapter 2, in which are visualised the steps made in this research to get from the current situation of the supply chain to the improved situation. The cost elements of the first-tier physical distribution streams that were examined are as follows:

- transport;
- handling.

To make a comparison between the current situation and the optimisation scenarios, an ABC model has been presented in Chapter 3, in which the supply chains can be mapped. This ABC model is based on Voordijk (2011), TNO research (2013) and practical experiences.

In Phase 1, corresponding to Chapter 4, 29 interviews were conducted to retrieve the required data in order to map the current situation of a case study project. In Phase 2, corresponding to Chapter 5, a literature review and business case meetings with LPCs were conducted to find optimisation scenarios that improve cost efficiency in the supply chain of the case-study project. Three selected LPCs were invited to make an offer on specifications that fit to the proposed optimisation scenarios. In Phase 3, corresponding to Chapter 6, optimisation scenarios are mapped with the figures of the LPCs. On both mappings of the case study project and optimisation scenarios, ABC analyses were conducted in order to compare them.

Chapter 4's ABC analysis on the mapping of the case study project found that 6.64% of the total building sum is spent on logistics costs, with a total of €210,000. Five different physical distribution stream categories are identified:

1. direct heavy distribution;
2. direct light distribution;
3. employees;
4. employees with small materials and standard tools;
5. equipment.

This logistics costs consist of 86% for transport, 11% for on-site logistics and 3% for handling costs. The potential for the improvement of cost efficiency for first-tier physical distribution streams is the highest for the transport and on-site logistics elements in the supply chain of the case study project.

From the literature review and business case meetings in Chapter 5 resulted ten different optimisation possibilities from which three optimisation scenarios are proposed:

- *Optimisation Scenario 1: Logistic hub, Type 1*;
- *Optimisation Scenario 2: Logistic hub, Type 2*;
- *Optimisation Scenario 3: Modularity and prefabrication in a factory*.

Physical distribution stream categories 1, 2 and 4 were selected, based on their fit, to go through the optimisation scenarios and were used in the mapping of the optimisation scenarios in the ABC model.

The results of all Chapter 6's ABC analyses, conducted with the figures of the LPCs and on the selected optimisation scenarios, present the potential to improve the cost efficiency of the first-tier physical distribution streams in the supply chain of the HWC projects. The best optimisation scenario shows *a cost savings potential of €23,000, a logistic costs savings potential of around 10% and a profit increase* for the total project in comparison to the analysis conducted on the case study project. These results were attained in an analysis in which all cost parameters were overestimated and all cost saving parameters were underestimated. In practice, the scope of the cost savings could even be higher. The logistic hub proves to lower the logistic costs of the optimisation scenarios, but the costs of the logistic hub need to be compensated for by increased productivity. The increased productivity results from the carry-on approach that reduces the costs of the on-site logistics activities: waiting, finding and transporting of goods. In the optimisation scenarios the transports of the waste streams are carried out by the LPC taking out the corresponding transport costs. With an expected 600 houses to be built in 2016, *the extrapolated cost savings potential per year is around €300,000*.

The results of the ABC analysis on the mapping of the case study project show almost no synchronisation between the CCs nor the co-makers. The optimisation scenarios can help HH to benefit from the fourth aspect of the co-maker relationship; improves the logistic coordination. The expectation of Optimisation Scenario 3 are promising, however, still need to be further investigated.

The answer to the research question is that by implementing a logistic hub, it is possible to improve the cost efficiency of the first-tier physical distribution streams in the supply chain of the case study project during the execution of the construction phase. The cost savings potential of Optimisation Scenarios 1 and 2 are not sufficient to help to fulfil the team's ambition to save up to 10% on the TCO of a HWC house, but could be implemented as part of the solution.

Next to the above financial considerations, the implementation of the optimisation scenarios results in the following:

- coordinated first-tier physical distribution streams;
- increased productivity;
- higher delivery accuracy.

The next section presents the recommendations of the research.

8.2 Recommendations

In this section, the recommendations of the research are elaborated upon. The main recommendations of this research are the following:

- Implement Optimisation Scenario 1, Logistic hub, Type 1, and investigate which of the physical distribution streams of Optimisation Scenario 2 can be carried out against a lower price by the LPCs.
- LPC 4 is the ideal LPC to carry out the logistic hub due to:
    - the highest cost-savings potential in Optimisation Scenario 1;
    - construction logistics being its core business;
    - the openness for subcontracting and risk-sharing LPC 4, meaning that is seen as the ideal option to carry out optimisation scenario logistic hub Type 1.

  LPC 4 is not open to incorporate the direct heavy transports to the construction site as well as the transports from the CCs to the logistic hub. The responsibility of these transports which can be carried out against a lower price than in the current situation, could be carried out by a different CC or LPC to benefit from the cost savings potential of Optimisation Scenario 2.

Other practical recommendations:

- Heijmans should continue to improve the cost efficiency of the other physical distribution streams categories that do not go through the logistic hub. The optimisation possibilities and how they can improve the cost efficiency per physical distribution category are presented in Section 5.4 in Table 12.
- Implement the ability to switch between logistic hub locations of the LPC that are closest to the construction site.
- Estimate the actual logistic hub costs and the increased productivity in a pilot project to see whether or not the results of the research are reachable in practice.
- Increase the percentage of modularity and prefabrication in the HWC projects where possible:
    - leading to the benefits as described in Section 7.1.
- The contract form subcontracting offers the ability to incorporate efficiency gains. The LPC is forced to reach efficiency gains over, for example, six months, or the following years.
- Discuss the expected increased productivity cost savings with the CCs that needs to be freed up from the building sums of the CCs. All CCs with physical distribution streams that fit to flow through the optimisation scenarios are presented in Figure 34.
- Investigate in which other sectors a logistic hub is beneficial and whether or not the different logistic hubs could be merged together. For example, in the non-residential building projects,

the scope of the finishing phase is larger and has higher potential with the benefits of a logistic hub.

- Investigate how control-tower optimisation could be implemented at the HWC [88, p. 8489].
- The IT systems of the CCs in the supply chain should be standardised such that information can flow easily from CC to CC. In Appendix 9.2.1, more information on the role of IT in supply chains is presented.

In the next section, the plan of action that follows from this research is presented.

8.3 Plan of action

In this section the plan of action, presented in Figure 43, is laid out for Heijmans, Heijmans Housing and the HWC team to follow after this research if the decision is made to continue with the implementation of the logistic hub optimisation scenarios. The first five steps focus on the implementation of the logistic hub optimisation scenarios. Step 6 should be researched further and could be the topic of future research.

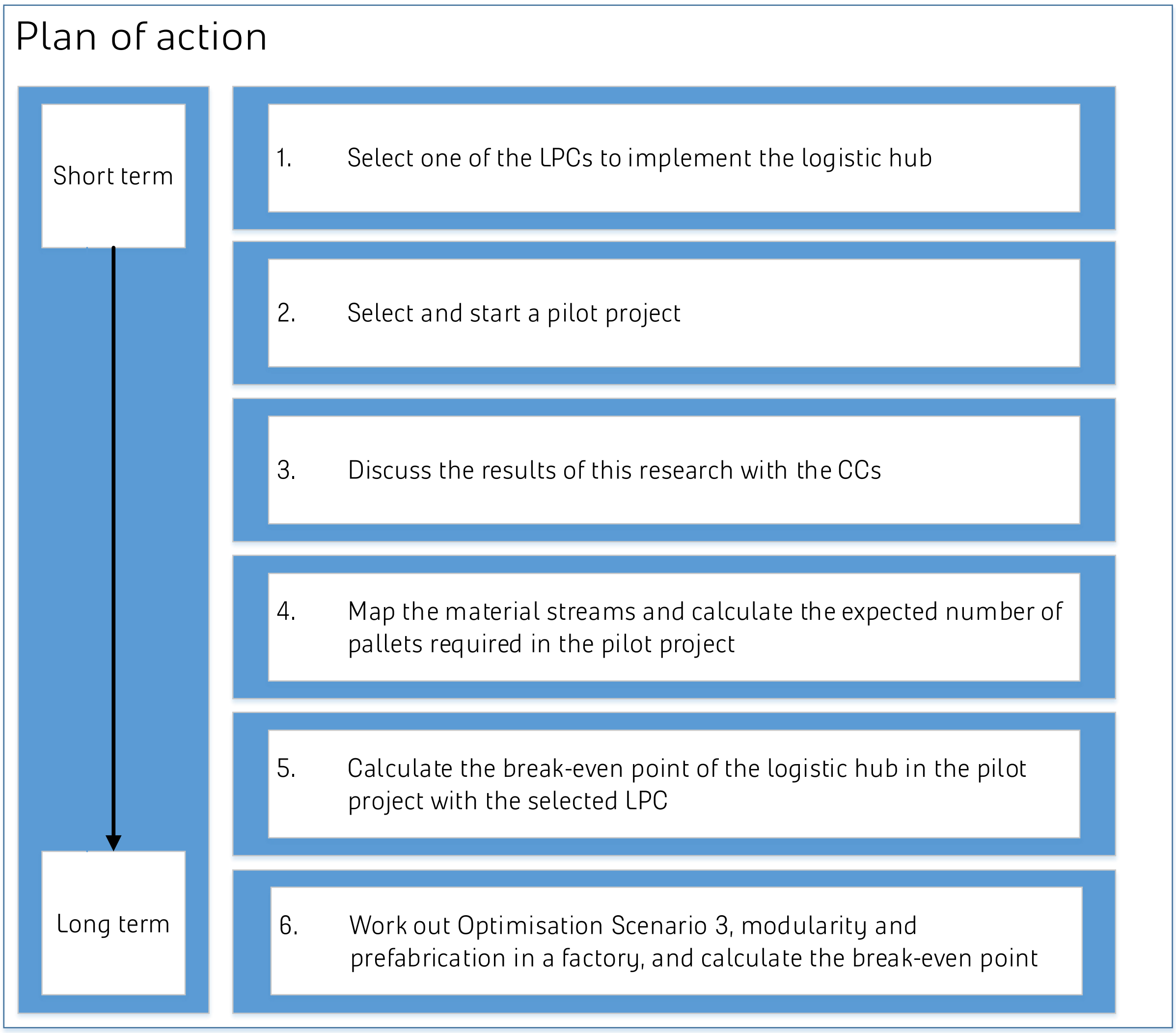

FIGURE 43: THE PLAN OF ACTION AFTER THE RESEARCH.

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9 Appendices

In this chapter the appendices of the research are set out.

9.1 Request for cooperation

Subject: Request for cooperation in logistic research 9-11-2015

Dear sir/madam,

Through this letter I want to introduce myself to you. My name is Richard Bloemheuvel and I am studying Business Administration at the University of Twente where I am following a logistical track in my Master. As completion of my study I am performing a research at Heijmans within the Heijmans Woon Concept. This research is under guidance of Pim Ketelaars. Your involvement at the Heijmans Woon Concept is the reason that you are receiving this letter.

The goal of the research is to map the logistic physical distribution streams within the total supply chain of a project of the Heijmans Woon Concept and discover the cost structure behind these logistic streams. Examples of question that I want to ask you are: 'How many transport movements do you need to execute your services and with what type of transport vehicle do you perform the transports'? and 'What are the costs to make the transport vehicle transport ready?' The research focusses on the 29 houses of the project Leeswand phase 2 and 3 in Waalwijk.

I need your help in order to receive all the information that is necessary for the research. Therefor I want to ask you to collaborate with my research and before the end of the week I will contact you per telephone in order to make an appointment. During this phone call I will provide a more extensive explanation on the research and the information that I need.

The information discussed is treated confidential and the outcomes of the research will be shared when finished. I hope that you are willing to collaborate and I am looking forward to our first meeting.

I work from the Heijmans office in Rosmalen and I am accessible by e-mail **rbloemheuvel@heijmans.nl** and by telephone on **06-53**[redacted]. If there are any question these are the ways to reach me.

With kind regards,

Richard Bloemheuvel

Intern at Heijmans Rosmalen

9.2 Background information

The purpose of this appendix is to give an extended elaboration on the history of logistics, supply chain management and the role of IT in Section 9.2.1. In Section 9.2.2 and Section 9.2.3, the make or buy decision and the ABC approach are set out.

9.2.1 History of logistics, supply chain management and the role of IT

The purpose of this section is to elaborate on the history of logistics and supply chain management and the role of Information Technology (IT) in order to understand:

- what the status of literature is on these topics in April 2016;
- which practices and IT possibilities are available for the optimisation of supply chains in general.

The importance of logistics and supply chain management started to grow in the 1970's when the advanced economies and companies were occupied with increasing the efficiency of the different logistics components and physical distribution by ensuring the availability of the necessary raw materials, the handling of the merchandise and its storing, packaging and transport [78, p. 159]; [64, p. 143]. In the 1980's the emphasis was on configuring and optimising the logistics flow and on the integration and coordination of activities related to procurement, production and distribution. It changed the role of IT into a substantial driver behind competition in many supply chains and industry networks. The performance effects were mainly dyadic, meaning between two companies, and not on the whole supply chain [93, p. 84]. Companies started to establish logistics departments or began to work with companies specializing in the logistics field, and subcontracting some or all logistics activities to the latter. In the 1990's, along with the breakthroughs in IT, which allowed control over the flows of information in the supply chain, a more holistic approach was chosen with the focus on the integration between companies and information flows with the aim to optimise the entire supply chain [78, p. 160]. At the beginning of the 2000's, the developments were concentrated on the flows of goods and the planning and controlling of information. Not only within departments of a company, but also at the supplier-client level. This integration became possible by implementing supply chain management IT systems such as Enterprise Resource Programs (ERP), connecting systems through Electronic Data Interchange (EDI) links and Advanced Planning Systems (APS) [12, p. 64]; [78, p. 161]. Investment in EDI systems requires close coordination to achieve a certain degree of electronic integration. Intercompany coordination, where proprietary information is being shared on a one-to-one basis could only be sustained by high transaction specific investments necessary to implement EDI systems. Apart from the costs it is hard for smaller companies to implement EDI in their supply chain [24, p. 97]. EDI gave organizations the ability to exchange information on a more timely and frequent basis [24, p. 97].

The developments led to infrastructures that are in place to facilitate external systems integration (ESI) beyond internal system integration (ISI). Companies can begin building upon the capabilities of these infrastructures and focus on benefits beyond dyadic coordination and collaboration processes.

These developments gave new opportunities for logistic changes and optimisations in the construction industry and its whole supply chain [12, p. 64]. Benefits of these IT systems are [90, p. 383]:

- reduced inventory costs;
- decreased errors;
- enhanced visibility;
- increased return on investment;
- improved operational efficiency;
- increased accuracy.

The IT systems make supply chain optimisations easier and cheaper. Instead of employees, computer systems calculate the optimisations, making the process faster, more intelligent and cheaper [, p. 1003]. The construction industry has traditionally been behind in its use of ICT compared with many other industries. In the recent years however significant ICT developments took place in the construction industry [29]; [30, p. 898].

The Building Information Model (BIM) is one of those developments. BIM is a digital representation of physical and functional characteristics of, for example, a house. BIM is a shared knowledge platform for information forming a reliable basis for decisions during the life cycle of the house. A basic premise of BIM is collaboration by different stakeholder at different phases of the lifecycle of a house to insert, extract, update or modify information in the BIM to support and reflect the roles of the stakeholders [76, p. 21]. All data sources can be linked to the representation such as construction schedules and the costs of the house [2, p. 27]. A BIM opens up the possibility to use libraries in which also learning experiences from other projects have been processed and contributes to integration in the construction sector. With BIM the planning can be simulated and visualised for the entire supply chain and the right data can be transferred easily to the different CCs [2, p. 30]. In the BIM models the actual status of the on-site situation can be monitored and the supply chain can be steered with Just-In-Time deliveries [2, p. 41].

9.2.2 Make or buy decision

Heijmans is not a company providing logistics services as its core business. This results in higher costs to perform logistic activities in comparison to LPCs.

There are two logistic outsourcing possibilities:

1. 3rd Party Logistics (3PL) is the supply chain practice where one or more logistic functions are outsourced to a 3PL provider. Services that a 3PL player can conduct are repackaging, assembling or prefabrication and return logistics by using its own assets and resources. The idea is that the company who outsources can stay competitive by keeping the processes lean without owning many assets, allowing it to focus on niche areas and to reduce operational costs [23, p. 311]. Companies engaging 3PL practises are likely companies that do not focus on logistics as one of its core competencies and are at least mid-sized such that the logistics cost is substantial enough to justify engagement of the outsourcing services. Heijmans fits to these characteristics and is able to benefit from 3PL service providers [23, p. 314].
2. 4th Party Logistics (4PL) is the supply chain practice where a company that assembles and manages resources, capabilities and technologies of their own company, at the same time complements it with services of multiple logistic operators such as transport companies and storage agents. They develop the highest accurate logistic configuration of the commercial

model of the company [23, p. 317]. This 4PL provider is the manager of the supply chain where in 3PL, the control is not totally at the logistic provider.

Benefits of logistic outsourcing are:

- focusing on developing core competences;
- cost competitiveness;
- freeing up resources such as money;
- benefits from the logistics know-how of specialized 3PL logistic providers;
- improving customer service through shorter shipment times;
- reducing inventory costs through better management abilities;
- giving cost benefits through volume shipping discounts;
- giving risk reduction possibilities;
- giving increased expertise in supply chain security.

Challenges that a company needs to overcome are:

- the loss of control over the logistic functions;
- more distance from clients;
- differences of opinion or perception of the service level.

A 4PL provides a supply chain with services that searches the ideal logistical solutions for its client, typically without using own assets and resources [23, p. 317]. In the next part, in-house logistics is shortly described.

Companies can perform logistics in-house on several ways. A company with an in-house logistic division means that a company possesses its own material handling and distribution facilities, warehousing or delivering goods without outside assistance [54, p. 37]. Two strategies that a company can use are [54, p. 38]:

1. maximizing the net-value of its organisation as a whole;
2. maximizing its own profit.

The first strategy unavoidably brings loss to the in-house logistics division. The second strategy is identical to that of the 3PL and the 4PL because both of them pursue the maximization of their own profits. If performed in-house the second strategy charges its users more but produces less.

9.2.3 Activity-Based Costing approach

The traditional accounting methods are based on assumptions of stable and predictable markets, long product life-cycles, large production runs and large portions of direct, variable costs in the total product costs [36, p. 102]. These methods assumes that products drive the cost directly and continue to allocate the overhead costs in construction on a volume driven basis such as labour hours or machine hour which no longer reflect the true consumption of resources [67, p. 704]. Therefore, these methods are not suitable for logistics on many construction projects.

The ABC method is an accounting method that works accurate in situation in which these assumptions are not true. The underlying assumption of the ABC method is that activities drive the costs, but the activities are driven by the product as visualised in Figure 44. With ABC the overhead is directly traceable, and variable costs of the individual activity or process become visible [36, p.

102]. This makes the ABC approach a better method to calculate the logistics costs in the construction industry. It is a more advantageous decision making tool providing better information to understand the logistics activities and underlying costs [67, p. 704]. The method is used to generate accurate cost information that relates to a variety of decisions and allows a company to determine the actual cost associated with each product and service [89, p. 566].

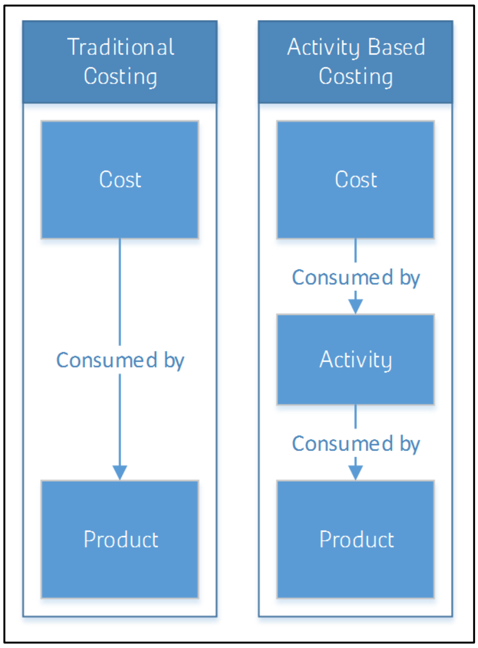

FIGURE 44: DIFFERENCE BETWEEN TRADITIONAL COSTING (L) AND ACTIVITY BASED COSTING (R).

ABC uses financial data and isolates direct costs and overhead costs to specific products, customers, and services attributing activity costs only if the activities are performed on the products and services. ABC opens the black box of costing that are the process costs. Activities are performed orderly at the feasible cost and profit following the time. The activities and links between them disclose the process that costs generate. ABC supports other newly strategic approaches such as total quality management, just-in-time and lean production (LP). A clear relationship can be established between sources of activity demand and the related costs [89, p. 566].

ABC assists management in identifying unused resources and capacity in order to achieve the major goals of business process improvement and simplification. Business managers need to fully understand the cost, time and quality of activities performed by employees or machines throughout the organization. Optimal construction site management requires the identification of all the companies active on a site during the construction process [87, p. 75].

In the next part trade-offs that results of the ABC approach are elaborated upon.

In order to minimise the cost of construction materials, managers and planners should not only strive to reduce the wastage and rework. They shall have to cut down on the cost pertinent to the physical distribution of goods especially goods that are transported in bulk [35, p. 2]. Any action towards the renationalisation of the size, structure and organisation of material consumption, along with proper planning of delivery and storage can increase project efficiency and prompt to a reduction in construction costs [36, p. 259]. 25% of time saving can be achieved in a typical construction work package without any increase in the allocated resources [116, p. 253].

Many factors can drive up the physical distribution costs elements, and it is necessary to identify which are the highest cost-sensitive within a supply chain such that appropriate actions can be taken to control if not to reduce the cost [36, p. 260]. One way to analyse the logistics distribution cost is by adopting the ABC approach [105, p. 72]. The supply chain costs found in the trade-off category between elements of the construction supply chain are the measurements for this optimisation research as recommended by literature [18, p. 469]; [41, p. 457]; [13, p. 394].

Optimising the supply chain involves measuring all the relevant costs and optimizing those in such a way that the total costs decrease [74, p. 93]. Warehouses such as logistic centres should be operated such that all the services are performed in sufficient levels of quality with minimal costs and in shortest term to satisfy customers [23, p. 313].

Supply chain optimisations have their effects on non-physical and physical distribution costs elements. Non-physical logistics cost elements, such as risk costs or administration costs, can also be reduced through supply chain optimisations practises such as standardisations of EDI, APS and TMS systems.

9.3 Background information on supply chain optimisations possibilities from the literature research

In this appendix the supply chain optimisation possibilities that resulted from the literature review in Section 5.1 and the conducted business case meetings in Section 5.2 are further elaborated upon.

9.3.1 Logistic hub

The purpose of this section is to elaborate on the logistic hub and consolidation center methods. A logistic hub, which is a logistic distribution centre, is a defined area within which all activities relating to transport, logistics and the physical distribution of goods, are carried out [5, p. 4]; [91, p. 1]. In a beneficial situation the prices of a logistic hub should be relatively low. A logistic hub is an independent business entity which [91, p. 1]:

- has its own territory, connected with road and telecommunication networks;
- has its own infrastructure, such as internal roads, car parks and buildings;
- has its own technological equipment necessary for freight-reloading, warehousing and transport and IT devices;
- has its own qualified personnel;
- carried out to a company which fits to logistic tasks.

A logistic hub offers logistic services such as freight reloading, warehousing, separation, assemblage, packaging, labelling and transport in one concentrated place [91, p. 1]. A different type of logistic hub is the consolidation centre which is a distribution facility for materials that receives goods and delivers them to the sites in consolidated loads [91, p. 1]. The focus in the latter is on consolidation of truckloads which is also an activities of a logistic hub. Both are business-to-business marketplaces and claim that major efficiencies can be achieved by both buyers and sellers through the streamlining of communications, the support of collaboration and buying. The improvements in the supply chain are the main source of value and cost savings created by logistic hubs.

A logistic hub is a useful way to manage inventories, design products and manage projects more effectively and leads to business network-level optimisation (NLO) [65, p. 96]. This is defined as *performance benefits resulting from the calculation of efficiencies across companies within and* *between supply chains.* This key capability of a logistic hub is a result from the ability to have real-time, inter-company information available, which can be used to monitor, exchange and act upon in an integrated manner; called cross-chain monitoring [65, p. 96]. The coordination of business processes in the logistic hub is highly dependent on the ability of CCs to coordinate flows of goods and information. Sharing of information is a principal component in supply chain integration [115, p. 83]. Information should flow independently of physical goods in a supply chain having a significant impact on the coordination of transactions and relationships. Exchange of information in a timely, effective way is a key driver of supply chain performance [37, p. 212]. In many markets information is shared with a limited number of CCs. It is difficult to demonstrate and allocate collective benefits to participating CCs. Connectivity through the whole supply chain can considerably reduce costs associated with information asymmetry, such as inventory-level reduction and collaborative planning and forecasting. If business networks are to possess benefits from NLO it is due to connectedness in their network [6, p. 1]. Conditions are often such that the real benefits can only be achieved by creating an exchange environment where CCs not only look at their own outcomes but mainly to the joined outcomes. The relational environment surrounding the exchange is a major determinant of the outcomes of collaborative agreements [24, p. 97].

An application of a logistic hub can collaboratively be outsourced when enough members are connected and open to [24, p. 99]. Cash netting illustrates potential with cross-company payments within the network. The costs of managing and executing these cross-company payments are huge. If the main source of errors, the data, is improved the settlement of accounts becomes easier. This takes out a non-value added activity of both the buyers and the sellers [24, p. 99].

Scaling up is what adds value to the magnitude of the network optimisation solution across a supply chain, however it is hard to achieve scalability in a logistic hub, making it a large inhibitor. The ability of the network to quickly deploy process integration solutions while keeping the costs down is a next challenge. The cost of adding an additional partner or product line might be higher than the expected returns. A lack of intercompany process standards asks for a collaborative integration effort requiring the alignment at the business process level between CCs [79, p. 68]. Lastly there are institutional factors including intercompany power, trust, relational embeddedness that determine the success of the logistic hub. These are the crucial inhibitors for a logistic hub [24, p. 100].

The corporate log files kept at the logistic hub allow optimisation of transports, forecasting and other logistic services across the participating companies and business partners. The real power of a logistic hub is the coordination of the physical distribution of goods and transports by tracking and tracing. Interoperative data exchange should by translated into messages recognizable by the other CCs' systems. CCs must have trusting long-term relationships with each other and with the logistic hub itself to allow members to penetrate deeply into each other's internal business processes [24].

The objective in many cases is to determine the number of logistic hubs to be opened and the routes used in the network. The profitability of a logistic hub lays in its opening costs and travel time savings. The latter due to both consolidation as well as trip time savings. The problem can be seen as a variant of the network design and facility location problems, which seeks to determine flows on a network while taking into account the fixed costs of opening facilities, necessary for routing the flows [81, p. 453]. The success of a logistic hub depends on four major factors that are location, efficiency, financial sustainability and level of services. Examples of a level of services are price, punctuality, reliability or transit time [11, p. 71].

9.3.2 Cross-docking

Cross docking is a method used by many companies in different industries. Cross-docking is receiving products from suppliers or manufacturers for several end destinations and consolidating these products with other suppliers' products for common final delivery destinations [56, p. 49]. The basic idea is to transfer incoming shipments directly to outgoing vehicles without storing them in between. This serves different goals such as consolidation of shipments, a shorter delivery lead time and reduction of costs [17, p. 414].

Cross docking is a method that eliminates two expansive handling costs; storage and order picking [38, p. 228]; [66, p. 1343]. The focus is on consolidation of shipments to achieve economies of scale in transport costs [104, p. 828]. Cross-docking requires a correct synchronisation of incoming (inbound) and outgoing (outbound) vehicles. An ideal synchronisation is difficult to achieve. In practice staging is required due to many inbound shipments that need to be sorted, consolidated and stored until the outbound shipment is complete and able to leave [104, p. 828]. Cross-docking can improve the order lead time [90, p. 162]. If materials or products are temporally stored this, should be only for a short period of time. The literature speaks of about 24 hours [103, p. 12]. Other authors speak off a longer storage time as long as the goods move from supplier to storage to customer virtually untouched except for truck loading [113]. Cross-docking strategies are effective only for large distribution systems in which a large number of vehicles are delivering and picking up goods at the cross-dock facilities at any time [90, p. 233].

The biggest benefits compared to traditional distribution centers are:

- cost reduction;
- shorter delivery lead time;
- improved customer service;
- reduction of storage space;
- faster inventory turnover;
- fewer overstock;
- reduction of risk for loss and damages.

Cross-docking is effective with a stable and constant product demand rate and low unit stock-out cost [104, p. 828]. Due to the stable product demand the transports are predictable, and consequently the planning and implementation of cross-docking becomes easier [7, p. 297]. The unit stock-out cost is important for cross-docking due to the minimizing effect on the level of inventory at the warehouse making the probability of stock-out situations higher.

Other factors that influence the suitability of cross-docking are the distance of suppliers and customers, the product value and life cycle, the demand quantity and the timeliness of supplier shipments [82, p. 51].

If a company chooses to use a cross-docking approach the following problems need to be taken into account [104, p. 843]:

- the location of the cross-dock;
- the layout design;
- the cross-docking network;
- the vehicle routing;
- the dock door assignment;
- the truck scheduling;
- the temporary storage.

9.3.3 Control tower

A control tower is implemented to sustain competitive by improving the operation of the entire supply chain efficiency and benefits. It is a way to control the supply chain quality and functioning.

One company has the control and looks at the total demand of transports in order to optimise the physical distribution of goods to perform the demand of transports for a given time period.

The control tower has five layers that are [88, p. 8489]:

First layer	The supply chain business layer. The members of this layer are raw material suppliers, manufacturers, outsourcing logistic service providers, distributors, dealers and users. They perform activities such as procurement, transport, warehousing, loading and unloading, handling and distribution processing and packaging.
Second layer	The information perception layer. In this layer technologies such as the Internet of Things are used to achieve real-time sensing and LPC 6 of supply chain data.
Third layer	The information operation control layer. In this layer the data of the supply chain is stored and controlled. The information comes from all the members of the first layer. In this layer the real-time logistics information is stored.
Fourth layer	The information service platform layer. This is an integrated quality information service platform containing all links and subjects of the supply chain. It can store and update the information from the previous layers to implement the transparency and visualization of information to real-time monitor all the data of the supply chain.
Fifth layer	The information manpower layer. In this layer the decision-making center is constituted. It is responsible for the centralized monitoring in all links of the supply chain. It is an integrated information logistic hub that is able to provide the whole supply chain with visibility of what is transported, where and when. It gathers and distributes information and allows employees that are trained to use the visibility to detect and act on risks or opportunities in the supply chain more quickly. This layer is active on three levels that are.

Benefits:

- Strategic — It provides control over the design of the whole supply chain.
- Tactical — It enables proactive planning of procurement, operations and distribution according to market demand.
- Operational — It encompasses various real time functionality including transport management and inventory tracking.

The company in the control tower has the overview of the first layer and uses the second and the third layer to collect and interpreted the data from the supply chain. It combines, controls, and updates the data in the fourth layer such that, in the fifth layer, the decisions can be made in order to optimise the total supply chain at any moment in time.

9.3.4 Modularity and prefabrication in a factory

A house has a product architecture that is divided into elements linked together. The elements are assembled and together form, for example, a house. There are two approaches [101, p. 422]; [70]:

- *Integral*: a complex mapping between elements and physical components and/or coupled interfaces between components. Changes in one element requires a change to the other elements in order for the final house to function correctly. An example is a chair that is fabricated out of one piece of wood.
- *Modular*: a one-to-one mapping from elements in the architecture to the physical components of the house, and it specifies interfaces between the components. It is composed

of modules that are designed independently but function as an integrated whole [9, p. 84]. A change in one element does not require other elements to change if the change complies with the standards or design rules. An example is a chair that is composed of multiple modules that together form a whole. If the arm-rest is redesigned following the design rules the frame of the chair does not have to change. Design rules enable a designer to modify one part of the architecture without the need to communicate this with designers of other parts [50, p. 34].

Elements together can form a module. An example is the module 'rooftops', from the case study project, that is composed of the elements wood, insulation material and dormer windows. In a modular architecture the modules are fabricated by the module suppliers known as prefabrication. Modularization allows the overall house to be differentiated to a high degree and meet the varied customer requirements while development and production costs are minimized by the reuse of the modules at a multi-project level [50, p. 32].

The key for adopting platform approaches is the process of identifying and exploiting commonalities among a company's products, target markets and processes used to create and deliver products. Requirements for a platform are [43, p. 784]:

- a certain degree of modularity to allow for the decoupling of elements;
- the standardisation of a part of the product architecture.

The platform-based approach offers new opportunities for the housing industry to find a balance between the demand for individualised housings solutions and the economies of scale that result from mass production [75, p. 594]. Costs and cycle times can be reduced even further by extending the processes to include suppliers and benefiting from the power associated with bulk material procurement [26, p. 33]. The design customisation options include interior and exterior design components, as well as the spatial arrangement that determine the total area of a home. Suppliers are exposed to the classic trade-off between maintaining efficient processes and offering a high degree of customer choice which is a goal of the HWC [43, p. 785].

A process platform refers to the specific setup of the production system such that it easily produces the desired variety of products. A well-developed production system includes flexible supply chains and carefully designed inventory systems [55, p. 47]. If both are implemented successfully it can lead to the following benefits [42, p. 152]:

- reduction of process complexity;
- increasing flexibility in product design;
- increasing efficiency of product development and manufacturing;
- optimised effectiveness of market positioning.

The supply chain can also have a degree of modularity defined by whether certain functions or tasks are carried out by a single organization or not [114, p. 164]. A house can be prefabricated in one or many factories from which the modules are transported to and assembled on the construction site [27, p. 501].

9.3.5 Reverse logistics

Traditionally, managers considered the direction of flow of materials from the point of extraction up to its consumption [53, p. 500]. Reverse logistics is relatively settled in the manufacturing industry, however, not yet in the construction industry [86, p. 2]. Reverse logistics offers an opportunity to the construction industry to further improve its public image. It can be used as a marketing strategy and could be linked with economic advantages [53, p. 506]. Reverse logistics is the process of planning, implementing and controlling the backward flows of raw materials, in-process inventory, packaging, and finished goods, from a manufacturing, distribution or use point, to a point of recovery or point of proper disposal [84, p. 2]. Reverse logistics concentrates on the movement of materials from the point of consumption back to the market [84, p. 129].

Despite the interest in re-use, recycling and general environmental concerns, the construction industry suffers from not having a well-organised reverse logistics network that is connected to the forward logistics [11, p. 384]. Companies implement reverse logistics in response to customer demand and to boost environmental image [8, p. 306]. Evidence has acknowledged that reverse logistics frameworks developed for the manufacturing industry would be just as beneficial for other industries such as the construction industry [22, p. 123].

Activities in reverse logistics are [85, p. 179]:

- *reuse* meaning giving the building components or materials to a new use after extraction from the obsolete building with no or trivial processing;
- *recycling* meaning reprocessing a component in the same quality;
- *down-cycling* meaning processing building materials to produce lower grade material.

Products and materials that are seen as waste of one supply chain can be a source of supply to another supply chain. Materials, goods and products might move towards secondary consumption points, which could be secondary markets outside the boundaries of the construction industry [53, p. 501]. There are three categories of benefits of reverse logistics in the construction industry that are environmental, economic and social. Paying attention to these practices can benefit constructors by means of scoring higher on MEAT criteria in tenders.

The principles of reverse logistics could be incorporated into the HWC by which it could lower the transports required for the waste disposal activities. New building materials that are lighter than the current ones could lower the logistics costs significantly.

9.3.6 Waste management

Waste is one of the few physical distribution streams that flow back from the construction site and add no value to the overall construction process. The activities considering the waste disposal should be performed at the lowest costs and as efficient as possible. On many construction sites one company takes care of the waste disposal. A different approach is that the LPC takes care of the waste disposal on its round trips. In this situation no extra transports are required for this activity [80, p. 5].

9.3.7 Transport consolidation

In this approach truckloads are consolidated such that the total number of transports, kilometres and driving time is reduced to a minimum. This method is based on economies of scale offering higher benefits if the scope is enlarged [90, p. 31]. Trailer swopping is another way of transport consolidation.

9.3.8 Optimal routing

In this approach in many cases algorithms in software packages with or without the influence of employees optimise the routs that vehicles travel in a supply chain such that the total number of transports, kilometres and driving time is reduced to a minimum. There are various different algorithms that can be used that are out of scope of (International) Business Administration [90, p. 90].

9.3.9 Carry-on approach

With the carry-on approach the central placement of materials is extended from delivery at the gate to a more decentral placement on the construction site [80]. The materials are dropped at a point closer to the actual usage of the materials resulting in efficiency gains. Without the carry-on approach the specialist spends many working time to on-site logistics activities such as waiting, finding and transporting goods. It is recognised that improvements in the supply logistics offer improvement possibilities for the on-site logistics. For example, a bricklayer traditionally has to pick up the bricks on a central point where they are dropped and has to transport them to the wall that is constructed. In this situation the bricklayer is not only laying bricks, which is his core competence, but is also transporting the bricks to the wall. In an optimised situation the transport of the bricks from the central drop-off point could be changed such that the bricks lay closer to the walls that are constructed. A 'carry-on' person with a lower wage level could carry-on the bricks from the central points on to the scaffold such that the bricklayer can focus on his core competence; laying bricks. Now the on-site logistics or internal transport is done by the 'carry-on' person. The bricklayer is able to increase his output. Moreover, not only the productivity is increased, also the transport costs of the bricks on the construction site are reduced because a person with a lower wage is performing the activity.

9.3.10 Carpooling

The employees that work at the construction site need to be transported together. By carpooling initiatives the total number of transports could decrease Carpooling is an emerging transportation mode that is eco-friendly and sustainable as it enables employees not only to reduce the costs of transportation, such as fuel and parking costs, but also to reduce emissions and traffic congestions. Carpooling is the sharing of a car between people from a certain origin to a specific destination [39, p. 83].

9.3.11 Local sourcing

Work is outsourced to CCs that are located close to the construction site such that the costs of the transport are reduced [100, p. 1012].

9.3.12 Incoterms

Incoterms regulate and uniform the supply chain and the physical distribution of goods. In 1936 the International Trade Chamber in Paris published a set of rules concerning the delivery of goods, named Incoterms 1936. These terms were applicable internationally and were revised various times.

The last revision was from 2010 [77, p. 86]. The Incoterms are a tool for all companies that are involved in (international) commercial transactions.

Incoterm define the extent to which each of the CCs is liable concerning logistics. The proper use of the codified conditions of the Incoterms is important for the physical distribution of goods, as well as the security of the involved employees, of both the sending and receiving company [77, p. 86].

Incoterms have various characteristics that are [77, p. 86]:

- the delivery conditions offer a precise definition of the obligations of the seller concerning the delivery of goods;
- they establish which CC involved bears the risks at each part of the transport of goods;
- the division of the expenses between the companies during the transport period;
- the documents, or the equivalent electronic messages, owed by the seller to the buyer.

Even though Incoterms do not regulate the transfer of the property right, they do offer a clear solution for the problem of the transfer of the risks concerning the delivery of the goods at (inter)national level from the seller to the buyer. Despite its optional character, CCs have the freedom to apply the embedded rules and, as such, the Incoterms are used on a large scale in (international) trade [77, p. 86].

In the HWC supply chain Incoterms play a role. If optimised the various CCs and their responsibilities change. Incoterms are part of the answer for a prime organisation, management and control of the supply chain.

9.4 The cooperating companies at the case study project

In the case study project supply chain there are various CCs participating. These CCs are divided into different types of collaboration following definitions used by Heijmans as visualised in Figure 10 [71, p. 14]. The network of CCs in the case study project is complex. If there is a reference made in this research to these types of collaboration this explanation can be used to understand the relation that Heijmans has with the CC.

At the bottom of the pyramid is the supplier. The scope of the working relationship with a supplier company is not necessarily focussed on a long-term relationship and:

- has to meet certain basic requirements;
- has a prime products and is offering security of supply;
- offers value for money.

One level higher is the preferred supplier. The scope of the working relationship with the preferred supplier is focussed on a longer term relationship. The preferred supplier:

- meets the criteria of a supplier;
- is reliable;
- has prime in-house expertise on processes, systems and products;
- has proven value for money.

Out of the group of preferred supplier a smaller group can develop into a co-maker. A co-maker adopts its responsibility for part of the primary process of its employer such that the co-maker adjust its own process, systems and products in alignment to the employer. The scope of the working relationship is often longer than five contract years.

A co-maker company:

- meets all criteria of a supplier and a preferred supplier;
- is in the top-segment of its business;
- is prepared to share cost formation;
- improves the logistic coordination.

The first three abovementioned aspects are implemented in the HWC, however the fourth aspect has not been addressed so far. In order to receive the highest benefits of the co-makership relationships the fourth aspect of co-makership should be explored more thoroughly.

A partner company:

- meets all criteria of a supplier, a preferred supplier and a co-maker;
- is prepared to share in the risk of projects and products;
- is focussing on a long term relationship;
- is accepting mutual interdependences.

There are no partner relationships present in the network of the case study project.

The CCs involved in the first-tier physical distribution of goods and transport of employees in the supply chain are the same from one HWC construction project to the other, although there may be some variety with regard to regional requirements. In these cases the type of products and quantities are still the same, only the supplier is different.

9.5 The cooperating companies and the activities they are responsible for at the case study project

The CCs in the supply chain of the HWC concept are addressed to (anonymously) by recalling to them as, company (x) where x = a capital letter of the alphabet. References to the CCs are made as such. In this Appendix, the CCs are elaborated upon their core business and the activities they are responsible for in the construction process of the case study project.

Company A is a preferred supplier from the south of the Netherlands and its core business is soil transport. It has expertise in sewer connections connected to the municipality sewer. This CC stands by for any last minute soil problems at the construction site. For example, when there was many rain in the first weeks it built a barrier to keep the water out. This is an activity that is not incorporated in the lean planning. It is responsible for six activities.

Activity 1	Excavation of the building pits;
Activity 5	Connecting the houses to the sewer (dirty water transport);
Activity 8	Filling the fundaments;
Activity 9	Laying down driving plates (steel);
Activity 73	Soil work gardens;
Activity 74	Laying down salvage fundaments.

Extra activities that the CC performs are the preparation and assemblage of the construction site and trailers.

Company B is a co-maker and its core business is facilitating all the products and services required to make the fundament of a construction. For the case study project it used rotary bored piles instead of prefab piles due to the soil composition. Activity 3 is outsourced to a specialised company. It is responsible for three activities.

Activity 2	Placing of the rotary bored piles;
Activity 3	Measuring the placed rotary bored piles;
Activity 4	Placing the prefab fundaments.

An extra activity that the CC performs is the dimensioning of the to be bored piles. This activity is outsourced to an subcontractor.

Company C is a co-maker and its core business is electrical installations in the houses. It has many specialised employees that are able to perform all the activities it is responsible for. In activity 44 the milling is outsourced to a partner. It is responsible for six activities.

Activity 6	Assembling the ground connections;
Activity 13	Assembling the pipe work in the cavities;
Activity 44	Milling and applying of markings;
	The applying of markings is outsourced to a subcontractor;
Activity 45	Assembling electra in the floors and inner walls;
Activity 60	Assembling distribution boxes and wall sockets boilers;
Activity 65	Final assembling electra.

Company D is a co-maker and its core business is mechanical installation meaning everything that has to do with the dirty and clean water sewer, piping system, heating system and toilet facilities. With its experienced employees it is able to perform these activities. It is responsible for eight activities.

Activity 7	Connecting the sewer in the fundaments;
Activity 33	Assembling the zinc gutters;
Activity 34	Delivery of the roof glands;
Activity 42	Installing carcassing pipe systems;
Activity 43	Assembling floor heating systems;
Activity 52	Assembling shower drains or bathtubs;
Activity 59	Assembling boilers and set them up;
Activity 64	Final assembling of toilet facilities.

An extra activity that the CC performs is the delivery of 'invoerbochten' and the dial, 'meterplaat'.

Company E is a co-maker and its core business is the prefabrication of the carcasses of the houses. When the carcasses of the houses are up it outsources the stuccowork that is required to company L. It is responsible for two activities.

Activity 10	Assembling ground level floors;
Activity 11	Assembling of the carcasses.

An extra activity that the CC performs is the finishing of the cementitious materials. This is outsourced to company Q.

Company F is a preferred supplier and its core business is to rent out telescopic handlers. It is responsible for one activity.

Activity 12 Placing Ytong into the houses on the floors where the Ytong is processed. With the Ytong the indoor walls are made.

Company G is a preferred supplier and its core business is the rental and construction as well as deconstruction of scaffolding. It is responsible for five activities.

Activity 14 Construction of the scaffoldings first level;
Activity 15 Construction of scaffoldings second level;
Activity 16 Construction of scaffoldings attic level;
Activity 36 Deconstruction of the scaffoldings at the back site of the houses;
Activity 37 Deconstruction of the scaffoldings at the front site of the houses.

Company H, Heijmans, takes care of the organisation of the building project. Heijmans is responsible for eighteen activities from which many in the finishing phase.

Activity 17 Placing the constructions for the string line required for bricklaying ground floor;
Activity 18 Placing the constructions for the string line for the first floor;
Activity 19 Placing the constructions for the string line for the additional building;
Activity 20 Placing the constructions for the string line for the attic;
Activity 28 Preparations required for the placement of the rooftops;
Activity 29 Placing the rooftops;
Activity 30 Finishing the rooftops;
Activity 31 Assembling the preparations for the gutters;
Activity 32 Assembling Rockpanel gutters;
Activity 53 Assembling back wall meter cupboards;
Activity 54 Finishing woodwork window frames;
Activity 55 Finishing woodwork rooftops;
Activity 61 Drying time (heating the houses);
Activity 69 Assembling Jonka meter cupboards;
Activity 72 Sealing all remaining aspects of the houses;
Outsourced to a subcontractor.
Activity 79 Inspection with the house owners;
Activity 80 Final inspections of the houses;
Activity 81 Final delivery of the houses.

Company I is a co-maker and its core business is window frames. It is responsible for four activities.

Activity 21 Assembling anchors of the window frames;
Activity 22 Assembling the window frames;
Activity 23 Adjusting the window frames;
Activity 66 Assembling the exterior doors.

The CC outsources the assemblage of the activities to a subcontractor.

Company J is a preferred supplier and its core business is laying bricks. It is responsible for four activities.

Activity 24 Brick laying of the first crew;

Activity 25 Brick laying of the second crew;
Activity 26 Brick laying of the third crew;
Activity 27 Applying grouting applications.

Company K is a preferred supplier and its core business is assembling roof tiles. It is responsible for one activity.

Activity 35 Assemblage of roof tiles.

Company L is a preferred supplier and its core business is assembling roof covering. It is responsible for one activity.

Activity 38 Assembling roof covering on the additional buildings.

Company M is a preferred supplier and its core business is the fabrication of staircases. It is responsible for three activities.

Activity 39 Assembling and adjusting staircases;
Activity 57 Finishing woodwork staircases;
Activity 68 Assembling banisters.

Company N is a preferred supplier and its core business is the construction of Ytong indoor walls. It is responsible for two activities

Activity 40 Assembling and construction of the Ytong indoor walls;
Activity 48 Applying stuccowork on the Ytong indoor walls.

Company O is a preferred supplier and its core business is assembling metal-studs. It is responsible for two activities.

Activity 41 Assembling metal-studs in the attics;
Activity 47 Assembling metal-studs in the toilet shafts including the toilet conversions.

Company P is a preferred supplier and its core business is applying top screed. It is responsible for one activity.

Activity 46 Applying top screeds.

Company Q is a preferred supplier and its core business is applying stuccowork and spray work. It is responsible for two activities

Activity 49 Applying stuccowork;
Activity 62 Applying spray work.

Company R is a preferred supplier and its core business is being a warehouse and assembling wall and floor tiles. It is responsible for three activities.

Activity 50 Assembling wall tiles;
Activity 51 Assembling floor tiles;
Activity 63 Applying sealing work in the bathrooms.

Company S is a preferred supplier and its core business is the production and assemblage of indoor door windows and doors. It is responsible for one activity.

Activity 56 Assembling indoor door windows and doors.

Company T is a preferred supplier and its core business is painting. It is responsible for two activities.

Activity 70 General painting;
Activity 71 Painting staircases.

Company U is a preferred supplier and its core business is the production and assemblage of storage facilities. It is responsible for three activities.

Activity 75 Delivery of the fundaments of the storage facilities;
Activity 76 Placements of the storage facilities;
Activity 77 Placement of the fences and gates.

Company V is a preferred supplier and its core business is clean-up work. It is responsible for one activity. Moreover, company V is responsible to clean the construction trailer twice a week.

Activity78 Cleaning of the houses and construction trailer.

Next to all these activities there are a few more CCs involved that are responsible for other activities:

Company W is a preferred supplier and its core business is waste management. It is responsible for all the waste streams that need to leave the construction site. In total there are four waste streams that are plaster, paper, rest building materials and wood. The CC is also responsible for the making of reports on how the waste is processed.

Company X is a preferred supplier and its core business is fabrication and delivery of sills. Its responsibility is to deliver the sills when called off by the foreman.

Company Y is a preferred supplier and its core business is the delivery of staircase opening security. Its responsibility is to deliver and pick up the staircase opening security equipment when called off by the foreman of Heijmans.

Company Z is a co-maker and its core business is the prefabrication of roofs. It is responsible for the fabrication and delivery of the roofs and all materials required for the assemblage of the roofs. The delivery is before activity 28.

Company AA is a preferred supplier that fabricates and delivers artificial stone frameworks. It is responsible for one activity.

Activity 67 Assembling the artificial stone frameworks.

Company AB is a preferred supplier and its core business is the delivery of bricks and roof tiles. It is an intermediary trade company with a showroom for its customers and is internationally active.

Company AC is a supplier and its core business is assembling the public utilities. It is responsible for one activity that is outside the scope of the research.

Activity 58 Assembling the public utilities.

9.6 Variables ABC model formation

In this appendix the variables present in the calculation steps of the ABC model as elaborated upon in Chapter 3 are presented.

Variable #	Explanation on the variable	Abbreviation
Variable 1	Distance one-way trip in kilometres	DS_{trip}
Variable 2	Distance round trip in kilometres	DR_{trip}
Variable 3	Number of transports	TR
Variable 4	Total distance in kilometres	D_{total}
Variable 5	Distance inside built-up areas one-way trip	$DinBUAS_{trip}$
Variable 6	Distance outside built-up areas one-way trip	$DoutBUAS_{trip}$
Variable 7	Kilometres travelled inside built-up areas	DTinBUA
Variable 8	Kilometres travelled outside built-up areas	DToutBUA
Variable 9	Total driving time inside built-up areas	TinBUA
Variable 10	Total driving time outside built-up areas	ToutBUA
Variable 11	Total driving time	T_{dri}
Variable 12	Wage per hour	W
Variable 13	Emission CO_2	$EMco_2$
Variable 14	Emission fine particulates	EMpart
Variable 15	Emission NO_x	$EMno_x$
Variable 16	Cost of transport per hour	C_{tra_hour}
Variable 17	Cost of transport per kilometre	$C_{tra\_kilometres}$
Variable 18	Transport costs	TRc
Variable 19	Depreciation costs per kilometre	DPc
Variable 20	Fuel costs per kilometre	Fc
Variable 21	Handling costs	Hc
Variable 22	Handling time in hours	Ht
Variable 23	Inventory and warehousing costs	IN&WAc
Variable 24	Logistic costs	Lc
Variable 25	On-site logistic costs	OSLc
Variable 26	Average speed inside built-up areas in kilometre per hour	SinBUA
Variable 27	Average speed outside built-up areas in kilometre per hour	SoutBUA

9.7 Calculation formulas ABC model formation

In this appendix the calculation formulas as presented in Section 3.3 of Chapter 3, are presented and visualised. The variables used in the calculation are set out in Appendix 9.6.

Calculation 1 Total distance in kilometres

D_{total} = TR x DR_{trip}

Calculation 2 Kilometres travelled within built-up areas

DTinBUA = ($DinBUAS_{trip}$ x 2) x TR

Calculation 3 Kilometres travelled outside built-up areas

DToutBUA = ($DoutBUAS_{trip}$ x 2) x TR

Calculation 4 Total driving time within built-up areas

TinBUA = DTinBUA / S_{inBUA} +1

Calculation 5 Total driving time outside built-up areas

ToutBUA = DToutBUA / S_{outBUA}

Calculation 6 Total driving time

T_{dri} = TinBUA + ToutBUA x 1.1

Calculation 7 Emission CO_2

Total $EMco_2$ = $EMco_2$ x D_{total}

Calculation 8 Emission fine particulates

Total EMpart = EMpart x D_{total}

Calculation 9 Emission NO_x

Total $EMno_x$ = $EMno_x$ x D_{total}

Calculation 10 Transport costs

TRc = W x T_{dri} + (DPc + Fc) x D_{total}

Calculation 11 Handling costs

Hc = W x Ht

Calculation 12 Logistic costs

Lc = Hc + TRc + IN&WAc + OSLc

Next, in Figure 45, the 12 calculations are visualised.

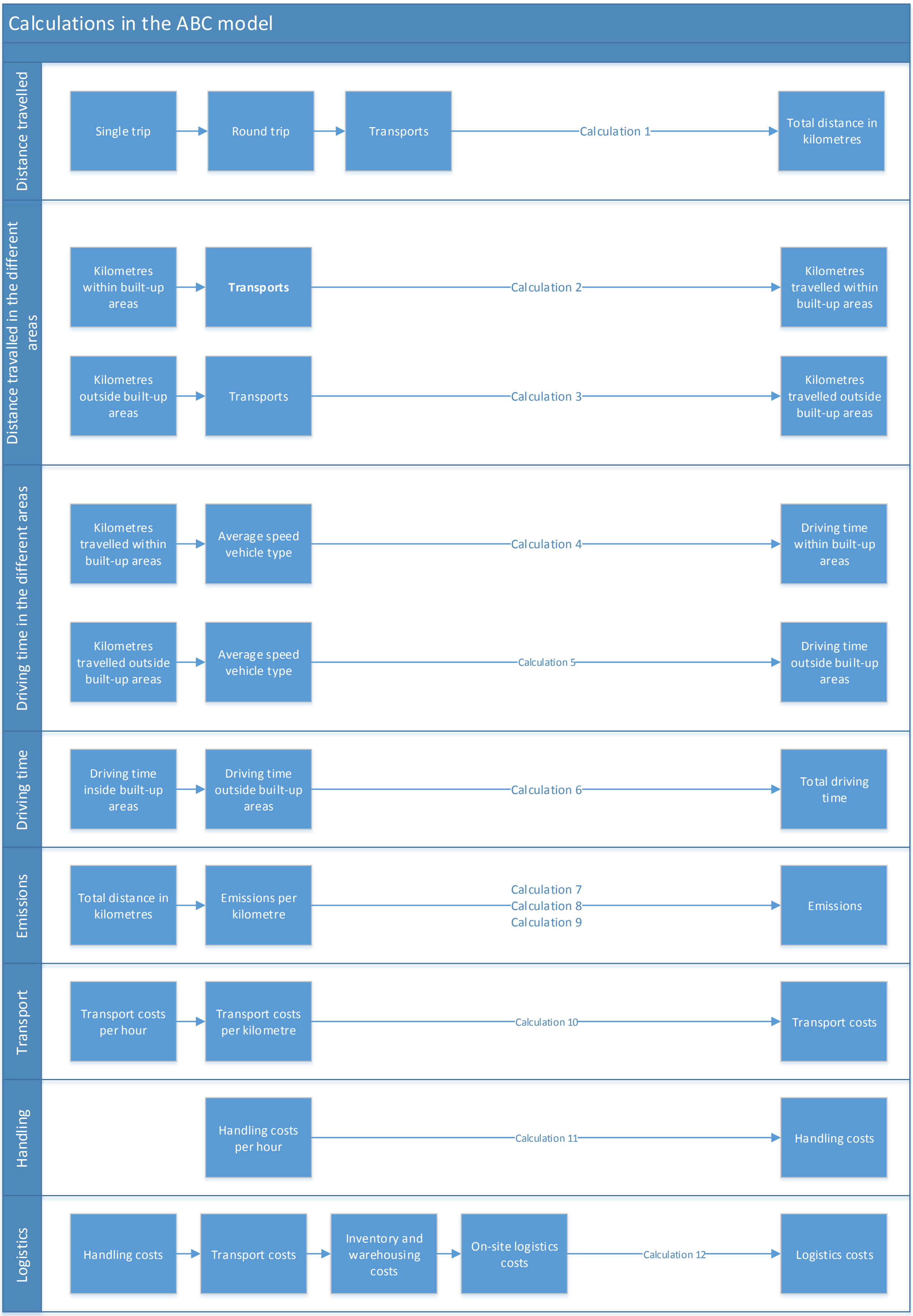

FIGURE 45: CALCULATIONS IN THE ABC MODEL.

9.8 Results of the ABC analysis conducted on the case study project

In Table 25, the extended results of the ABC analysis conducted on the case study project are presented for the CCs.

Cooperating Company	Number of transports (#)	Total kilometre travelled (*1000)	Total driver's hours (#)	Total logistic costs per CC (€*1000)	Percentage logistic costs over building sum (%)
Company A	122	3	112	Confidential	11
Company B	36	10	198	Confidential	15
Company C	65	3	77	Confidential	4
Company D	97	3	115	Confidential	2
Company E	139	29	572	Confidential	10
Company F	6	1	24	Confidential	7
Company G	60	8	149	Confidential	51
Company H	390	23	393	Confidential	17
Company I	44	5	108	Confidential	3
Company J	92	7	141	Confidential	9
Company K	28	2	37	Confidential	4
Company L	13	2	31	Confidential	11
Company M	20	2	39	Confidential	4
Company N	39	3	69	Confidential	12
Company O	38	2	48	Confidential	9
Company P	13	1	31	Confidential	6
Company Q	42	6	91	Confidential	10
Company R	41	2	53	Confidential	7
Company S	16	3	52	Confidential	11
Company T	23	1	17	Confidential	4
Company U	18	2	44	Confidential	3
Company V	53	2	42	Confidential	25
Company W	20	2	45	Confidential	47

Continuing Table 25					
Cooperating Company	Number of transports	Total kilometre travelled (*1000)	Total driver's hours	Total logistic costs per CC (€*1000)	Percentage logistic costs over building sum (%)
Company X	3	1	13	Confidential	23
Company Y	2	0.1	5	Confidential	N/A
Company Z	23	4	90	Confidential	4
Company AA	18	1	25	Confidential	8
Company AB	16	1	80	Confidential	6
Company AC	N/A	N/A	N/A	N/A	N/A
Total	**1477**	**132**	**2701**	**186**	**N/A**

TABLE 25: RESULTS OF THE CASE STUDY PROJECT ABC ANALYSIS PER COOPERATING COMPANY.

9.9 Results of the ABC analyses conducted on the optimisation scenarios

In this appendix the extended results of the ABC analyses for the LPCs LPC 1, LPC 2 and LPC 4 are presented and visualised for Optimisation Scenario 1. For LPC 1 en LPC 2 the three logistic hub costs levels and the three increased productivity levels are presented. The logistic hub cost levels do not apply for LPC 4 due to the fixed costs it presented in its offer. At last the results of the cost savings potential per year per LPC and optimisation scenario is presented.

Optimisation Scenario 1 LPC 1

In Figure 46 and Figure 47, the results of the ABC analysis conducted on the mapping of Optimisation Scenario 1 of the LPC 1 are presented.

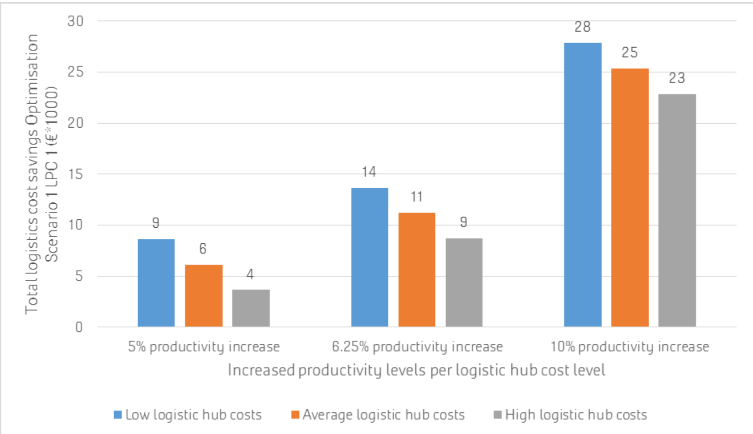

FIGURE 46: TOTAL LOGISTICS COSTS OPTIMISATION SCENARIO 1 LPC 1.

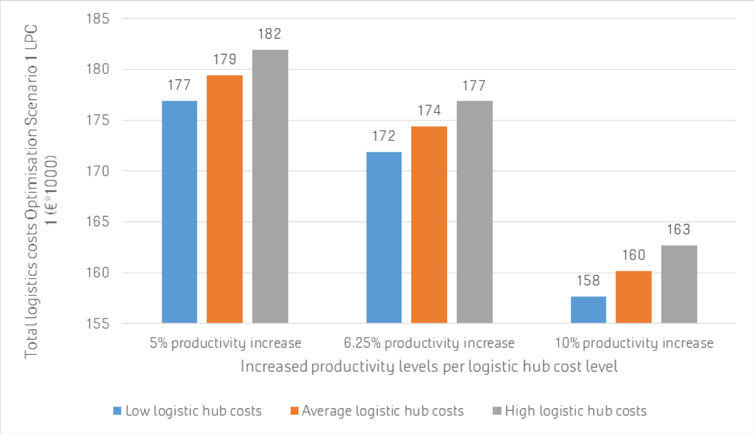

FIGURE 47: TOTAL LOGISTIC COST SAVINGS OPTIMISATION SCENARIO 1 LPC 1.

In Table 26 and Table 27 on the next page the extended results of the ABC analysis conducted on the mapping of Optimisation Scenario 1 for the LPC 1 are presented.

LPC 1 Optimisation Scenario 1 total logistics costs			
	5% productivity increase	6.25% productivity increase	10% productivity increase
	Total logistics costs (€*1000)	Total logistics costs (€*1000)	Total logistics costs (€*1000)
Low Logistic hub costs	177	172	158
Average logistic hub costs	179	174	160
High logistic hub costs	182	177	163

TABLE 26: RESULTS ABC ANALYSIS LPC 1 OPTIMISATION SCENARIO 1 TOTAL LOGISTIC COSTS.

LPC 1 Optimisation Scenario 1 total logistics cost savings			
	5% productivity increase	6.25% productivity increase	10% productivity increase
	Total logistic cost savings (€*1000)	Total logistic cost savings (€*1000)	Total logistic cost savings (€*1000)
Low Logistic hub costs	9	14	28
Average logistic hub costs	6	11	25
High logistic hub costs	4	9	23

TABLE 27: RESULTS ABC ANALYSIS LPC 1 OPTIMISATION SCENARIO 1 TOTAL LOGISTIC COST SAVINGS.

Optimisation Scenario 1 LPC 2

In Figure 48 and Figure 49 the results of the ABC analysis conducted on the mapping of Optimisation Scenario 1 of the LPC 2 are presented.

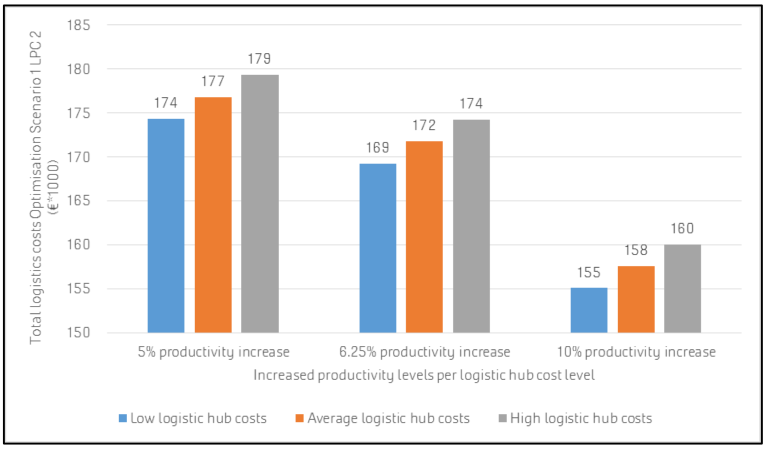

FIGURE 49: TOTAL LOGISTICS COSTS OPTIMISATION SCENARIO 1 LPC 2.

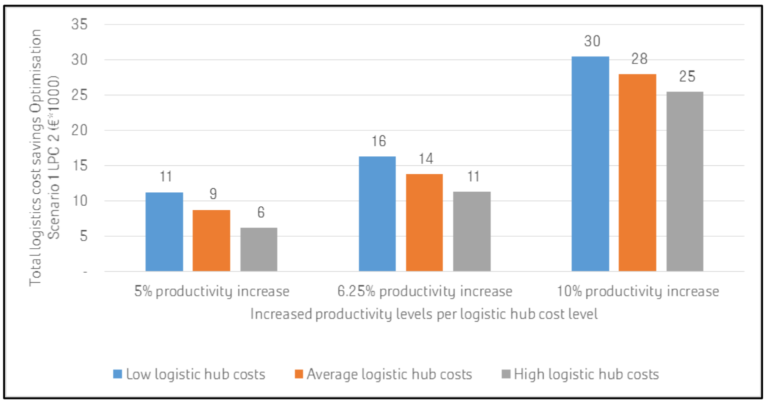

FIGURE 48: TOTAL LOGISTIC COST SAVING OPTIMISATION SCENARIO 1 LPC 2.

In Table 28 and Table 29, the extended results of the ABC analysis conducted on the mapping of Optimisation Scenario 1 for the LPC 2 are presented.

LPC 2 Optimisation Scenario 1 total logistic costs			
	5% productivity increase	6.25% productivity increase	10% productivity increase
	Total logistics costs (€*1000)	Total logistics costs (€*1000)	Total logistics costs (€*1000)
Low Logistic hub costs	174	169	155
Average logistic hub costs	177	172	158
High logistic hub costs	179	174	160

TABLE 28: RESULTS ABC ANALYSIS LPC 2 OPTIMISATION SCENARIO 1 TOTAL LOGISTICS COSTS.

LPC 2 Optimisation Scenario 1 total cost savings			
	5% productivity increase	6.25% productivity increase	10% productivity increase
	Total logistic cost savings (€*1000)	Total logistic cost savings (€*1000)	Total logistic cost savings (€*1000)
Low Logistic hub costs	11	16	31
Average logistic hub costs	9	14	28
High logistic hub costs	6	11	26

TABLE 29: RESULTS ABC ANALYSIS LPC 2 OPTIMISATION SCENARIO 1 TOTAL LOGISTIC COST SAVINGS.

Optimisation Scenario 1 LPC 4

In Figure 50, the results of the ABC analysis conducted on Optimisation Scenario 1 of the LPC 4 are presented.

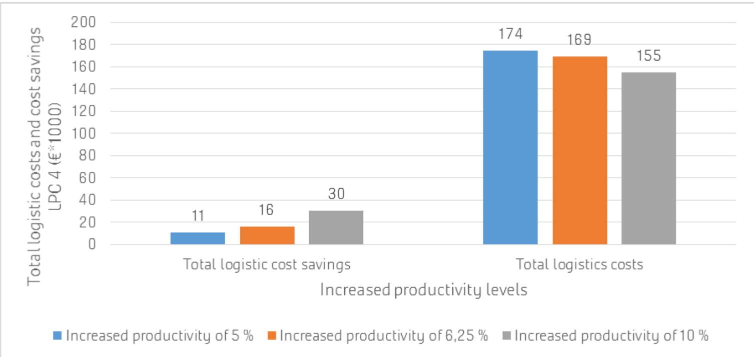

FIGURE 50: TOTAL LOGISTIC COST SAVINGS OPTIMISATION SCENARIO 1 LPC 4.

In Table 30, the extended results of the ABC analysis conducted on the mapping of Optimisation Scenario 1 for the LPC 4 is presented.

Costs characteristics	5% productivity increase	6.25% productivity increase	10% productivity increase
Total logistics costs	174	169	155
Total logistic cost savings	11	16	30

TABLE 30: RESULTS ABC ANALYSIS LPC 4 OPTIMISATION SCENARIO 1.

In Table 31, the expected cost savings per year based on 600 houses is presented under linear cost savings conditions.

LPCs	LPC 1	LPC 2	LPC 4
Characteristic	Cost savings (€*1000)	Cost savings (€*1000)	Cost Savings (€*1000)
Optimisation Scenario 1	232	287	337
Optimisation Scenario 2	393	467	N/A

TABLE 31: EXPECTED COST SAVING PER YEAR BASED ON 600 HOUSES.