The Improvement of the Performance and Acceptance of a Crane Scheduling Tool

A case study at Dura Vermeer

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ABSTRACT: During this case study the implementation process of a *crane scheduling tool is analysed*. The tool predicts the needed crane hours of construction projects and creates a day schedule for the crane to improve the productivity of the crane. The goal of this research is to improve the performance and acceptance of the tool to fully embed the crane model in the processes of construction company Dura Vermeer. This is done by defining the needed updates, the enablers, drivers and barriers and the remaining (essential) steps. The performance and acceptance of the tool are analysed on a company and project level by performing model evaluations, conducting interviews and performing observations. The results show that employees on both a company and project level noticed possible updates for every version of the tool mainly about the factors *output quality, result demonstrability and ease of use.* The tool's enablers were based on performance factors on a company level and on acceptance factors on a project level. For the drivers and barriers the factors were spread over both levels. The found drivers are mainly about creating learning opportunities, improving standardization and creating output for the nitrogen legislation. The drivers did not contain logistics factors which showed that employees do not think from a logistics perspective. Multiple barriers were solved during this research with the tool updates, but not every barrier could be solved such as the doubt of generalization of data, estimations of input values and limitations of Excel to improve the ease of use. With the performed updates, the model is now ready to be used on a micro level for a few projects, but not on a macro level for all the projects of DV. Therefore, it is recommended to improve the model by collecting more data about the activities of the crane and changing the application of the model. The crane model is a *bottom-up innovation*, but by showing the feasibility during this research, it can become a *top-down innovation* which enables the model to be embedded in the processes of Dura Vermeer. Additionally, this research showed that most employees saw potential in the model to improve decisions instead of improving the entire process. Therefore, *System thinking* can also help to embed the model in the processes of DV.

Keywords: Innovation performance, Innovation acceptance, Construction industry, Logistics processes

1. Introduction

The productivity of resources in the construction industry is still lower than it should be (Windapo, 2021). To increase the productivity, the logistics processes of the projects gain more focus in the construction industry. In construction, the management of logistics involves the strategic storage, handling, transportation and distribution of resources. Additionally, the planning of the construction site layout and its evolution during the development of the construction project can be included in logistics management (Whitlock, Aband, Manjia, Pettang, & Nkeng, 2018). There are multiple new technologies available on the market to improve the productivity of resources such as Internet of Things, big data analytics and machine learning, but these are not fully adopted yet in the construction industry (Windapo, 2021).

Dura Vermeer (DV), a large construction company in the Netherlands wants to put more focus on their logistics processes. One of the suborganizations in the division housing & utility, Dura Vermeer Bouw Hengelo (DVBH), hired a logistics manager three years ago to accomplish this goal. This logistics manager focusses on creating more standardization for the logistics processes by for example implementing a transportation management system. With more standardization the productivity of resources can increase which decreases the costs and the processing time of construction projects.

DVBH uses three technical logistics tools to improve the logistics processes to and on the construction site. The first tool, *the volume model*, calculates the number of arriving trucks. Based on the building parameters, this model calculates when trucks will arrive and predicts the emission of the arriving trucks. The second tool is a transportation management tool.

With this tool suppliers or construction managers can suggest an arriving time for the truck which will automatically be communicated. Additionally, this tool creates a ticket which gives information about where to place the material and which can be used to check the reliability of the arrival time. The third tool, *the crane model*, is a crane scheduling tool. This model predicts in the preparation phase how many crane hours are needed for the entire project and creates on a day level a schedule for the crane. The crane model uses input of the volume model and the transportation management tool and can produce output to suggest a schedule for the arriving trucks in the transportation management tool. The first two tools are already in use for 2 years. The third tool just started with the implementation process. There are no projects yet which use all three tools. Since the focus on logistics processes is still new in the company, the implementation of the logistics tools faces several challenges such as a lack of data and commitment of employees. Therefore, DVBH would like to know how they can improve the implementation of these tools. This research will focus on the crane model, but will also take the other two tools into account since they need input and output from each other and therefore are closely related.

The tool of the crane model was created in Excel during earlier research (Jansma, 2022). Due to time restrictions and the complexity of the process, which is modelled, the tool is still very basic and many assumptions were made. Therefore, there are still many possible updates which will create more accurate results. The most important recommendation of that research is to perform these updates.

Currently, the tool is filled in by the logistics managers and the results are shared with the employees of the different departments of DVBH. In the future the tool should be independently used by the end-user which shows the importance of the acceptance of the tool by the end-users. This research will define the path towards the independent use of the tool by the end-users.

The goal of this research is to improve the implementation process of the crane model. As described in the previous paragraphs, the *performance and acceptance* influence the implementation. This research will systematically define which updates should be performed to improve the output quality and to define the remaining steps which are required for the full acceptance of the tool. Therefore, the research question is:

> *How can the performance and acceptance of the crane model be improved such that it can be embedded in the processes of construction projects of DV?*

The structure of this research is the following: First, Section 2 describes the literature review about the performance of technical innovations in a logistics and construction context and the acceptance of innovations. At the end of this section the theoretical framework shows how the results of the literature review are used in this research. Second, Section 3 describes the methodology of the data collection and data analysis which are based on the main research question and three sub questions. Next, Section 4 present the results of the data analysis and the answers to the sub questions. Section 5 discusses these results and compares them to the results of the literature review. Last, Section 6 gives the conclusion of this research.

2. Theoretical Background

As explained in Section 1, this research focusses on the performance and acceptance of a technical innovation to improve the logistics processes of a construction company. This chapter performs a literature review about factors which can be used to describe the performance and acceptance of technical innovations. Section 2.1 explains the factors influencing the performance of the implementation of technical innovations of logistics processes in the construction industry. Section 2.2 explains theories about the acceptance of an innovation. Section 2.3 describes how the theories of the literature review are used in this research by forming a theoretical framework. Appendix A gives a more detailed description of how the framework is set-up.

2.1 The performance of an innovation

This subsection describes a literature review about the factors influencing the performance of technical innovations. To understand the implementation process, it is important to understand the context of the innovation. Therefore, this subsection also describes relevant characteristics of logistics processes and of the construction industry which can influence the performance of an innovation.

2.1.1 Technical innovation

Innovation is about any idea, technology or material that is perceived as new by the respective adopting

unit. Innovation is essential for the business growth and for keeping a competitive advantage (Klosova & Kozlovská, 2020). *Technological innovation* can be about the introduction of a new product, but it can also be about the change of a process to decrease the production cost. Technological innovations are often developed in cooperation with other companies. Many complementary innovations are required before the technological innovation is ready for use. The following factors influence the performance of a technical innovation according to Dasgupta, Gupta and Sahay (2011):

- *Knowledge* - Companies need to integrate tacit knowledge (experience based) with explicit knowledge (documented and shareable).
- *Learning & Development* - In order to gain knowledge, a company needs to be open to learning. This includes the learning and development of employees, but also having open communication channels to learn from customers and suppliers.
- *Inter-functional integration* - Inter-divisional teams ensure employees learn from each other and promote innovation. Autonomy of employees gives them the freedom to try out new tools and techniques.
- *Top-management* - Top-management plays an important role in creating a culture of innovation.
- *Economic, legal, competitive, technological and social aspect* - The budgetary allocations of a government can for example be used to stimulate innovations.

Dasgupta, Gupta and Sahay (2011) use in their paper two factors to define technological innovation which are *technology strategy* and *organizational factors*. Technology strategy can be defined as a portfolio of choices and plans that a firm uses to address the technological threats and opportunities in its external environment. It is therefore closely related to the business strategy, the rules and regulations and governments policies within its environment. Organizational factors involve the learning and development of employees and the communication with and learning from suppliers and customers.

2.1.2 Characteristics logistics (4.0) process

Logistics can be defined as the part of supply chain management which plans, implements and controls the efficient and effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption to meet the requirements of the customer (Facchini, Olésków-Szłapka, Ranieri, & Urbinati, 2020). A new development within logistics is the introduction of *Industry 4.0*. Industry 4.0 introduces new technologies such as big data, Internet of things and smart factory. These technologies can each improve a company's performance by solving issues such as resource idleness. *Logistics 4.0* focusses specifically on the logistics area of Industry 4.0. With Internet of Things, logistics 4.0 for example links physical objects to collect real-time data visualization to automate the logistics flows. To evaluate the logistics of a company, the total process is split in different dimensions. Logistics 4.0 divides the company in the macro-dimensions: management and flow of material and information, but also in the sub-dimensions: knowledge, strategy and leadership, employees, IT systems, smart products, smart warehouses and technologies (Facchini, Olésków-Szłapka, Ranieri, & Urbinati, 2020).

Logistics 4.0 is already implemented in other industries of which the implementation process is analysed. Perotti, Santacruz, Bremer and Beer (2022) performed a literature review of these studies. In their literature review they found the most described influencing factors, benefits and barriers and criticalities. *Influencing factors* are referring to the elements that might influence the company's decisions to adopt Logistics 4.0. *Benefits* indicate the advantages that Logistics 4.0 solutions might offer and *barriers and criticalities* deal with all the challenges that companies might face when embracing Logistics 4.0. The influencing factors and barriers overlap with the factors named in Section 2.1.1 about general technical innovations. The benefits like process optimization, traceability and visibility enhancement and flexibility increase were not named before and are more characterizable for logistics processes. Table 1 gives an overview of these factors which are relevant for this research.

Table 1 Factors which form the influencing factor, benefit or barrier and criticalities for the adoption of Industry 4.0 adopted from (Perotti, Santacruz, Bremer, & Beer, 2022)

Influencing factors	Benefits	Barriers and criticalities
Company's digitial awarenes and readiness	Process optimization	No standardized implementation exists
Employees educational level	Human resource and safety enhancement	High implementation costs
Government support and policies	Traceability and visibility enhancement	Obsolete infrastructure
	Human error reduction	Companies are not ready for advanced technologies
	Transaction costs	
	Sustainability improvement	
	Flexibility increase	

2.1.3 Characteristics construction industry

The construction industry has several characteristics which make it different from other sectors. The paragraphs below describe three of these characteristics which are important to consider when analysing the implementation of an innovation in a construction company.

Collaboration – Every construction project requires a wide range of skills and specialisms. Therefore, a project is built in cooperation with multiple organizations each with their own resources and way of working which act in their own interest. This makes the communication and information transfer for the project more complicated, but also more important. A new innovation of a contractor will therefore often involve and be dependent on other organizations such as subcontractors and clients (Harty, 2005).

Project-based - The focus of a construction company is mainly on the efficiency of individual construction projects. Therefore, decision making and financial control is decentralized. For each project a new supply chain and logistics setup is created (Janné & Fredriksson, 2018).

Complexity of operation - A construction company consists of different systems which interact with each other and their environment. Introducing a new innovation can create disturbances throughout these interactions which are hard to trace (Slaughter, 1998).

Traditionally innovation is measured in terms of inputs and outputs. Ozorhon, Oral and Demirkesen (2016) propose in their research a new framework to measure innovation in the construction industry. In their framework drivers, barriers and enablers form the input. *Drivers* are defined as the main motivations to initiate the innovation process such as the client requirements, design trends and project performance improvements. *Barriers* are the challenges that might hinder the innovation such as the lack of financial resources and time constraints. *Enablers* are the factors that overcome innovation challenges such as cooperation, leadership and commitment. Table 2 gives an overview of these factors which are relevant in this research. The input influences the output on two levels, the project-level and the firm-level. On the project level, benefits can be a decrease in project duration and an increase in productivity. On the firm level, benefits can be gaining experience and improvement of the company image.

Table 2 Factors which form the enablers, drivers and barriers of innovations in the construction industry adopted from (Ozorhon, Oral, & Demirkesen, 2016)

Enablers	Drivers	Barriers
Cooperation	Competition level	Lack of financial resources
Leadership	Project performance improvement	Unsupportive organizational culture
Commitment	Technological developments	Temporary nature of projects
Knowledge management	Regulations and legistlations	Unavailability of materials
Reward schemes	Corporate Responsibility	Lack of experiences / qualified staff
Training policy	Environment and sustainability	Lack of clear benefits
		Time constraints

This section showed that there are multiple factors influencing the implementation of a technological innovation which can be mainly subdivided in technology strategy and organizational factors. For logistics innovations, data gathering is important to measure, improve and learn from the current performance of the processes. In the construction industry, the implementation of innovations is influenced by the complexity of operations, the project-based operations and the collaborations with suppliers.

2.2 Technology acceptance

When implementing a new technology, it is important that it is accepted by the users. There are multiple theories which focus on the acceptance of new technologies by the users. This section describes three of the most important theories in this field, the Technology Acceptance Model, the Unified Theory of Acceptance and Use of Technology and the Theory of Diffusion.

2.2.1 Technology Acceptance Model

The Technology Acceptance Model (TAM) is a dominant model in investigating factors which affect the acceptance of the technology by the user. This model explains the user's motivation with three factors: perceived ease of use, perceived usefulness and attitude toward using which is influenced by the two other factors. *Perceived usefulness* is defined as the degree to which the person believes that using the particular system would enhance his/her job performance. *Perceived ease of use* is defined as the degree to which the person believes that using the system would be free of effort. In TAM 2.0 factors that influence the perceived usefulness are added to the model which are (Marangunic & Granic, 2015):

- *Subjective norm* - The influence of others on the user's decision to use or not to use the technology
- *Image* - The desire of the user to maintain a favorable standing among others
- *Job relevance* - The degree to which the technology was applicable
- *Output quality* - The extent to which the technology adequately performed the required tasks
- *Result demonstrability* - The production of tangible results

2.2.2 Unified Theory of Acceptance and Use of Technology

Unified Theory of Acceptance and Use of Technology (UTAUT) is a comprehensive synthesis of prior research in technology acceptance such as TAM and TAM 2.0. There are four key factors which influence the behavioral intention to use a technology according to UTAUT (Yildiz Durak, 2019):

- *Performance expectancy* - The degree to which the individual believes that the technology will contribute to their performance
- *Effort expectancy* - The belief of the individual in the ease-of-use of technology
- *Social influence* - The perception of the individual regarding the belief in the use of technology by other people who are important to the individual
- *Facilitating conditions* - The belief of an Individual that the technical infrastructure exists to use the technology

2.2.3 Theory of Diffusion of Innovation

The Theory of Diffusion of Innovation focusses on the employee's adoption of a new technology. This theory focusses on the process by which an innovation is communicated through certain channels over time among the members of a social society. Since the crane model is used in multiple departments of DV, this is a very relevant theory. The theory is explained in five factors (Turan, Tunç, & Zehir, 2015):

- *Relative advantage* - The perception of employees that the innovation takes some advantages for their job performance
- *Compatibility* - The degree to which an innovation is perceived as being consistent with the existing values, needs and past experiences of potential adapters
- *Complexity* - The degree to which the implemented system is easy to learn and free of effort for employees
- *Triability* - The possibility of users to experiment with the innovation
- *Observability* - The degree to which employees attain concrete evidence after using the innovation and to which employees can see the innovation indicators in the adoption context

This section showed that the acceptance and adoption of an innovation in a company is dependent on multiple factors. The acceptance theories each use multiple factors of which several overlap.

2.3 Theoretical framework

Based on the literature review, a theoretical framework is formulated. With the theoretical framework the *performance and acceptance* of the crane model will be evaluated. The framework is adjusted to the research context by adding factors of *logistics processes* and the *construction industry*. Based on the factors named in the theoretical framework the enablers, drivers, barriers and possible updates will be defined on a company and project level. The project level is split in preparation and execution since the tool can be used in those two phases of a construction project.

The baseline of the framework is based on the theory of Dasgupta, Gupta and Sahay (2011) which separates technological innovation in technology strategy and operational factors. Technology strategy is further divided in factors based on Dasgupta, Gupta and Sahay (2011). Organizational factors are further divided into information and resources based on Facchini, Olésków-Szłapka, Ranieri, & Urbinati, (2020). The factors of the resources are defined based on TAM, UTAUT and the Theory of Diffusion of Innovation. Figure 1 shows the final theoretical framework.

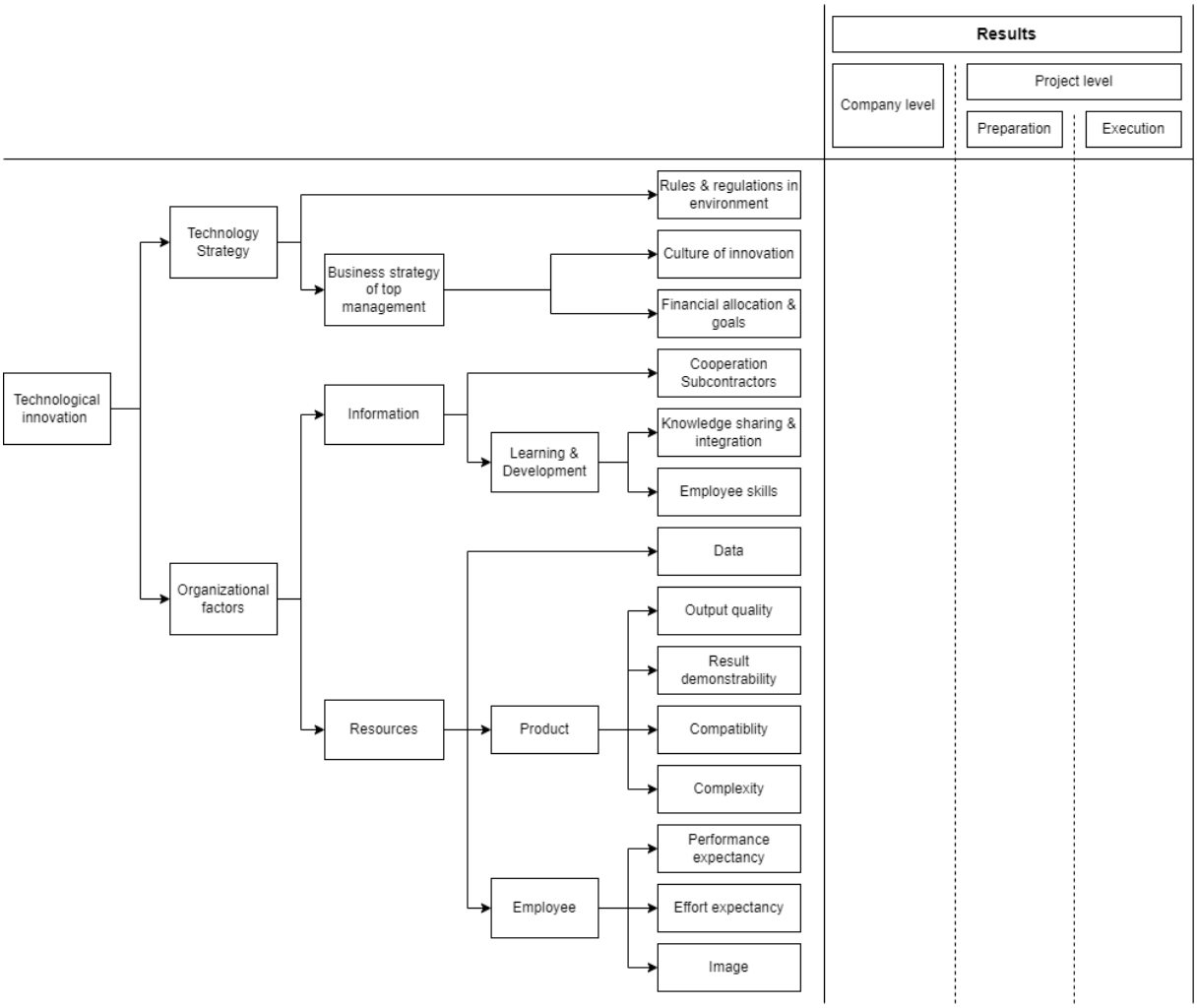

Figure 1 Final theoretical framework adjusted from Dasgupta, Gupta and Sahay (2011), Facchini, Olésków-Szłapka, Ranieri, & Urbinati, (2020), TAM, UTAUT and Theory of Diffusion

3. Methodology

This section describes the methodology of this research. Section 3.1 describes the sub questions in which the research question is split. The research is a case study performed at the company Dura Vermeer Bouw Hengelo which is further explained in Section 3.2 Section 3.3 describes the data collection methods and Section 3.4 describes the data analysis methods. Section 3.2 and 3.3 also give an explanation of one of the analysed projects of DV. The other projects are explained in more detail in Appendix E, F and G. The projects are named by their location instead of their real names because of confidentiality.

3.1 Research Question

As stated in Section 1 the main research question is:

How can the performance and acceptance of the crane model be improved such that it can be embedded in the processes of construction projects of DV?

This research bases the implementation process of the crane model on its performance and acceptance. Therefore, the first sub question is about the performance which can be improved by defining possible updates. The second sub question is about the acceptance of the tool which is measured by defining the enablers, drivers and barriers. The last sub question is about the remaining steps to fully embed the crane model in the processes of DV. This sub question is necessary because not all updates can be performed due to time constraints of the research. This results in the following three sub questions:

1. *What updates does the crane model need to improve the performance?*
2. *What factors form the enablers, drivers and barriers for the embedment of the crane model?*

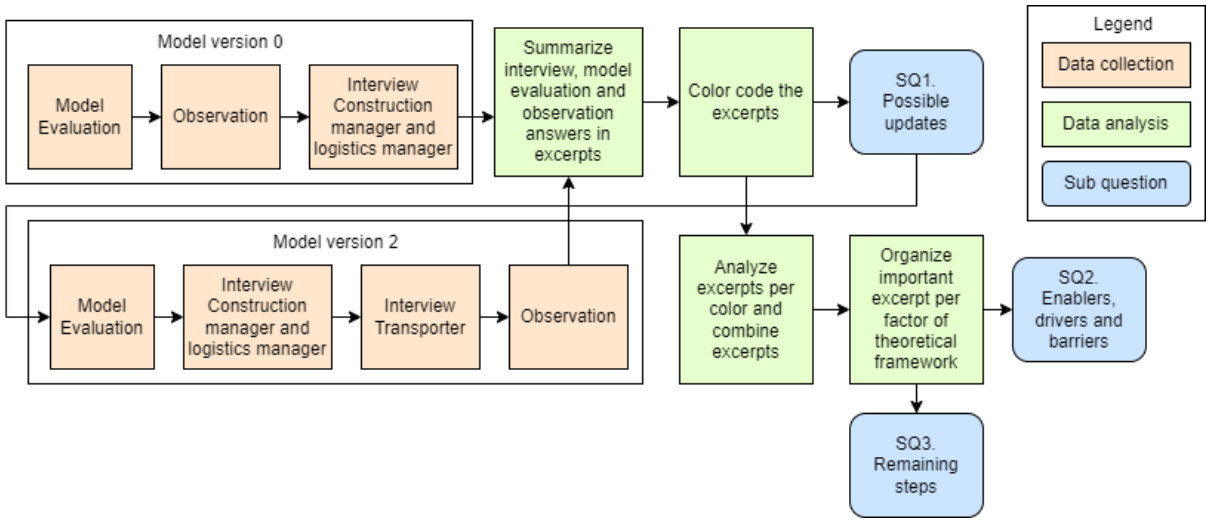

Figure 2 Research steps project Twente

3. *What are the remaining steps to embed the crane model in the processes of DV?*

The sub questions are answered by performing a case study at Dura Vermeer. The data is collected in several rounds for multiple projects. After every round the data is analyzed and updates are performed which answer the first sub question. In total 5 rounds of updates will be performed. Every version of the model is tested on at least one project. After all the data is collected, the data is further analysed to answer the second and third sub question. Figure 2 gives an overview of the steps taken in this research for one of the projects. These steps are further explained in the next sections.

3.2 Case description

The case study will be performed at the company Dura Vermeer Bouw Hengelo (DVBH). DVBH is part of Dura Vermeer. DV is one of the ten largest construction companies in the Netherlands. They have projects in housing, utility and infrastructure which form a division of DV. Dura Vermeer consists of more than 20 suborganisations of which DVBH is one. DVBH has around 230 employees and focusses on housing and utility projects. Dura Vermeer is one of the first construction companies in the Netherlands which looks more into what logistics processes they have and how they can further improve these processes (Dura Vermeer Bouw Hengelo, 2022). DVBH uses three logistics tools to improve the logistics processes to and on the construction site. These are *the volume model, a transportation management system* and *the crane model* which were already introduced in Section 1. The tools are explained in more detail in Appendix B.

The main focus of this research will be on the suborganization DVBH, but there are two other suborganizations which are also interested in the tool. Therefore, these organizations are also considered. These are Dura Vermeer Bouw Midden West (DVBMW) and Dura Vermeer Bouw Zuid West (DVBZW) which are in the same division as DVBH. The tool is tested on four projects of the three suborganizations. Each project is in a different project phase. One project is extensively analysed which is project Twente. Twente is a construction project of DVBH in Hengelo which consists of two buildings. The first building is an apartment complex of 29 apartments of which the construction started in June 2022. The second building is a block for five houses of which the construction started in October 2022. For the second building a transportation company is involved which stores all the material of the suppliers and transports it to the construction site. The first truck of the day from this company is self-unloading. The crane of this truck is used to move the needed materials of the whole day to the building. The buildings are constructed in the middle of the city centre. Therefore, the storage capacity is limited and the trucks need extra time to enter the construction site backwards. The logistics manager was already involved in an early stage of the project because of these challenges. The three other projects are: Rotterdam, Amsterdam1 and Amsterdam2 which are all three apartment buildings constructed in the Randstad. Rotterdam is at the end of the preparation phase and will start soon with the construction. Amsterdam1 is in the middle of the preparation phase and Amsterdam2 already started with the construction phase some months ago.

3.3 Data Collection

The data collection and analysis are based on *qualitative research*. Qualitative research is for example used for productivity enhancement or for new product development which makes it an appropriate method for the data collection of this research which improves productivity with a new tool.

There are three data collection methods used in this research: *model evaluations, interviews and observations*. To answer the sub questions, a theoretical framework was formed of factors which can describe the performance and acceptance of an innovation. These factors are used to define the needed updates, enablers, drivers and barriers and the remaining (essential) steps of the crane model. Table 3 gives an overview of the different factors named in the theoretical framework of figure 1. The table shows which research method is used for which factor. With the model evaluation the reliability and availability of the input data for the tool are analysed and the ease of use is tested. This is done by filling in the tool with the input data of a construction project of DV. The results of the model evaluations are discussed with employees working on the project during an interview. The interviews are face-to-face and semi-structured which means that they generally start with a few specific questions and then follow the thoughts of the interviewee. The observations are performed on the construction site during which the crane and its activities are analysed. With these observations the difference between the schedule of the tool and reality can be analysed.

Table 3 Division factors per research method

Factors	Model Evaluations	Interviews	Observations
Rules & regulations		x	
Culture of innovation		x	
Financial benefit		x	
Cooperation subcontractors		x	
Knowledge sharing & integration		x	
Employee skills		x	
Data	x		x
Output quality	x	x	x
Result demonstratability	x	x	
Compatibility		x	
Ease of use	x	x	
Performance expectancy		x	
Effort expectation		x	
Image of product		x	

Figure 3 shows which data collection methods are used for construction project Twente as was also shown in figure 2. This figure shows that the data collection methods are used multiple times for one project and the results of one method are used for the next method. The used methods are not the same for every project because not every project is in the same project phase.

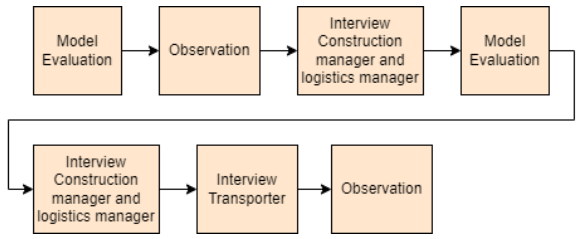

Figure 3 Order data collection methods Twente

For every factor of the theoretical framework questions are formulated to evaluate the influence of the factor for this case study. These questions are used for all three data collection methods. Figure 17 in appendix C shows the interview protocol including which questions will be answered. Table 14 in Appendix C gives an overview how many people were interviewed per function and per level. Table 15 and 16 in Appendix C show for the observations and model evaluations which questions will be answered during the collection and on which factors these are based. The questions of the interviews are answered by the interviewee. The observations and model evaluations questions are answered by the researcher based on the observations and model evaluations. The answers of the model evaluation are discussed with the company supervisor who completes the answers if necessary.

All three data collection methods are used to answer the three sub questions of this research. Possible updates for the tool named during an interview are checked with employees with similar functions for their added value. Additionally, the updates are only performed if the company supervisor agrees with the added value. Similarly, the answers are defined as an enabler, driver or barrier if the answers are confirmed by at least one other interviewee.

3.4 Data Analysis

The results of the data collection methods are analysed with *thematic analysis* in which the researcher looks for themes within the data and writes down excerpts of the data into these themes. In thematic analysis the themes form a template which enables a structured approach for the data interpretation (Cassell & Bishop, 2019). The steps of the thematic analysis of this research are adapted from the research of Sundler, Lindberg, Nilsson, & Palmér (2019). First, the important interview, model evaluation and observation answers are summarized

in excerpts. Next, every excerpt gets a color to define it as an enabler, driver or barrier. Additionally, potential updates are made bold. Table 4 shows the color codes of the excerpts. After these two steps the most important updates are selected and performed which answers the first sub question. In the third step the excerpts with the same color code are analysed and excerpts with the same meaning are combined. Last, the excerpts are organized in important points per factor of the theoretical framework which answers the second sub question. All data from the three data collection methods are analysed with these four steps. This is possible because each data collection method uses questions to define the result. The third sub question is answered based on the results of the four steps. In the fourth step the barriers are summarized which are the main problems to overcome before the crane model can be fully embedded in the processes of DV. For each problem a possible solution is defined which can solve or decrease the impact of the problem. These solutions are based on possible solutions mentioned during meetings and are discussed with the company supervisor. Figure 4 visualises the steps of the thematic analysis of this research as was also shown in figure 2.

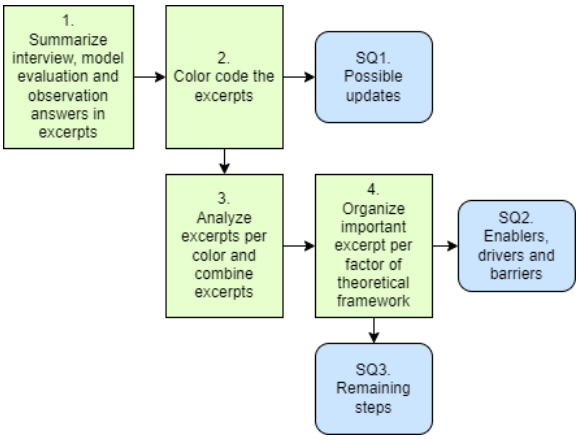

Figure 4 Step thematic analysis

Table 4 Color code factors

Possible update
Enabler
Driver
Barrier

4. Results

This section explains the results of the data collection and analysis methods. The data is collected from four construction projects of DV. The data analysis of one project, Twente is discussed in this section. Appendix E, F and G show the data analysis of the three other projects. Beside the interviews conducted on a project level, there are interviews conducted on a company level which are more about the culture of DV and the tool in general. Appendix H shows the analysis of these interviews.

Section 4.1 describes the results of the steps of the data analysis. Section 4.2 answers the first sub question of the possible updates and Section 4.3 answers the second sub question of the enablers, drivers and barriers. Section 4.4 answers the third sub question by describing the recommended steps to take in the future.

4.1 Results thematic analysis

This section gives a small description of results of the steps of the data analysis of Twente. The full explanation can be found in Appendix D.

The tool is tested in the execution phase based on input of Twente. The construction manager provided a planning for one day with the number of arriving trucks and the number of elements per truck. With this information a day schedule was created with the tool for the model evaluation. The results of de model evaluation were used for an observation on the construction site. During the observation, the reliability of the input data is tested by measuring the movement times per element. Second, the created schedule is compared to the actual arrival and departure times of the trucks. The results of the observation were discussed with the construction manager and the logistics manager. The results show that not all the input is known with certainty and that there are multiple updates possible to improve the results of the tool and to resolve the barriers. The observation showed that the input data was reliable, but the outcome was not the same as the reality due to multiple causes. Some of the causes can be solved by updating the input data and the tool, but part of the causes can also not be influenced by DV. Therefore, these causes form a barrier. The logistics manager named 3 characteristics of this project which make it challenging for the logistics processes. 2 of these characteristics were already implemented in the tool. Therefore, these are coded as enablers. The third characteristic about combining multiple elements in one truck was not implemented in the tool, so it is a barrier and a possible update. The construction manager already named drivers even though he only saw the tool for the first time and never used it. Table 5 shows the answer per question of the data collection methods. The answers are first summarized in the explanation column. The excerpts of the summary are formulated in the next column which are color coded as shown in table 4.

Table 5 Results first round model evaluation, observation and interviews Twente

Model evaluation	
Factors	**Excerpt**
Data	The times of the lifting methods are unsure
	There is no data of all the lifting methods
	The changing times are estimated
	The planning on a day level is known
Output quality	**The day schedule is too exact by using minutes**
	The days are independent which is not true
	The unloading time of self-unloading trucks is incorrect
Ease of use	**The causes of a non-feasible solution are unknown**
	There is no possibility to manually fill in the movement times
	There are no variable working hours on a day
Result demonstratability	The results are compleet
	The results are presented in a good overview
Observation	
Factors	**Excerpt**
Data	Most movement times are correct
Output quality	**There is no start up and close up time used**
	The output of the tool does not align with reality of which the causes cannot always be influenced by DV
Interview construction and logistics manager	
Factors	**Excerpt**
Rules & regulations	There is little storage space which is included as a constraint in the model
	The changing times are high which is included as a constraint in the model
	Different type of materials are combined in one truck which is not possible in the model
Culture of innovation	The day schedules are needed by all construction employees on site
Employee skills & knowledge of the product	**The skilllevel of the crane operator is not used**
Output quality	In theory the results are correct, but not necessarily in practice
	The exceptions of deviations from the standard are not taken into account
Result demonstratability	The results are compleet
	There is no information about the type of truck in the day schedule
	There are no breaks shown in the day schedule of the cranes
	There is no difference between the needed and minimal number of crane hours
Compatibility	The results align with the expectation of the employee
Performance expectancy	The day schedule is automatically created
	The tool makes learning easier
	The tool improves standardisation

Table 5 showed that there are multiple possible updates for the next versions of the tool. The named updates were implemented in the second version of the tool except for including the skill level of crane operators since this was not considered relevant by all employees. Version 2 was tested with the input data for the block of five houses. All, the input data was available from an overview sent to the transportation company. During this test the questions of the model evaluation were again answered. The results of the model evaluation were discussed with the construction manager and the logistics manager. Additionally, the results were discussed with the transporter and tested during a second observation. During the observation the movement times were measured again and the created schedule was compared to reality. The results show that certain input is still estimated and that there are still possible updates, but less than during the first round and the results are more realistic. The managers saw no barriers anymore and are very positive about the outcome of the tool. They did not repeat the drivers they already saw, but found a new driver about giving incitement to think about the changing strategy. The meeting with the transporter showed that usually the transporter makes its own planning without

collaborating with the construction company based on their own experience. This is something Dura Vermeer is improving by collaborating with their suppliers and transporters. Overall, the transporter was very positive about this tool and they think that they can also benefit from it. They had a few comments about what can be added which form the barriers. The results of the observation show that a good collaboration between DV and the transporter can improve the productivity of the crane. Table 6 gives an overview of the results of these data collection methods.

Table 6 Results second round model evaluation, interviews and observation Twente

Model evaluation	
Factors	**Excerpt**
Data	The number of trucks is an estimation
	The changing times are an estimation
	The planning is incomplete
Output quality	The results are realistic
	The results are consistent
Ease of use	**The update to combine several type of elements in trucks was not necessary and makes the inputform too complex**
	It is not possible to print dayschedules of multiple days with one click
Result demonstratability	The results are shown in a clear overview
Interview construction and logistics manager	
Factors	**Excerpt**
Output quality	The results are realistic
Result demonstratability	The results are complete
	The results are clear
Compatibility	The results align with the feeling of employees after the adjustments
Performance expectancy	The tool gives incitement to think about the changing strategy
Interview transporter	
Factors	**Excerpt**
Cooperation subcontractors	The supplier creates its own schedule instead of DV who uses the model
	The supplier bases its decisions on experience instead of data
	The supplier can fully adjust to the customer
	DV thinks further compared to other construction companies
	DV steers in making the decisions
	DV thinks further with more calculations
Employee skills & knowledge of the product	The results are clear
Output quality	After a few days, the job becomes easier and the movement times improve which is not included in the model
Result demonstratability	The material to retour to the transporter is not scheduled
	With this tool the supplier also knows what needs to be done per day
Compatibility	The results are similar to what the supplier would expect
Ease of use	It is needed to explain to the employees on site what you are doing by using the model which is not done yet
Observation	
Factors	**Excerpt**
Data	All the movement times are incorrect
Output quality	The schedule set by the transporter is different from the schedule of the tool

The results of this project show that the project can benefit from the tool on multiple aspects which the employees also see, but there are still multiple barriers which hinder the full implementation of the tool.

4.2 Possible updates

This section gives a small summary of the most important updates per version. The full list of updates with explanations can be found in Appendix J. Not all updates are performed. Some updates were not considered relevant and other updates were not essential during this research. The table in appendix J also includes a description of these updates. Table 7 shows the most important updates for each version. In total 5 rounds of updates were performed and each version was finished after two weeks. There were in total 19 updates which were based on data collected on a company level and 16 on a project level. So, updates were needed on both levels. Table 7 shows that the first three versions focus mainly on the

execution phase while the last two versions focus mainly on the preparation phase.

Table 7 Most important updates per version

Version	Important update
1	Round off schedule based on input construction manager
	Define start and end time day in input form
2	Add multiple element to the same truck
	Information about the truck added to the day schedule
	Overview of needed crane hours plus buffers for breaks and set-up time added to graph needed crane hours on a day level
3	Overview of buffers in new pie chart
	Change end date to delivery date on a day level
4	Overview of needed crane hours plus buffers for breaks and set-up time added to graph needed crane hours on a project level
	Take non-workable days into account
5	Show financial benefit for crane operator
	Add possibility for multiple resources

Table 8 gives an overview on which factors the updates were based per version. This table shows that most updates were performed to improve *the output quality, the results demonstrate ability and the ease of use*. The number of possible updates does not decrease after a few versions. This shows that for this tool employees with different functions looked at it from a different perspective and continued on seeing new possibilities.

Table 8 overview factors on which the updates are based

Factor	V1	V2	V3	V4	V5	Total
Rules & regulations		1				1
Knowledge sharing & integration				1		1
Employee skills				1	1	2
Data	1		1			2
Output quality	1		1	2	1	5
Result demonstratability		3	1			4
Ease of use	3	1	1	1	2	8
Performance expectancy		1			1	2
Effort expectation					1	1
Total	5	6	4	5	6	

4.3 Enabler, drivers and barriers

After the data is collected from all the projects and the excerpts are extracted from the answer summaries, the excerpts are analysed per color code which answers the second subquestion. The color represents if the factor is an enabler, driver or barrier. Appendix I gives an overview of all the enablers, drivers and barriers named per data collection method. The paragraphs below discuss the most important results per color on a company and project level. More barriers were found in this research which are not discussed in this section since most of them were already resolved with the performed updates. Other barriers are not named in this section, because they were also named as enablers or drivers. Tables 56, 57 and 58 of Appendix I give an overview of all the barriers and if applicable how they are resolved. There was no clear difference between the results of the preparation and execution phase. Therefore, there is no distinguishment made between these two levels.

4.3.1 Enablers

This section discusses the enablers of the tool. There are more enablers, but this section only discusses the enablers found during this research. The results of the research show that most enablers are on a company level. A construction project can have several characteristics which make it logistically challenging. These characteristics are all included in the tool and therefore are an enabler. The management of DV is working on strategic goals which align with the benefits of the tool. The goals of the innovations are not always financial but also focus on for example safety of employees and making the tasks more enjoyable. This is possible since the employees are very entrepreneurial, but also accept data given by other employees. This is also noticed by the suppliers who are able to adapt to these changes. The tool gives the needed information without extra effort. The results are reliable and clear on a project level. Table 9 gives an overview of the enablers of this research.

Table 9 Important points which form the enablers of this case study

Company level	
Rules & regulations	The needed characteristics of the construction site for the logistics processes are taken into account
Culture of innovation	DV puts effort in internal cooperation
	The strategic goals of DV align with benefits of the tool
	DV has enterprising employees
Financial benefit	DV has non-financial goals
Cooperation subcontractors	Suppliers can adjust to the needs of DV
Knowledge sharing & integration	Employees use and accept experience numbers
Performance expectancy	The tool gives input of important decisions
Effort expectation	The tool does not require extra effort
	Information of the volume model is easy to copy
Project level	
Employee skills	The tool is clear
Data	The created data is reliable
Output quality	The results are logic
	The results are realistic
Result demonstratability	The results are complete
	The results are clear and presented in a clear overview
Compatibility	The results are credible

4.3.2 Drivers

The results of the research show that again most drivers are on a company level. The drivers are solely

based on the interviews since the model evaluation and observations did not show any drivers. A strategic goal of DV is to increase the use of data which can be achieved by using the tool. The use of data will also increase the standardization and automation of processes in the company which enables the company to also learn more about the decisions they made. The tool gives results based on data which incite the employees to think about possible improvements based on their experience. Additionally, the output of the tool is needed for nitrogen legislation. During this research a new law about nitrogen emission was introduced. For this law the number of productive hours per resource on the construction site is needed. Therefore, this tool became very valuable for the company and the idea arose to use the tool for multiple resource. On a project level the tool gives output to automate decisions which helps everyone on the construction site. The factor performance expectancy is mainly used to define the drivers on a company and project level. This is because the tool gives outputs which can be used to improve multiple jobs. Table 10 gives an overview of the drivers found in this research.

Table 10 Important points which form the drivers of this case study

Company level	
Rules & regulations	The output of the tool is needed for the nitrogen legislation
Culture of innovation	The tool enlarges the use of data which is one of the strategic goals of DV
Cooperation subcontractors	Incite to optimze the logistics process
Performance expectancy	Learning on project level
	Improve standardisation
	Decision making based on a combinations of experience and data
Image of product	Performance focussed steering
	Next step after full implementation of existing tools
Project level	
Culture of innovation	Usable output for everyone on the construction site
Financial benefit	Resource to catch up on the planning
Result demonstratability	Shows per day what needs to be done
Performance expectancy	Automatic optimal dayschedules
	Learning on day level
	Calculates day capacity

4.3.3 Barriers

In contrast to the enablers and drivers, most barriers are on a project level for this research. On a company level the main barrier is that the digitalization level is not as high as required for the tool. As a consequence, knowledge is also often shared in cooperation instead of with documentation which would make sharing knowledge among employees and projects faster. On a project level an important barrier is the dependence on other stakeholders such as the suppliers. Additionally, there is not enough data to demonstrate the generalizability and to prevent the use of estimations. Excel is also limited in improving the user-friendliness and the integration with other software programs to decrease the amount of double work. Table 11 shows the results of the barriers of this case study.

Table 11 Important points which form the barriers of this case study

Company level	
Culture of innovation	The digitalisation level of the company is not ready
Knowledge sharing & integration	Knowledge is generally shared in cooperation
Project level	
Rules & regulations	Outcome dependent on suppliers
Employee skills	Doubt generalisation input values
Compatibility	
Data	Multiple input values are an estimation
Output quality	The output is correct in theory, but the reality is different
Ease of use	Limitations Excel
	Double work

A lot of barriers were found during the model evaluations which used yes or no questions. The biggest barriers are formed for the factors *data and output quality* as was also concluded in Table 11. This was also not improved after updates of the tool. So, these are important barriers to solve in the next steps of the implementation process of the tool. Table 12 shows the division of the answers given as a percentage.

Table 12 Overview division answers model evaluation

Factors	Question	Answers	
		Yes	No
Data	Is the data reliable and available?	13%	88%
Output quality	Are the results consistent and realistic?	38%	63%
Ease of use	Is the tool easy to use?	75%	25%
Result demonstratability	Are the results presented in a clear overview?	100%	0%

4.4 Recommendation

Section 4.2.3 showed that there are still multiple barriers which need to be solved. This section describes several possible solutions for the remaining problems which form the recommended next steps for DV. Appendix K gives a more extensive description of each step.

A reoccurring problem is a *lack of data*. The number of movements per truck and the used lifting method was in multiple projects an estimation. Therefore, a recommendation is to do more observations in the execution phase such that the predictions in the preparation phase can be improved and the generalization of the data can be proved. The data of movement times is based on a certain way of working which is not documented. By creating clear working instructions, the process is documented and it is easier to see where the process of the project deviates from the standard process.

Excel has multiple limitations which disable the possibility to improve the user-friendliness and the integration with other applications. Currently, a new application is created for the volume model and the transportation management system already has its own application. Therefore, it is recommended to add the crane model to these applications. The introduction stated that in the future the tool should be independently used by the end-user. During this research it was noticed that it is hard for employees to use the tool in Excel without proper explanation of the limitations of Excel. Therefore, the tool was generally filled in by the researcher. While Excel is still used for the model, it is recommended that the main users are the logistics managers since they are better trained and informed about the model. They can first fill in the tool and share the results with the end-users who can afterwards adjust the model and create several scenarios to improve their decisions.

There are several other problems which form barriers for the implementation process of the tool such as the digitalization level of the company, the dependence on the suppliers and the way of sharing knowledge. Table 13 gives an overview of the problems which are based on the barriers found during this research. For each problem, possible next steps are described which can solve or decrease the impact of the problem. For each step it is indicated if the step is essential for the implementation of the tool. It is recommended to the company to follow these steps when fully implementing the tool.

Table 13 Recommendation points

Number	Problems	Possible next steps	Essential
1	The digitalisation level of the company is not ready	Cooperate with digitalisation team	no
2a	The data set is not complete	Perform observations to measure the movement times of more lifting methods	yes
2b		Create work instructions for the execution phase	no
2c		Find and document deviations from the model to learn and be able to predict deviations	no
2d		Document and request information about the movements per truck	yes
3a	Limitations of Excel	Let the logistics manager fill in the input form and let the end-user adjust the input	yes
3b		Add the crane model to the application for the volume model and the transportation management system	yes
4	Depence suppliers	Increase cooperation suppliers	no
5a	Sharing knowledge in cooperation	Use the model to optimize projects and not only for logistics challenging projects	no
5b		Create an overview of the goals and next steps for the logistics department	no

This section showed that the tool can contribute to the goal of DV to improve the productivity of cranes, but also has multiple other advantages which form the drivers to continue with the implementation of the tool. The tool can already be used on a micro level by using it for a few projects, but not on a macro level for all projects of DV since there are still several barriers which need to be solved. These barriers can be solved by following the steps explained in the recommendation which will improve the performance and acceptance of the tool.

5. Discussion

This section discusses the results of Section 4 and compares them to the results of the literature review. Section 5.1 evaluates the differences between the performance and acceptance factors for the enablers, drivers and barriers and evaluates if the tool is ready to be embedded in the processes of DV. Section 5.2 compares the results with similar studies of logistics processes and of the construction industry to evaluate the influence of the context of the tool. Section 5.3 discusses the limitations of this research and possibilities for further research.

5.1 Discussion results

The factors of the theoretical framework were based on the performance and acceptance of innovations. This section discusses the results to analyse the difference between the use of performance and acceptance factors for the enablers, drivers and barriers. The factors which influence the performance of the tool were named as an enabler mostly on the company level. These also include the factors for the logistics performance. The factors which describe the acceptance of the tool were also named as an enabler, but on the project level. This shows that the performance is good on a company level and that the tool is accepted on a project level. The performance and acceptance factors are named on both levels for the drivers. There were no logistics factors named as a driver which shows that employees do not think from a logistics perspective. The crane model was initially developed to improve the productivity on the construction sites, but this was never mentioned as a driver to use the tool. The barriers also consist of performance and acceptance factors spread over both levels including the logistics factors. So, the performance and acceptance can still be improved on both a company and project level, but they also form drivers on both levels. The performance is more important to define the enablers on a company level and the acceptance on a project level.

There were no factors in the theoretical framework to define that the tool was developed for the construction industry, only the division of the factors between the company and project level. There was a clear difference between these two levels which made this a useful division. There was also a division made between the preparation and execution phase of a project, but there was no clear difference between these phases regarding the acceptance of the tool. The employees of both phases experienced the same kind of enablers, drivers and barriers. They suggested different updates, but for the same factors of the theoretical framework. Noktehdan, Shahbazpour, Zare, & Wilkinson (2019) discuss the opposite in their research in which they explain the difference between the resources and constraints of innovation in the different construction phases. They argue that the construction phase has less new innovations, but focusses more on sharing knowledge. There was not a different approach used for the preparation and construction phase for the implementation of the crane model which was also not needed according to the results of this research. This difference can be a result of the focus on the operational logistics processes of the tool.

The tool was initially created to answer a question of multiple employees. Therefore, it is a *bottom-up innovation*. The enablers proved that the organization supports these type of innovations, but a lot of effort is required of the employees. Gaynor (2013) stated that a bottom-up innovation eventually becomes a *top-down innovation* when the feasibility is proven. In this research the feasibility is proven. So, the next step is to make it a top-down innovation which also allows the tool to be fully embedded in the processes of the company as was the goal of this research. This step is also included in the recommendation by creating a vision for the logistics of DV.

Except for the factor facilitating conditions, the two other logistics tools, the volume model and the transportation management tool were not mentioned in the interviews. The employees did not relate the tool often to the two other tools except if this was asked in a question. Employees do not think about how they can improve their entire logistics processes but about how they can improve one decision. *System thinking* would help to let the tool improve the entire environment of DV as this theory looks at the world in terms of wholes and relationships instead of splitting it down in parts. Al-Raqadi, Rahim, Masrom, & Al-Riyami (2016) stated that System thinking is important and needed in learning and knowledge sharing which is also an important driver for this tool. Therefore, developing a culture of System thinking would improve the implementation process of new logistics tools within DV.

5.2 Discussion research context

Section 2.2 described two studies which also looked into the enablers, drivers and barriers of innovations in other contexts. This section compares these results with the results of this research to evaluate the influence of the research context. Perotti, Santacruz, Bremer and Beer (2022) did this for innovations of logistics processes and Ozorhon, Oral and Demirkesen (2016) did this for innovations in the construction industry. Table 1 and 2 summarize their findings. When comparing these results with the results of the research, it can be seen that there are many new factors found in this research. The enablers named in both studies are almost all used in this research except for commitment and reward schemes which were not mentioned in this research. This is because the use of this tool is not obligated for an employee and the

financial reward for a project is hard to measure. The drivers of the logistics research were all not mentioned except for process optimization which aligns with the results of Section 5.1. Half of the drivers of the construction research was mentioned, but competition level, corporate responsibility and environment & sustainability were not mentioned while they are also relevant for the tool. This is because the employees only looked at the improvements for their decisions instead of the improvements for the entire environment of DV as was also mentioned in Section 5.1. The drivers of the tool were more focussed on the work of the employees instead of the relevance for the whole company. The barriers of the logistics and construction studies were not mentioned except for obsolete infrastructure, companies are not ready for advanced technologies, unsupportive organizational culture and lack of experienced staff. While these barriers are not directly mentioned, they overlap with some mentioned factors. These factors are complemented with multiple barriers on a project level. So, this research found a lot of new enablers, drivers and barriers and the results do not match more with logistics innovations or construction innovations except for the drivers which match more with construction innovations.

5.3 Limitations and further research

Unfortunately, it was not possible to talk to the management of the suborganizations about their strategy choices regarding the logistics processes during this research. Therefore, employees on a tactical and operational level were interviewed about the strategic choices of the management. For this research this was a suitable alternative, but in the next steps of the implementation phase when the innovation becomes top-down, it is important to include the management.

The results of this research showed that the drivers do not include logistics factors. Employees do not directly see the added value of improving the logistics processes. This is also partly due to the difficulty of showing the financial benefit. Therefore, in further research it is important to investigate how to show the added value of optimizing the entire logistics process of a construction project instead of the benefit of one tool as was done in this research.

For logistics 4.0 it is important to have a good data set to make reliable predictions and to automate the process. In construction it is often a challenge to collect data, since the process times for example have to be manually measured during observations and the crane activities are not always documented. Therefore, in further research it is important to evaluate how this data can efficiently be collected such that it can be used for logistics 4.0 techniques.

6. Conclusion

The first sub question of this research focussed on *the updates of the crane model*. The most important updates are shown in Table 17 which focussed both on the preparation phase and execution phase. The number of updates collected from data on a company level is similar to the number on a project level. There were several versions made of the tool, but for all versions new possible updates were mentioned which were mainly about the factors *output quality, result demonstrability and ease of use*. People continued seeing new possibilities as can also be seen in the drivers. The initial goal of the tool was to improve productivity on the construction site, but while developing and updating the tool new possibilities arose. The tool still has multiple possibilities to continue growing and giving more benefits to the employees such as showing more financial benefits and predicting deviations from the standard process.

The second sub question of this research focussed on defining the *enablers, drivers and barriers* of which table 13, 14 and 15 give an overview. These tables showed that performance is important for the enablers on a company level and the acceptance is important on a project level. Performance and acceptance are important on both levels to define the drivers and enablers. There was a clear difference between the company and project level which is a characteristic of the construction industry. There were no differences between the results of the preparation phase and the execution phase. The logistics factors such as data were named as enablers and barriers, but not as drivers which shows that employees do not think from a logistics perspective. The tool was seen as a resource to improve decisions instead of improving their logistics processes of the total construction process which is done in system thinking. The results of this research did not match the results of studies in a logistics or construction context except for the drivers which matched with the construction research. This research showed that there are a lot of enablers and drivers to continue with the implementation of this tool, but there are

also several barriers which still need to be solved before the tool can be fully embedded in the processes of DV.

The third sub question of this researched focussed on *the next (essential) steps* of the implementation process. Table 18 shows which next steps are recommended in this research. More than half of the steps are essential and are based on multiple barriers. The tool is ready to be used, but not independently by the end-users. Therefore, it is recommended to let the logistics managers fill in the tool first and let the employees of the projects adjust the input if needed. Additionally, it is important to continue collecting more data to make better predictions in the future and to increase the acceptance of the generalizability.

This research defined the problems which DV faces when implementing the crane model, but also the benefits of the model. An important benefit of the model is an increase in the standardisation of the decisions made in the preparation phase and the processes on the construction site which is a long-term goal of DV as mentioned in Section 1. The goal of this research was to define the steps to embed the model in the processes of DV. Several updates were performed to improve the tool and several benefits were found to convince the management to embed the tool in the processes of DV. There are still barriers on multiple levels within the company involving different people. Therefore, there are multiple focus points for the future which improve both the performance and acceptance.

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Appendix A Set-up theoretical framework

Based on the literature review, a theoretical framework is formulated. With the theoretical framework the performance and acceptance of a new technological tool will be evaluated. The innovation will be measured as proposed by Ozorhon, Oral and Demirkesen (2016). Based on the factors named in the theoretical framework, the barriers, enablers and drivers will be defined. Since this is a tool to improve the logistics processes of a construction company, the framework is adjusted to the research context. The framework is created by combining several theories explained in the literature review. This section describes how the framework is set-up and on what theories it is based. The first paragraph describes the baseline of the framework. The remaining paragraphs describe the adjustments for the research context.

The baseline of the theoretical framework is based on the theories of Dasgupta, Gupta, & Sahay (2011). As described in Section 2.1.1, technological innovation is closely related to technology strategy and organizational factors. Technology strategy is related to the choices a company makes in its external environment. Dasgupta, Gupta, & Sahay (2011) showed in their research that technical innovation is influenced by the rules & regulations in their environment and the decisions of the top management. The influence of the top management can be split in the attitude of the top management towards innovation and the allocation of the financial resources. Organizational factors are about the learning & development of employees and the communication with and learning from suppliers and customers. In the case of a construction company these are mainly the subcontractors. Dasgupta, Gupta, & Sahay (2011) explained that the integration of explict and tacit knowledge and the sharing of knowledge is important for the learning and development of employees. Additionally, an employee needs to have the skills to tryout and test new tools. Figure 5 visualises the relation between the factors influencing technological innovation. This figure is created during this research, but adapted from the theories of Dasgupta, Gupta, & Sahay (2011).

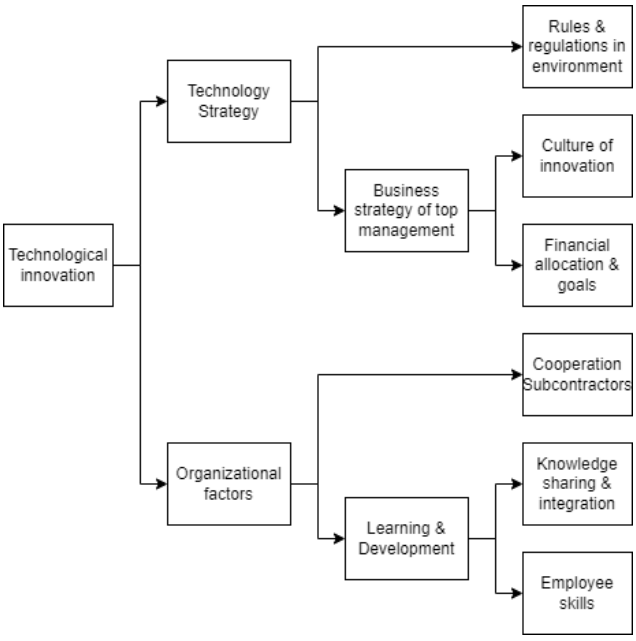

Figure 5 Theoretical framework technical innovation adapted from Dasgupta, Gupta, & Sahay (2011)

The new tool is used for improvements of logistics processes. Therefore, the framework should be adjusted to logistics processes innovations. Figure 6 shows the framework of figure 5 adjusted for logistics processes innovations based on the research of Facchini, Olésków-Szłapka, Ranieri, & Urbinati (2020) about logistics 4.0. To evaluate the logistics processes of a company, these are split into different dimensions. Logistics 4.0 can be split in the macro-dimensions: Management and flow of material and information. Management and flow of information are already incorporated in the framework, but flow of material is added to the framework as resources. The sub-dimensions of Logistics 4.0 are: knowledge, strategy and leadership, employees, IT systems, smart products, smart warehouses and technologies. Knowledge and strategy and leadership are already incorporated in the framework by learning & developments and business strategy of top management.

Employees and smart products are related to the resources of the company. Smart products is split in data and product since smart products are not common in the construction industry. This way, the data aspect can get more focus in the research and the product can be tested separately on the acceptance. Smart warehouses and technologies is not incorporated in the framework since this is less relevant for construction companies. Similarly, IT systems is not incorporated since this is partly covered by the factor data and not relevant enough for this tool to put more focus on.

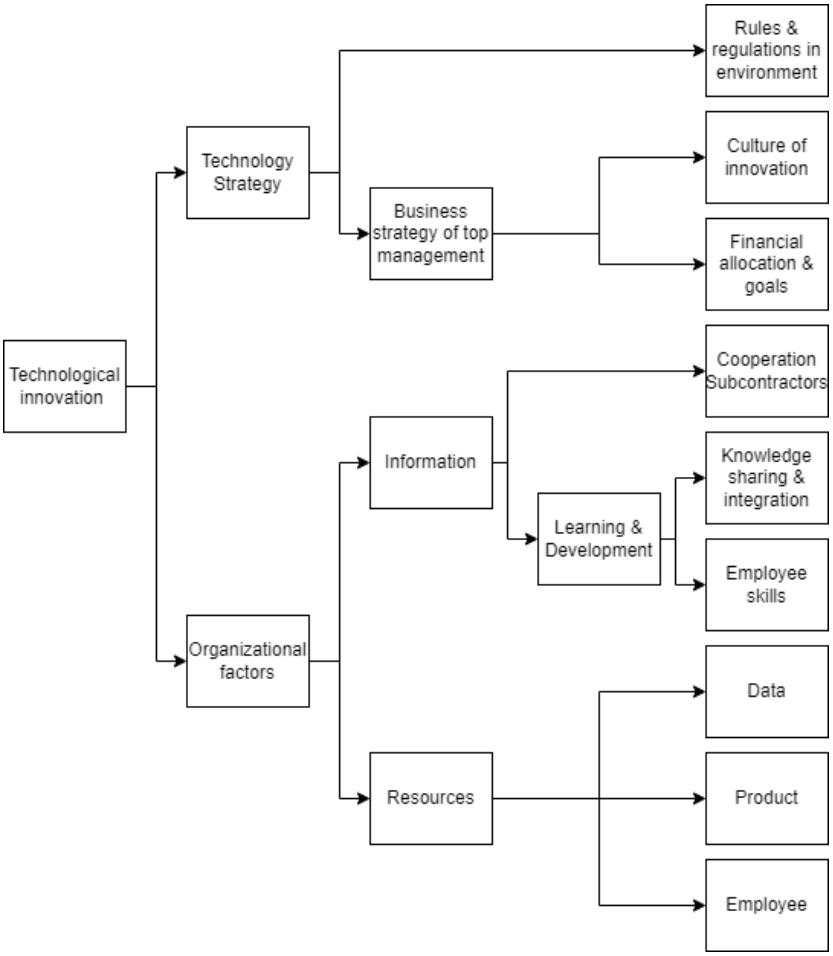

Figure 6 Theoretical framework technical innovation for logistics processes adjusted based on Facchini, Olésków-Szłapka, Ranieri, & Urbinati (2020)

Section 2.1.3 described the characteristics of the construction industry. This section described that the construction industry is project based (Janné & Fredriksson, 2018), but the tool is used to create more standardization in all the projects of the company. Therefore, it is important to analyse the results of the factors influencing the innovation on both a company and a project level (Ozorhon, Oral, & Demirkesen, 2016). The new tool is applicable in the preparation and execution phase of construction projects. Therefore, the project level is split in preparation and execution. Figure 7 gives an overview of the levels of the results. This overview is created during this research based on the research of Janné & Fredriksson (2018).

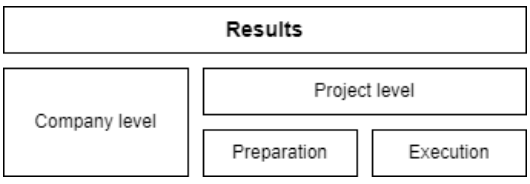

Figure 7 Categories of the results based on Janné & Fredriksson (2018)

The framework of figure 6 is mainly based on improving the performance of the crane model, but in this research, it is also important to improve the acceptance of the tool. Therefore, the framework is adjusted to include factors

which indicate the acceptance of the tool. The adjustments are based on TAM, UTAUT and Theory of Diffusion described in Section 2.2.3. All factors named in the three theories are included in the framework. When there is a big overlap between the factors of the theories, only one is named in the framework. The factors are divided between the employee and product based on which needs to change to improve the acceptance.

Figure 8 shows the final framework of this research. The framework shows on which factors the implementation process of the crane model will be tested and in which categories the results will be divided.[1]

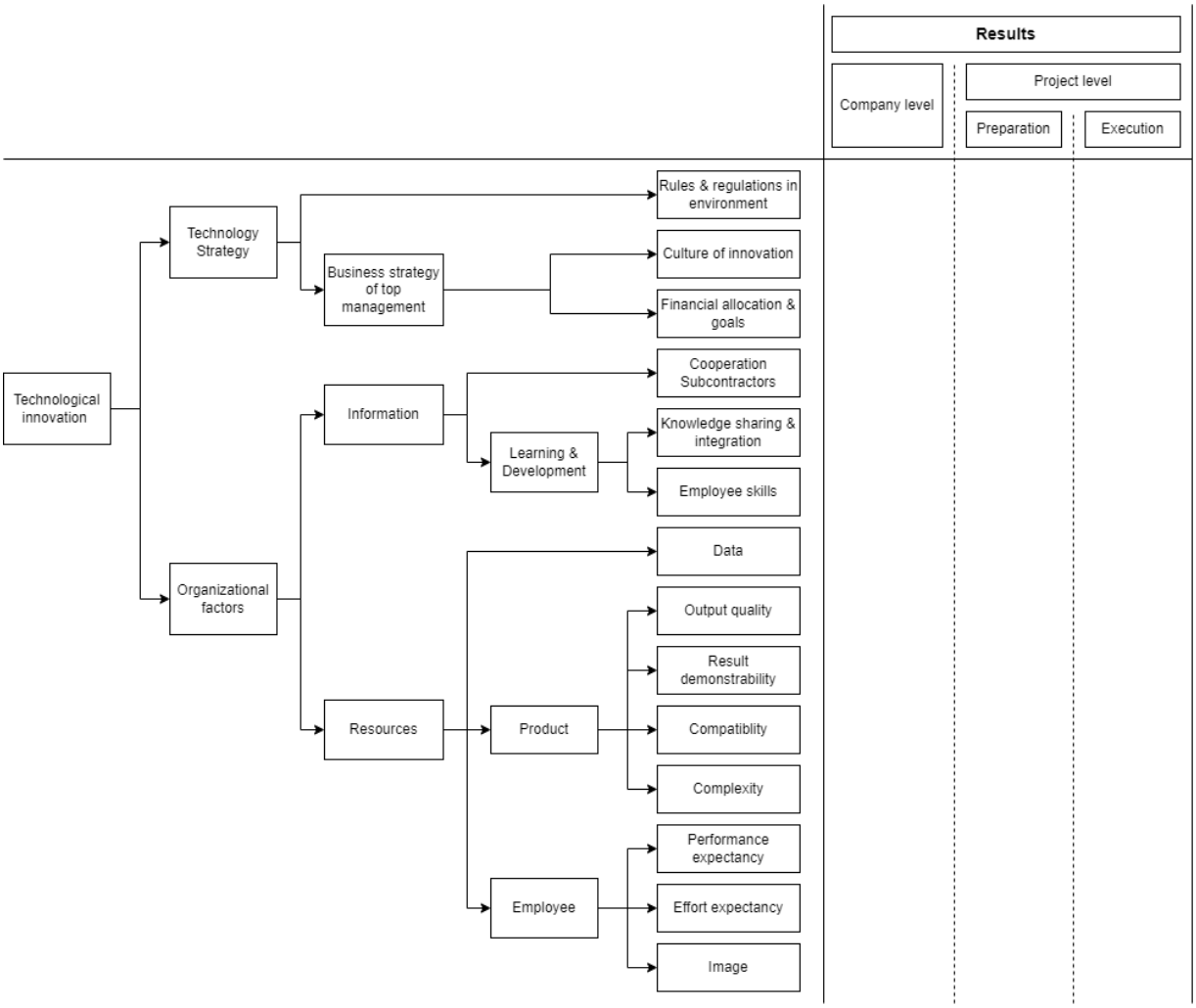

Figure 8 Final theoretical framework adjusted based on TAM, UTAUT and Theory of Diffusion

[1] This framework was discussed with the company supervisor and the logistics manager of DVBMW to check if they agree with the completeness and relevance of the factors of the framework based on their experience. They both agreed on the set-up of the theoretical framework.

Appendix B Description Logistics Tools

This appendix describes the three logistics tools used in this research. The volume model and the transportation management tool are briefly explained to give more context for the research. Since the crane scheduling tool is the main topic of this research, this tool is extensively explained.

The volume model

The volume model is used to calculate the number of arriving trucks which is done in Excel. First, all the objects in the building are chosen which results in the parameters of the building build. Next, all the information about the needed materials and their type of transportation needed is extracted. The materials each have characteristics which define their total volume. By using the total amount needed and the volume of one unit, the total volume of the material flow can be calculated. By adding the type of transport, the total number of trucks can be calculated. From the planning is extracted how much time each material has to be placed in the building. With this information the number of trucks in time can be calculated. Figure 9 gives an overview of the parameters in the calculation. These calculations are currently done in Excel, but a new tool is developed to increase the user-friendliness. The input is filled in by the logistics manager in cooperation with the project organisers. With this tool the busy periods can be defined and the CO2 emissions can be calculated (Dura Vermeer Bouw Hengelo, 2022).

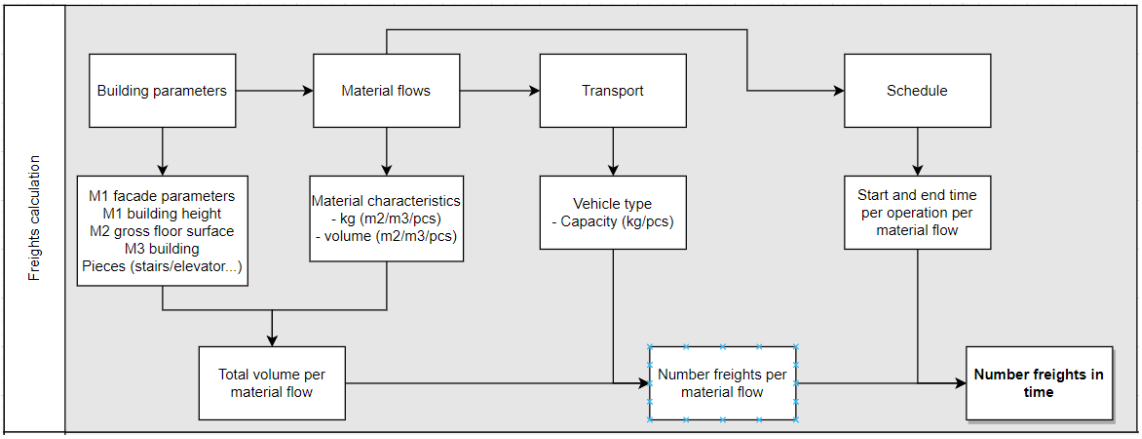

Figure 9 Parameters of the volume model and their relations (Dura Vermeer Bouw Hengelo, 2022)

The transportation management tool

In the transportation management tool, an overview is created of all the arriving trucks to the construction site per day on an hour level. The supplier can either fill in the expected arrival time themselves or they get a timeslot assigned by the construction manager. Every arriving truck gets a ticket which specifies the arrival time. When the truck arrives on site, a QR code on the ticket will be scanned to document the actual arrival time. This way, the system gives more insight in the delivery performance of the trucks of a supplier. Additionally, the schedule of a crane can be manually created and the occupation of the storage and unloading places can be manually filled in. Figure 10 gives an overview of a day schedule in the transportation management tool of one of the projects of DVBH. More and more projects are now using this new system whereby the logistics manager gains more data about the performance of suppliers and the use of the transportation management tool (Dura Vermeer Bouw Hengelo, 2022).

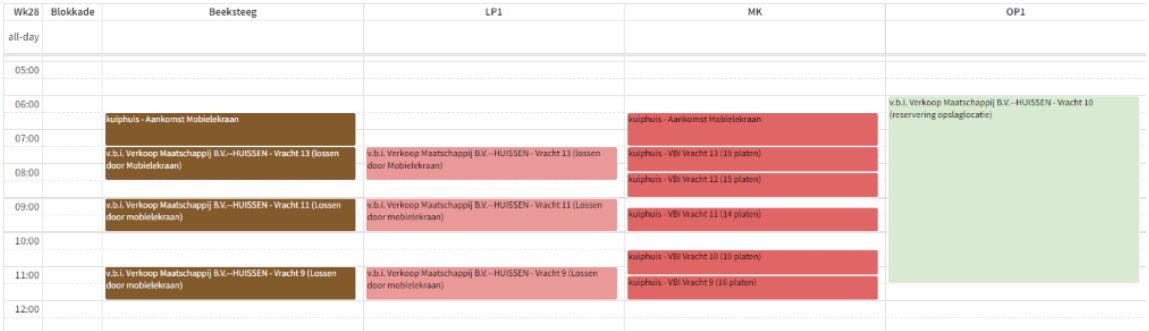

Figure 10 Day schedule in the transportation management tool for a project of DVBH (Dura Vermeer Bouw Hengelo, 2022)

Crane scheduling tool

The goal of the crane scheduling tool is to predict the number of needed crane hours of a construction project in the preparation phase and the needed number of cranes per day in the execution phase. Additionally, the tool calculates the productivity of the cranes in both phases. The crane scheduling tool is based on information from the volume model, the construction site characteristics and the reliability of the suppliers. With the output of the tool the days with low estimated productivity can be defined and the planning can be adjusted to improve the productivity of cranes on the construction site. The tool is also able to create a schedule for the arriving trucks per day. This schedule is created automatically and can serve as input for the transportation management tool. The sections below describe more extensively the input needed for the tool and the output given by the tool.

Input

There are three sheets which require input from an employee of DVBH. The first and second input sheet contain information about the trucks per construction task and the characteristics of the building site. The first sheet needs to be filled in by the project organizer and the second by the construction manager. The third input sheet requires information about the suppliers and their reliability. This sheet needs to be filled in by the logistics manager.

The first input form includes information about the building tasks which includes: the start and end date, the number of trucks in total, the supplier and the volume. The planning and number of trucks are used to calculate the number of trucks arriving per week. The supplier is used to take the reliability into account. In case a supplier is very unreliable, extra crane hours are added to also rent a crane when the trucks arrive too late. The volume is used to check if there is enough storage space on the construction site. All this data can also be extracted from the volume calculations. The project organiser needs to fill in additional data about the movement time, the percentage of self-unloading trucks and the percentage of cranes needed for the movement of the construction task. Therefore, these are highlighted with a different color. Figure 11 shows what this input form looks like in Excel.

Input calculation model									DURA VERMEER				
Construction task		Start day	End day	Building period in weeks	Number of trucks	Supplier	Possible deviations supplier	Volume	Movement time (minutes)			Self-unloading trucks (%)	Crane needed (%)
									Hook-up	Movement	Disconnection		
Site	Material												
	Pit												
	VBI												
Demolition	Demolition												
Ground	Ground												
Pile driving	Pile driving												
Foundation	Beams												
	Elevator pit												
	Piles												
Basement	Floor												
	Walls												
	Partition walls												
	Columns												
	Beams												

Figure 11 Input form trucks per construction part (Jansma, 2022)

The project organisers also need to fill in data about the characteristics of the building site. These are: the storage capacity, the number of unloading areas and the number of waiting spots. Lastly, the minimal rental period, the maximum waiting time of trucks and the maximum overtime need to be defined. Figure 12 shows what this looks like in Excel.

Site characterisitcs			Other	
Storage capacity			Crane rental period (hours	
Number of unloading spots			Maximum waiting time truck	
Number of waiting spots			Maximum overtime	

Figure 12 Input form site characteristics (Jansma, 2022)

The input form for the construction managers is similar. The characteristics of the construction site cannot be changed anymore during the construction phase. Therefore, these are not included in the input form of the

construction managers. Additionally, at this phase of the project a more detailed planning is known. Therefore, compared to the project organisers input form, the construction tasks and their start and end time are more detailed. The reliability of the suppliers is not included in the input form of the construction manager since in this phase it is assumed that the supplier will arrive on time.

The logistics manager can get information from the transportation management system about the reliability of suppliers. The KPI codes define how much the truck deviates from the scheduled arrival time. The logistics manager can continuously update this information when new data is acquired. Figure 13 shows the table in which this can be filled in. The logistics manager can fill in the number of observations for a KPI code per supplier. The Excel file will automatically calculate the number of possible deviations and fill this in in the input form of Figure 11.

Supplier	KPI codes					Number of Deviations
	4a	2a	1	2b	3b	

Figure 13 Input form suppliers (Jansma, 2022)

Output

The output of the dashboards can be used by the project organisers and the construction managers. The paragraphs below describe the output for these functions.

Project organisers

The project organisers indicated that they need to know how many hours a crane is needed. They need this information to know how high the budget should be set for the rental of cranes. Additionally, the productivity of these cranes is required to see what hours the crane is not working which is used as a buffer for cleaning the site or being used by sub-contractors. This is shown per week as the average per day. Figure 14 shows what this looks like in Excel. This sheet also shows the results of the calculation for the number of trucks per construction task per week. The sheet contains a button which the project organisers can use to update the result. This button is connected to the VBA code which runs the algorithm for the project organisers.

	Week	23	24	25	26	27	28	29	30	31	32
	Year	2021	2021	2021	2021	2021	2021	2021	2021	2021	2021
	First day of the week	08-06-2021	15-06-2021	22-06-2021	29-06-2021	06-07-2021	13-07-2021	20-07-2021	27-07-2021	03-08-2021	10-08-2021
Site	Material										
	Pit										
	VBI										
Demolition	Demolition										
Ground	Ground										
Pile driving	Pile driving										
Foundation	Beams										
	Elevator pit										
	Piles										
Basement	Floor										
	Walls										
	Partition walls										
	Columns										
	Beams										
Productivity											
Number of crane hours per day											

Calculate productivity

Figure 14 Output sheet project organisers with productivity and number of needed crane hours per day (Jansma, 2022)

Figure 15 shows the second output sheet for the project organisers. In this sheet the project organisers can fill in when they think a crane is needed and for how many hours. With this information the graph will be updated and a visual is made to see if the number of hours indicated by the project organisers is more than the needed number of hours according to the dashboard. When the costs are also filled in per crane, the total costs can be calculated. Lastly, this sheet also shows the difference between the number of hours for which the budget is set to rent a crane and the number of hours a crane is needed according to the dashboard.

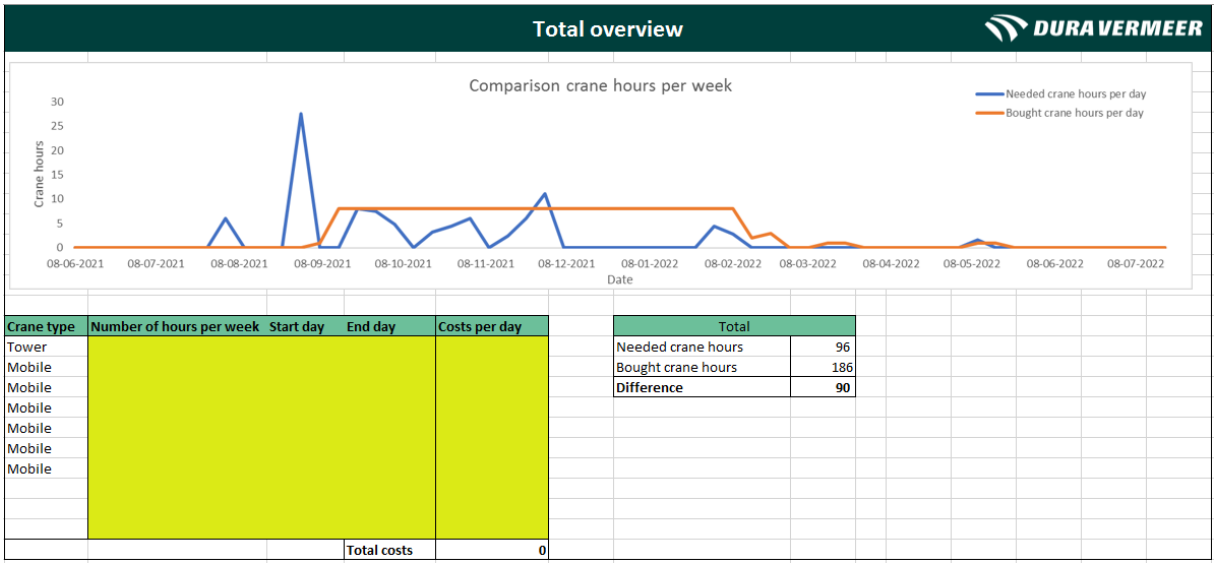

Figure 15 Comparison budgeted and needed crane hours (Jansma, 2022)

Construction managers

The output sheet for the construction managers is the same as for the project organisers, but here the output is shown per day. In meetings with construction managers, they indicated that they need to know the number of cranes, the number of hours it is needed and the productivity of this crane. Therefore, the number of needed cranes is added to the output sheet.

The construction managers can see on a different output sheet what a good schedule for the day would be. Figure 16 gives an example of such a sheet. The construction manager can fill in the date of the day for which he would like to know the schedule. After pressing the button, Excel will update the number of trucks and their scheduled arrival time according to the best found solution. Additionally, Excel will show the number of cranes needed and their start and end time.

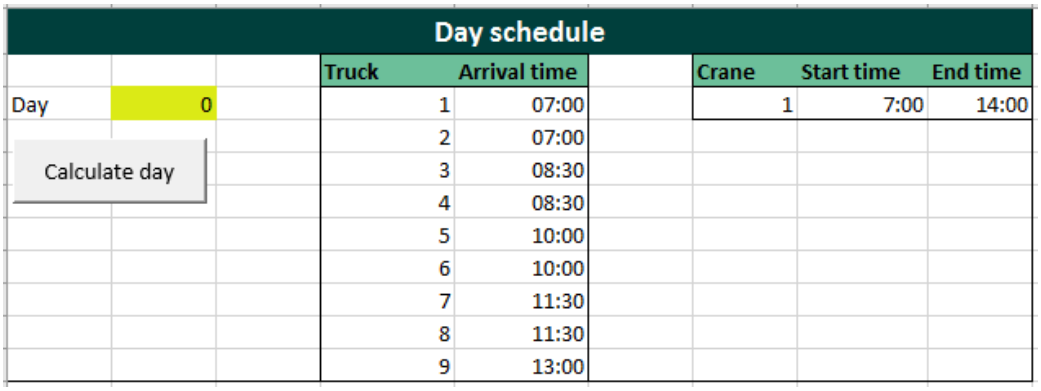

Figure 16 Output sheet which contains the day schedule (Jansma, 2022)

Appendix C Data Collection methods

Interview protocol

Introduction:

- *First meeting*, Currently I am working on my thesis at the logistics department of DVBH. In my previous thesis I developed a crane scheduling tool which can be used on two levels. On the project level, the tool can calculate the needed number of crane hours for a whole project and on the day level, the tool can calculate the needed number of cranes and the corresponding schedule for the crane. During my second thesis I want to analyse how this tool can be best implemented. Therefore, I am currently testing the tool on multiple projects and asking for feedback.
- *Follow up meeting*, In the period between this meeting and the previous meeting I have worked on…. This includes the following points you mentioned during the previous meeting….

Goal:

- *Feedback model*, during this meeting I would like to explain the tool to you and ask for your input about the input and output of the tool.
- Feedback results, during this meeting I would like to show you the results of the tool based on the input you have given previously. I would like to know if these results are realistic and if you have input on how to improve the performance of the tool.
- Other, ….

Interview questions:

Factors	Interview vragen
Rules & regulations	Is er wetgeving met betrekking tot logistieke processes in de bouw en geeft de regering steun hierin?
	In welke bouwprojecten wordt het logistieke team betrokken?
Culture of innovation	Hoeveel is DV bezig met innovatie?
	Heb je het met werknemers over logistieke processen?
	Wat is de houding van medwerkers tegenover innovatie?
Financial benefit	Zijn de doelen van DV gericht op financiële winst of zijn er ook andere doelen?
Cooperation subcontractors	In hoeverre ben je als leverancier bezig met de logistieke processen op de bouwplaats en waarom?
	In hoeverre kun je als leverancier je werkwijze aanpassen voor logistieke optimalisatie?
	Watvoor verschil merk je tussen DV en andere bedrijven in logistieke processen en eisen?
Knowledge sharing & integration	Hoeveel kennis haal je uit ervaring en hoeveel uit documenten?
	Hoe deel je je eigen kennis?
Employee skills	Wat is nu onduidelijk aan het model? Welke kennis mis je?
Output quality	Zijn de resultaten realistisch?
Result demonstratability	Welke resultaten mis je nog?
	Zijn de resultaten van het model duidelijk?
Compatibility	In hoeverre komen de resultaten overeen met je gevoel?
Ease of use	Wat zou je verbeteren aan de gebruiksvriendelijkheid?
Performance expectancy	Watvoor voordeel haal je nu uit het model en wat wil je eruit halen?
Effort expectation	Komt de tijd voor het invullen die je denkt kwijt te zijn overeen met de tijd je ervoor over hebt?
Image of product	Wat denk je dat het model in de toekomst kan bieden?

Closing:

Thank you for the input you gave. I will discuss this with my supervisor and implement the recommended changes if possible. When I have finished a new version, I will let you know and inform you about the new results.

Figure 17 Interview Protocol

Table 14 Overview functions interviewees

Interviews			
Function	**Company level**	**Project level**	
		Preparation phase	**Execution phase**
Project organiser	3	3	
Construction manager	1		3
Logistics manager	1	1	2
Project leader	1		
Improvement manager	1		
Supplier			2
Information manager	1		

Table 15 Questions for the observations

Factors	Observatie vragen
Employee skills	Begrijpt de werknemer de tool en kan hij/zij ermee omgaan?
Facilitating conditions	Kunnen de mogelijke koppelingen gemaakt worden en zijn alle technische eisen mogelijk?
Data	Is alle data betrouwbaar en beschikbaar?
Output quality	Komt de output van de tool overeen met de realiteit?
Ease of use	Is de tool makkelijk te gebruiken voor werknemers?
Triability	Kunnen alle werknemers de tool testen?

Table 16 Questions for the model evaluation

Factors	Data analyse vragen
Data	Is alle data betrouwbaar en beschikbaar?
Output quality	Zijn de resultaten consistent en realistisch?
Ease of use	Is de tool makkelijk te gebruiken?
Result demonstratability	Zijn de resultaten overzichtelijk?

Appendix D Twente

This appendix gives a detailed description of the results of project Twente. Twente is a construction project of DVBH which consists of two buildings. The first building is an apartment complex of 29 apartments of which the construction started in June 2022. The second building is a block for five houses of which the construction started in October 2022. For the second building a transportation company is involved which stores all the material of the suppliers and transports it to the construction site. The first truck of the day from this company is self-unloading. The crane of this truck is used to move the needed materials of the whole day to the building. So, it arrives in the morning, moves its own load to the building and remains on the construction site for the remaining movements of the day. The buildings are constructed in the middle of the city centre. Therefore, the storage capacity is limited and the trucks need extra time to enter the construction site backwards. The logistics manager was already involved in an early stage of the project because of these challenges.

The tool is tested in the execution phase based on input of Twente. The construction manager provided a planning for one day with the number of arriving trucks and the number of elements per truck. With this information a day schedule was created with the tool for the data analysis. Table 17 shows the answer per question of the data analysis. This table shows that not all the input is known with certainty and that there are multiple updates possible to improve the results of the tool and resolve the barriers.

Table 17 Answers to the data analysis questions for Twente based on version 0 of the tool

Thomasson V0			
Data analyse vragen	**Antwoord**	**Uitleg**	**Factor**
Is alle data betrouwbaar en beschikbaar?	Nee	De tijden van alle hijsmethodes zijn niet gecheckt en van bepaalde methodes missen nog tijden, omsteltijd is een ruime schatting, de planning van dagniveau is redelijk bekend	Tijden hijsmethodes, alle hijsmethodes, schatting omsteltijd, planning beschikbaar
Zijn de resultaten consistent en realistisch?	Nee	Er is maar 1 kraan nodig volgens het model en er is tijd over voor extra taken, maar het dagschema is op de minuut precies en dit is niet wenselijk, sommige elementen worden op voorraad geleverd en dit geeft het model niet weer, de lostijd van een vrachtwagen is korter dan van een kraan	**Te nauwkeurig, dagen onafhankelijk, lostijd vrachtwagen verkeerd**
Is de tool makkelijk te gebruiken?	Nee	In geval van geen feasible solution weet je de oorzaak niet, wanneer er geen data is van de hijsmethode is deze moeilijk in te vullen, de werktijden van het project zijn anders dus deze moeten aangepast worden	**Oorzaak non-feasible onbekend, geen mogelijkheid tot handmatig invoeren lostijd, geen variabele werktijden**
Zijn de resultaten overzichtelijk?	Ja	Het dagschema is duidelijk en de totale grafieken geven een goed overzicht, de nodige informatie wordt automatisch weergegeven	Compleet, overzichtelijk

In the next step, the created schedule of the tool was compared to reality by observing the construction site for one afternoon. This observation is done on two levels. First, the reliability of the input data is tested by measuring the movement times per element. Second, the created schedule is compared to the actual arrival and departure times of the trucks.

Table 18 shows the results of observations of the movement time of one type of element. The movement time is split in the hook-up, the movement to the project which includes the placement, the disconnection and the movement of the crane back to the truck. The two undermost rows show the average of the observed movement time and the predicted movement time which is used in the tool. A comparison between these two rows shows that the movement to the project and the disconnection are estimated very accurately for this element. There was no back movement time included in the prediction. Since this is 10% of the total 4 minutes and 38 seconds, this is important to also include. The hook-up time differs 20 seconds, so the estimation of the hook-up time should also be increased. The back movement and the hoop-up time explain the difference in the total movement

time. To create a more accurate estimation of the movement time of this element the hook-up time should be increased by 20 seconds and the back movement time should be included.

Table 18 Observations movement time

Truck	Element	Hook-up	Movement	Disconnect	Back movement	Total
1	1	00:01:32	00:01:19	00:02:07	00:00:21	00:05:19
1	2	00:01:39	00:03:55	00:00:33	00:00:29	00:06:36
1	3	00:01:47	00:01:27	00:00:26	00:00:24	00:04:04
1	4	00:01:47	00:02:57	00:00:53	00:00:22	00:05:59
1	5	00:01:45	00:02:26	00:00:33	00:00:28	00:05:12
1	6	00:01:38	00:01:25	00:00:18	00:00:29	00:03:50
1	7	00:01:12	00:01:47	00:00:31	00:00:34	00:04:04
1	8	00:01:46	00:01:20	00:00:21	-	00:03:27
2	1	-	00:01:47	00:00:30	00:00:29	00:02:46
2	2	00:01:39	00:01:07	00:00:23	00:00:21	00:03:30
2	3	00:01:32	00:01:18	00:00:23	00:00:24	00:03:37
2	4	00:02:00	00:04:28	00:00:40	00:00:35	00:07:43
2	5	00:01:30	00:01:48	00:00:28	00:00:29	00:04:15
2	6	00:01:32	00:01:48	00:00:18	00:00:27	00:04:05
2	7	00:01:34	00:01:47	00:00:39	00:00:31	00:04:31
2	8	00:01:45	00:01:45	-	-	00:03:30
3	1	00:01:28	00:02:36	00:00:34	00:00:35	00:05:13
3	2	00:01:24	00:02:07	00:00:36	00:00:33	00:04:40
3	3	00:01:23	00:01:58	00:00:20	00:00:32	00:04:13
3	4	00:00:47	00:01:32	00:00:21	00:00:29	00:03:09
Average		00:01:34	00:02:02	00:00:34	00:00:28	00:04:38
Predicted		00:01:14	00:02:03	00:00:33	-	00:03:50

Table 19 shows the schedule which was created by the tool and table 20 shows the schedule which was created by the construction manager and communicated to the supplier. The table shows when the truck arrived at the construction site, when the crane started moving the material, when the crane was finished with moving the material and when the truck left the construction site. These two tables show that the construction manager agrees with the set arrival time by the tool. Table 21 shows the actual times of the three different trucks. There are several reasons why the actual schedule differs from the prediction of the tool. These are:

1. Truck 1 and 3 arrived too late by 11 and 34 minutes.
2. The crane was working on another task that came up while truck 1 already arrived.
3. A truck cannot directly be unloaded when it arrives, but it needs some preparation time for tasks such as loosening straps.
4. A truck must depart the construction site before the next truck can arrive because of the small construction site. This time was estimated to be 30 minutes, but turned out to be 12 minutes.
5. The hook-up time is longer than estimated and the movement from the project back to the truck was not considered as explained in the beginning of this section.
6. The last truck had 3 elements instead of the 7 elements which were predicted.
7. 1 element was placed wrong for which the crane had to move back to place the element correct.

So, there are multiple reasons which cannot be influenced and therefore are hard to include in the tool. Reason 4, 5 and 6 can be prevented in the future by changing the input data. Reason 3 can be prevented by adding the set-up time of a truck to the changing time included in the tool.

Table 19 Schedule created by the tool

Tool				
Truck Number	Arrival	Start Crane	End Crane	Departure
1	13:00	13:00	13:30	13:30
2	14:00	14:00	14:30	14:30
3	15:00	15:00	15:27	15:27

Table 20 Schedule created by the construction manager

Scheduled				
Truck Number	**Arrival**	**Start Crane**	**End Crane**	**Departure**
1	13:00	-	-	-
2	14:00	-	-	-
3	15:00	-	-	-

Table 21 Actual schedule

Reality				
Truck Number	**Arrival**	**Start Crane**	**End Crane**	**Departure**
1	13:11	13:20	14:11	14:16
2	14:28	14:32	15:15	15:21
3	15:34	15:44	16:09	-

After the observations, the results were sent to the construction manager and the logistics manager. These results were discussed during a meeting with both managers. During this meeting multiple interview questions were asked. Table 22 and 23 show the results of the interview questions. These interviews were based on version 1 of the tool. The changes in the versions are further explained in Section 5. The tool was explained for the first time to the construction manager. Since the construction manager only looked at the tool and did not use it, the user-friendliness questions were not asked. Table 22 shows that the logistics manager named 3 characteristics of this project which make it challenging for the logistics processes. 2 of these characteristics were already implemented in the tool. Therefore, these are coded as enablers. The third characteristic was not implemented in the tool, so it is a barrier and a possible update. Table 23 shows that the construction manager already named drivers even though he only saw the tool for the first time and never used it.

Table 22 Results interview logistics manager project level

Interview vragen	Answers - Thomasson Logistics manager	Factor
Waarom is bij jouw project logistiek belangrijk?	Het is een binnenstedelijk project, vrachten kunnen er moeilijk komen en hebben een omsteltijd, daarnaast is er geen ruimte voor opslag en worden vrachten gecombineerd met een tussen hub	Weinig (opslag)ruimte, omsteltijd, **gecombineerde vrachten**
Zijn de resultaten van het model duidelijk?	Het dagschema geeft geen informatie over het soort vracht en het aantal elementen en de pauze is niet te zien in het kraanschema. De totaal grafiek laat het nodige aantal uren zien gebaseerd om de minimale kraanhuurperiode, maar ik wil graag weten hoeveel ik nodig heb en hoeveel ik gehuurd heb.	**Geen informatie soort vracht, pauze niet in dagschema, geen onderscheid tussen nodige uren en minimaal te huren uren**
Watvoor voordeel haal je nu uit het model en wat wil je eruit halen?	Met dit model kunnen we met kleine aanpassingen het model beter blijven maken en in de toekomst blijven leren tot we een optimaal schema hebben, net zoals in andere industriën al gedaan is	Makkelijker leren, makkelijker standaardiseren

Table 23 Results interview construction manager Twente project level

Interview vragen	Answers - Thomasson Construction manager	Factor
Heb je het met werknemers over logistieke processen?	Op drukke dagen krijgen werknemers waaronder de kraanmachinist een schema met het kraanschema van die dag, dus een kraanschema moet bruikbaar zijn voor meer mensen dan alleen de uitvoerder	Creeërt dagschema voor alle mensen op de bouwplaats
Wat is nu onduidelijk aan het model? Welke kennis mis je?	Ik mis nog een factor die het skilllevel van de kraanmachinist aangeeft	**Skilllevel kraanmachinist**
Zijn de resultaten realistisch?	Ja in theorie moet het in deze tijd uitgevoerd kunnen worden als er geen uitzonderingen zoals weersomstandigheden zijn. In werkelijkheid heb je dat mensen in de zomer bijvoorbeeld korter werken, dus dit kun je nog meenemen.	Mensen zijn niet 100% productief
Welke resultaten mis je nog?	geen	Resultaten compleet
In hoeverre komen de resultaten overeen met je gevoel?	De tool geeft aan om het uur vrachten voor breedplaten te plannen, dit doe ik nu ieder 1,5 uur, maar ik geloof dat dit wel in een uur kan en zo ga ik ze volgende week gelijk plannen	Gevoelsmatig kloppen de resultaten
Watvoor voordeel haal je nu uit het model en wat wil je eruit halen?	Het automatisch maken van schema's zowel voor de werkvloer als voor Ilips	Automatisch dagschema's

Tables 22 and 23 show that there are multiple possible updates for the next versions of the tool. Most named updates were implemented in the second version of the tool. Version 2 was tested with the input data for the block of five houses. All, the input data was available from an overview sent to the transportation company. During this test the questions of the data analysis were again answered. Table 24 shows the answers to these

questions. This table shows that certain input is still estimated and that there are still possible updates, but the results are more realistic.

Table 24 Results second data analysis Twente

Thomasson V2			
Data analyse vragen	**Antwoord**	**Uitleg**	**Factor**
Is alle data betrouwbaar en beschikbaar?	Nee	Het aantal vrachten waarmee de elementen komen is nog onbekend, maar de schatting is vaak redelijk accuraat, de omsteltijden zijn niet exact bekend, de planning is nog niet compleet voor iedere week	Aantal vrachten, schatting omsteltijd, planning incompleet
Zijn de resultaten consistent en realistisch?	ja	De dagschema's kloppen en geven consistente resultaten, de totale grafiek geeft een mooi overzicht, het aantal uren klikt ook realistisch en er is zoals voorspeld op 1 dag na alleen maar 1 kraan nodig	Realistisch, consistent
Is de tool makkelijk te gebruiken?	Nee	De elementen zouden worden gecombineerd, maar de element combinaties hebben dezelfde hijstijden. Je wilt graag snel een weekplanning genereren i.p.v. dag en dit kan nu alleen handmatig	**Combinatie elementen onnodig, weekschema i.p.v. dag generen**
Zijn de resultaten overzichtelijk?	ja	de totale grafieken geven een mooi overzicht	Overzichtelijk

The results of the test of version 2 on Twente were discussed with the construction manager and the logistics manager. Table 25 shows the questions which were asked during this meeting and the given answers. This table shows that the mangers saw no barriers anymore and are very positive about the outcome of the tool. They did not repeat the drivers they already saw, but found a new driver.

Table 25 Result second interview with the construction and logistics manager

Interview vragen	**Answers - Thomasson Construction & Logistics manager**	**Factor**
Zijn de resultaten realistisch?	Na de aanpassing zijn de resultaten wel realistisch, maar de hoeveelheden moeten wel gecheckt worden.	Realistisch
Welke resultaten mis je nog?	Opslagplaats kun je voor andere projecten gebruiken, maar is voor deze niet nodig	Geen
Zijn de resultaten van het model duidelijk?	De manier waarop het ingevuld is, is helemaal duidelijk	Duidelijk
In hoeverre komen de resultaten overeen met je gevoel?	De dagen zijn te lang en er zijn veel vrachten. Na het checken van de input blijk er een fout te zitten in de nodige hoeveelheden. Hierdoor halveren het aantal vrachten. Origineel zeiden we 15 minuten omsteltijd, maar bij nader inzien is dit wel heel erg krap. Na het aanpassen naar 25 minuten, wordt er wel erg veel tijd verspilt aan wachten op de vracht. Daarom is een nieuwe strategie bedacht voor de omsteltijd. Hiervoor heb je waarschijnlijk 5 minuten omsteltijd.	Input herzien
Watvoor voordeel haal je nu uit het model en wat wil je eruit halen?	Door het model zijn we meer gaan nadenken over de omsteltijd en de beste strategie hiervoor.	Aanzet nadenken omsteltijd strategie

Since all the material arrives from the same transporter, the schedule for the five houses was also discussed with the transporter. Table 26 shows the questions that were asked to the transported about the general collaboration with Dura Vermeer. This table shows that in general the transporter makes its own planning without collaborating with the construction company based on their own experience. This is something Dura Vermeer is improving by collaborating.

Table 26 Results interview transporter Twente

Interview vragen	Answers - Transporter	Excerpt
In hoeverre ben je als leverancier bezig met de logistieke processen op de bouwplaats en waarom?	Wij denken na hoelaat de vrachten moeten komen zodat ze op elkaar aansluiten. Dit baseren we op ervaring en hoelang onze werknemers denken ermee bezig te zijn. In principe komt het initiatief daarbij uit onszelf.	Eigen planning, Ervaring gebaseerd
In hoeverre kun je als leverancier je werkwijze aanpassen voor logistieke optimalisatie?	We denken graag samen na over hoelang we bezig zijn en wat de beste omstelstrategie is, daarbij passen we ons volledig aan op de klant	Volledig aanpassen aan klant
Watvoor verschil merk je tussen DV en andere bedrijven in logistieke processen en eisen?	Normaal denken we alleen zelf na over de planning. Dura Vermeer is een van de enigen die daarin meedenkt. Daarnaast heeft Dura veel al uitgedacht dus heb je weinig wachttijd en is het veilig werken.	DV denkt verder na, DV stuurt

The results of the tool for the construction of the five houses were discussed with the transporter in a second meeting during which also the truckdriver attended. Table 27 shows the answers given during this meeting. Overall, they were very positive about this tool and they think that they can also benefit from it. They had a few comments about what can be added which are shown as the barriers in the table.

Table 27 Results second interview transporter

Interview vragen	Answers - Transporter	Excerpt
Watvoor verschil merk je tussen DV en andere bedrijven in logistieke processen en eisen?	Andere bedrijven zijn niet bezig met hoe ze kleine dingen kunnen verbeteren en berekeningen kunnen maken. Bijvoorbeeld een tweede trap op de bouw kan veel tijd schelen, maar kost iets extra	DV denkt verder na over berekeningen
Wat is nu onduidelijk aan het model? Welke kennis mis je?	Het model is verder duidelijk	Duidelijk
Zijn de resultaten realistisch?	van de dag zijn we wel wat langer bezig met het opzetten van de kraan. Op een gegeven moment wordt het routine en gaat alles sneller en soepeler doordat je ook meer de mensen op de bouwplaats kent. Momenteel heb je op een paar dagen 3 vrachten staan, maar dit is onhandig met omsteltijd, we kunnen dan beter 1 verplaatsen en maximaal 2 per dag doen. Je heb nu geen verschil tussen verdiepingen of verplaatstijd van de kraan. Voor dit project is dit ook niet nodig als de kraan overal bij kan en per verdieping is er ook geen verschil	Na meer dagen gaat alles soepeler
Welke resultaten mis je nog?	Ik wil graag aan het begin van de dag weten wat ik moet doen en wat mee terug moet. Op die manier kan ik het zelf optimaal indelen. De last-minute taken kosten me het meeste tijd. Tekening helpen me daarbij heel erg. Je mist nu nog het meenemen van de retourvrachten. De retourvrachten kunnen lastig in te schatten zijn aangezien de tijd erg afhankelijk is van hoe goed het voorbereid is.	Geen retourvracht meegenomen, weten wat je per dag moet doen
In hoeverre komen de resultaten overeen met je gevoel?	klopt wel aardig. Het is wel afhankelijk van hoeveel mannetjes je op de bouw hebt staan, maar dit zit bij DV wel goed.	Overeenkomst
Wat zou je verbeteren aan de gebruiksvriendelijkheid?	Ik zou goed uitleggen aan de mensen op de bouw zelf wat je doet en wat zij moeten doen	Uitleggen werknemers

A second observations was performed to compare the schedule of second model evaluation with the reality. Table 28 shows the results of the movement times during observation 2. This table is similar to table 18 which shows the results of observation 1. During observation 2 the movement time of sand-lime bricks was measured. Table 28 shows that the four measured average movement times do not match with the predicted times. Except for the back movement time, all the measured times are lower than the predicted times. The total measured time is 38,75% lower than the predicted time. Therefore, the used input data for the movement times is not reliable for this material.

Table 28 Results movement time observation 1

Truck	Element	Hook-up	Movement	Disconnect	Back movement	Total
1	1	00:00:36	00:00:36	00:00:06	00:00:29	00:01:47
1	2	00:00:27	00:00:51	00:00:02	00:00:46	00:02:06
1	3	00:00:14	00:00:42	00:00:05	00:00:36	00:01:37
1	4	00:00:17	00:01:11	00:00:03	00:00:28	00:01:59
1	5	00:00:23	00:00:52	00:00:03	00:00:38	00:01:56
1	6	00:00:18	00:00:42	00:00:02	00:00:25	00:01:27
1	7	00:00:23	00:00:41	00:00:02	00:00:24	00:01:30
1	8	00:00:25	00:00:28	00:00:02	00:00:19	00:01:14
2	1	00:00:31	00:00:39	00:00:02	00:00:32	00:01:44
2	2	00:00:11	00:00:38	00:00:13	00:00:24	00:01:26
2	3	00:00:13	00:00:38	00:00:03	00:00:30	00:01:24
2	4	00:00:22	00:00:36	00:00:10	00:00:31	00:01:39
2	5	00:00:22	00:00:27	00:00:03	00:00:29	00:01:21
Average		00:00:22	00:00:42	00:00:04	00:00:30	00:01:38
Predicted		00:00:34	00:01:22	00:00:26	00:00:18	00:02:40

Table 29 shows the schedule which was created by the tool for the second observation. Table 30 shows the schedule which was created by the transporter for the trucks. This is schedule was based on an estimation of the truck and crane operator. The elements fitted on two trucks instead of the three trucks which were initially communicated. Table 31 shows the actual schedule of the day. This schedule shows that the start of unloading truck 1 was around the same time as predicted by the tool. The needed set-up time for the truck was longer than expected. The truck had instead of 24 elements 34 elements. Despite these extra elements, the trucks took a little more than an hour to unload. The first truck was unloaded an hour before the second truck was scheduled. Therefore, the crane operator had to wait before it could start with the second load. In this waiting time a few other tasks were performed, but there were not enough tasks to fill the whole hour. The changing time of the second truck was much less than expected. The truck was unloaded in 1,5 hours, but this also included a break for the operator of 10 minutes. So, if the arrival time of the trucks was set by the transporter in collaboration with Dura Vermeer, the schedule could have been predicted more accurate.

Table 29 Schedule created by the tool for observation 1

Tool				
Truck number	**Arrival**	**Start crane**	**End crane**	**Departure**
1	07:20	07:30	08:33	08:43
2	08:49	08:59	10:03	10:13
3	10:19	10:29	11:11	11:21

Table 30 Schedule created by the construction manager for observation 1

Scheduled				
Truck number	**Arrival**	**Start crane**	**End crane**	**Departure**
1	07:00	-	-	-
2	09:30 / 10:00	-	-	-

Table 31 Actual schedule for observation 1

Reality				
Truck number	**Arrival**	**Start crane**	**End crane**	**Departure**
1	07:00	07:26	08:41	-
2	09:50	09:55	11:25	11:30

Appendix E Rotterdam

Rotterdam is a construction project in Rotterdam which works on an apartment building. This is the third building which is built on the construction site. The other two buildings already started with construction and the third building starts in the first quartile of 2023. This building has 15 levels of which the first 7 are wider than the remaining 8 floors. Figure 18 shows which data collection methods were used for this project and in what order. The paragraphs below describe the results per step.

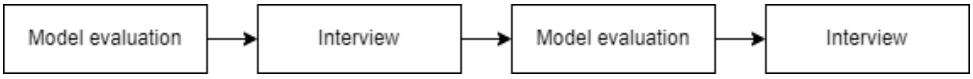

Figure 18 Order data collection methods Rotterdam

After an introduction meeting, access was given to the documents of the project such as the planning for the execution phase and the designs of the building. Based on this input data version 0 of the tool was filled in for this project. The tool was filled in on the project level and on the floor level. The volume model was not filled in for this project, so the number of trucks were estimated. The day level was used for the floor level by filling in the trucks per day of the cycle of a floor level. Table 32 shows the results of the model evaluation. This table shows that there are still a lot of estimations in the input data. Additionally, the results are not consistent on the project level and the floor level. This is an important barrier because it stimulates to make different decisions on different levels.

Table 32 Results model evaluation of Rotterdam based on version 0 of the tool

Hefkwartier V0			
Data analyse vragen	**Antwoord**	**Uitleg**	**Factor**
Is alle data betrouwbaar en beschikbaar?	Nee	Het aantal nodige elementen per onderdeel moet geteld worden vanuit de tekening, het aantal elementen per vracht is onbekend en is gebaseerd op informatie van google, veel leveranciers missen	Aantal vrachten/elementen onbekend, Aantal elementen per vracht onbekend, geen input van veel leveranciers
Zijn de resultaten consistent en realistisch?	Nee	De resultaten op project niveau zijn anders dan de resultaten op verdiepingsniveau. Op project niveau zijn er gemiddeld 2 uren per dag nodig en op verdiepingsniveu is dit gemiddeld 6.	Inconsistent op verschillende niveau's
Is de tool makkelijk te gebruiken?	Ja	Als de input eenmaal compleet is, werkt het model. De inputform is goed in te vullen	Makkelijk
Zijn de resultaten overzichtelijk?	Ja	De grafieken zijn overzichtelijk en duidelijk	Duidelijk

The results are discussed with the project preparer which focusses on the preparation of the crane schedule for this project. Table 33 shows the results of this conversation. This table shows that the project preparer was positive about the tool even though the results were not always realistic or consistent. Based on the explanation, the project preparer started testing the tool by himself to add other construction tasks as well.

Table 33 Results interview project preparer Rotterdam

Interview vragen	**Answers - Hefkwartier project preparer**	**Factor**
Wat is nu onduidelijk aan het model? Welke kennis mis je?	De input ziet er goed uit, je kunt voor de kolommen nog de data van de wandkisten gebruiken, maar dit kan ik ook voor je aanpassen.	Duidelijk
Zijn de resultaten realistisch?	In de praktijk draait de kraan 100%, altijd. Hier heb je gemiddeld maar 2 uur nodig. In de praktijk zijn deze uren natuurlijk minder verspreid. Er zit tussen de verdiepingen een kleine overlap, dus de tijden per verdieping zullen nog iets omhoog gaan. Je houdt wel genoeg tijd over voor de buffer die je altijd moet inplannen	Anders dan de praktijk
Welke resultaten mis je nog?	Bepaalde dagen zoals stortdagen staan vast, daar kunnen we niks veranderen aan de capaciteit.	**Vaste dagen**

The same input was again used in a different version of the tool. Table 34 shows the results of the model evaluation with the new version. The results are similar except for the consistency which increased and the results became more realistic.

Table 34 Results second model evaluation of Rotterdam based on version 4 of the tool

Hefkwartier V4			
Data analyse vragen	**Antwoord**	**Uitleg**	**Factor**
Is alle data betrouwbaar en beschikbaar?	Nee	Het aantal nodige elementen per onderdeel moet geteld worden vanuit de tekening, het aantal elementen per vracht is onbekend en is gebaseerd op informatie van google, veel leveranciers missen	Aantal vrachten/elementen onbekend, Aantal elementen per vracht onbekend, geen input van veel leveranciers
Zijn de resultaten consistent en realistisch?	Nee	De resultaten op project niveau zijn anders dan de resultaten op verdiepingsniveau, maar dit verschil is wel kleiner geworden. De resultaten van bedrijsbureau zijn wel realistischer geworden door de onwerkbare dagen en pauzes	Inconsistent op verschillende niveau's , realistischer
Is de tool makkelijk te gebruiken?	Ja	Als de input eenmaal compleet is, werkt het model. De inputform is goed in te vullen	Makkelijk
Zijn de resultaten overzichtelijk?	Ja	De grafieken zijn overzichtelijk en duidelijk	Duidelijk

The results of second model evaluation were discussed with the project preparer again. Table 35 shows the results of this meeting. The results shows that the project preparer was very positive about the tool and the results. He was looking forward to working with the tool. There was still one possible update, but with this update the employee can add something manually while this is now done by the logistics managers.

Table 35 Results second interview project preparer Rotterdam

Interview vragen	Answers - Hefkwartier project preparer	Excerpt
Wat is nu onduidelijk aan het model? Welke kennis mis je?	Alles is duidelijk	Duidelijk
Zijn de resultaten realistisch?	De resultaten zijn realistisch want de andere helft van de capaciteit wordt gebruikt door onderaannnemers.	Realistisch
Welke resultaten mis je nog?	Ik mis nog dat je nieuwe leveranciers kunt toevoegen	Compleet, **zelf leveranciers toevoegen**
Watvoor voordeel haal je nu uit het model en wat wil je eruit halen?	Verdiepingsniveau is een goede toevoeging. Op basis van deze resultaten kun je gaan schuiven om de efficiëntie te verhogen.	Verdiepingsniveau is praktisch, efficiëntie verhogen

The results of this project show that the employee was very positive about the tool and saw many enablers and drivers even though there were also several barriers mainly about the input data. The barriers did not decrease in the next version of the tool. So, there are still problems which should be solved, but the results of the tool can already be used by the employee for this project.

Appendix F Amsterdam1

Amsterdam1 is a construction project which works on an apartment building and is from DVBZW. This building consists of 20 levels and a basement. Every 5 levels the width of the level becomes smaller such that the building will be pyramid shaped. The construction of this project started in the second quartile of 2022. The project organizer of this project was enthusiastic about the tool and wanted to know more about its operation. Therefore, the tool was tested on this project. Figure 19 shows the steps of the data collection of this project. The paragraphs below the describe the results of each project.

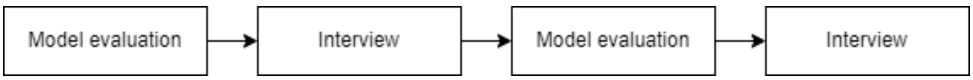

Figure 19 Order data collection methods Amsterdam1

The project preparer gave input about the planning and the needed quantities. With this input, version 1 of the tool was filled in for the project level and the floor level. Table 36 shows the results of this model evaluation. This table shows the same results as for the first model evaluation of Rotterdam, the input is an estimation and there is inconsistency between the project level and floor level.

Table 36 Results model evaluation of version 1 of the tool for Amsterdam1

Grote Beer V1			
Data analyse vragen	**Antwoord**	**Uitleg**	**Factor**
Is alle data betrouwbaar en beschikbaar?	Nee	Het aantal vrachten voor de elementen is onbekend, de lostijden zijn niet over gecheckt, de omsteltijden zijn onbekend, leverancier nog onbekend	Aantal vrachten, aantal elementen, onbekende omsteltijd, onbekende leverancier
Zijn de resultaten consistent en realistisch?	Nee	Gebaseerd op de input is de output logisch, er is veel verschil in kraanuren tussen week en dag niveau	Logisch, verschil dag en week niveau
Is de tool makkelijk te gebruiken?	Ja	Zodra de input ingevuld is, is alle informatie automatisch gegenereerd	Automatisch
Zijn de resultaten overzichtelijk?	Ja	De nodige output is makkelijk te vinden	Makkelijk

The results of the model evaluation were discussed with the project organiser. Table 37 shows the results of this meeting. This table shows that the project organizer was positive about the tool. First, he thought the movement times given in the tool were realistic. When he saw the results, he thought the resulting needed number of crane hours was very low and reconsidered if the values of the movement time were realistic.

Table 37 Results interview project organiser project level

Interview vragen	**Answers - Grote Beer Project organiser**	**Factor**
Wat is nu onduidelijk aan het model? Welke kennis mis je?	Niks is onduidelijk	Duidelijk
Welke resultaten mis je nog?	Ik mis geen resultaten	Resultaten compleet
Zijn de resultaten van het model duidelijk?	De resultaten zijn duidelijk	Duidelijke resultaten
In hoeverre komen de resultaten overeen met je gevoel?	De resultaten van bedrijfsbureau zijn laag, dit komt denk ik door de lage inschatting van de lostijden	Geen overeenkomt

After the meeting, the project organiser sent information about the movement times they usually use for the estimation of the needed crane hours. The tool was also filled in based on the original input of the tool and based on the numbers the project organizer of DVBZW generally use. Figure 20 shows the graph of the needed and the budgeted number of crane hours based on the input numbers the project organisers usually use. Figure 21 shows the same graph based on the original input of the tool. When comparing the numbers for the needed crane hours, the tool gives a higher needed number of crane hours with the original input of the tool. The difference is not more than an hour per week. Therefore, the input of the movement data is considered to be reliable. Table 38 shows the answers to the questions for the model evaluation. This table shows that not many barriers and enablers changed, only a few barriers were solved.

Table 38 Results model evaluation Amsterdam1 on version 4 of the tool

Grote Beer V4			
Data analyse vragen	**Antwoord**	**Uitleg**	**Factor**
Is alle data betrouwbaar en beschikbaar?	Nee	Het aantal vrachten voor de elementen is onbekend, de omsteltijden zijn onbekend. De lostijden zijn niet gecheckt, maar wel vergeleken met de tijden waar voor dit model mee gerekend werd. Deze tijden komen redelijk overeen, de tijden van de tool zijn net iets hoger	Aantal vrachten, aantal elementen, onbekende omsteltijd
Zijn de resultaten consistent en realistisch?	Nee	Gebaseerd op de input is de output logisch, er is veel verschil in kraanuren tussen week en dag niveau, maar dit is wel minder geworden door de buffers mee te nemen. De onderwerkbare dagen maken de resultaten ook veel realistischer	Logisch, verschil dag en week niveau, realistisch
Is de tool makkelijk te gebruiken?	Ja	Zodra de input ingevuld is, is alle informatie automatisch gegenereerd	Automatisch
Zijn de resultaten overzichtelijk?	Ja	De nodige output is makkelijk te vinden	Makkelijk

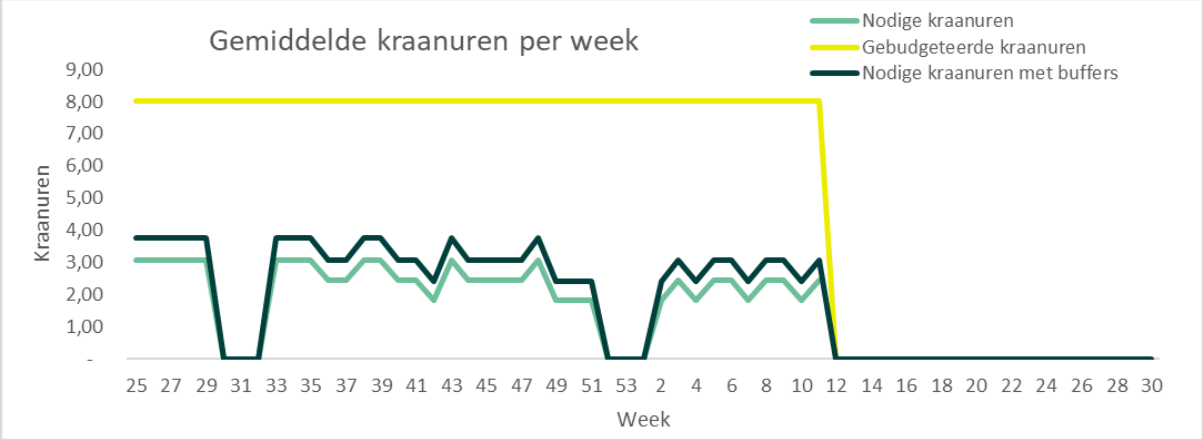

Figure 20 Results average needed crane hours per day on a week level with input of numbers used by DVBZW

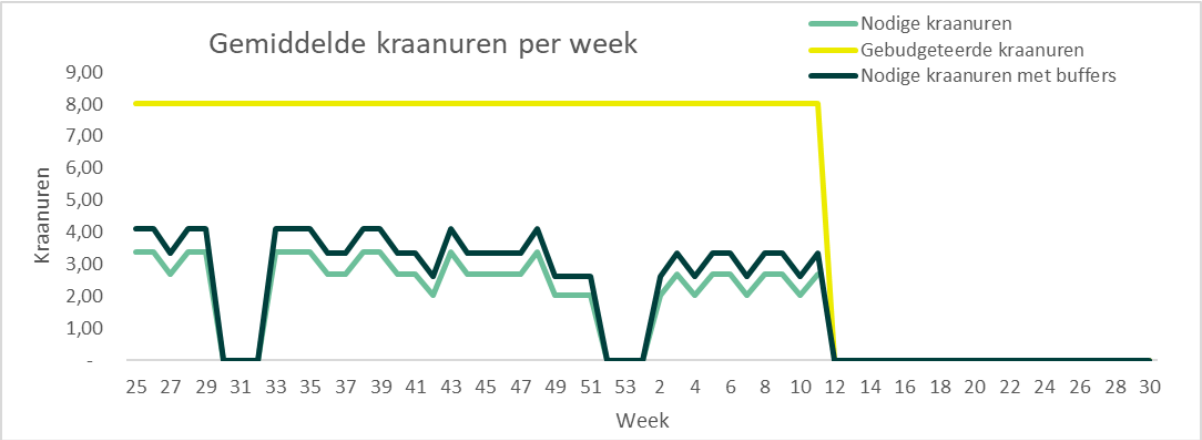

Figure 21 Results average needed crane hours per day on a week level with input of the tool

After the tool is filled in with the new information, the results were discussed with the project organiser. Table 39 shows the results of this meeting. This table shows that there is still a difference between the project level and floor level of the project. The project organiser also did not know what the cause of this inconsistency could

be. De results of the floor level were realistic, but of the project level it was too low. Beside this, the project organiser was positive about the tool.

Table 39 Results second interview project organiser project level

Interview vragen	Answers - De Grote Beert Project Organiser	Excerpt
Zijn de resultaten realistisch?	De dagen waarover je het verspreid is goed, het gebruik van onwerkbare dagen is goed. We hebben voor de kraan overuren gepland voor onderaannemers op basis van aannames van de leverancier. Onderaannemers nemen niet extra tijd in, de ruwbouw gaat voor. Het is wel gek dat het model anders resultaten geeft als je deze tijden gebruikt.	Andere resultaten dan aannames leverancier
Welke resultaten mis je nog?	Ik mis geen.	Compleet
In hoeverre komen de resultaten overeen met je gevoel?	De resultaten van project niveau zijn de helft van wat het zou moeten zijn. We hebben hier 1 torenkraan die altijd bezig hoort te zijn. Op verdiepingsniveau is het realistisch.	Project niveau de helft, verdiepingsniveau realistisch
Watvoor voordeel haal je nu uit het model en wat wil je eruit halen?	Dit is voor ons ook een nieuw project door het aantal prefab elementen, we zijn hierin nog een beetje zoekende, het model kan hierbij wel helpen	Beantwoord vragen

This project showed similar results as project Rotterdam. There are multiple barriers mainly about the input data which are not much improved during the research. The project organiser was positive about the tool and mentioned a lot of enablers, but never a driver. This employee would use the tool in the future, but is not driven to immediately use it.

Appendix G Amsterdam2

Amsterdam2 is a project which renovates an office into apartments and creates extra floors on the building. This project is from DVBMW and already started with the construction in 2021, but has a lot of delay. There are many subcontractors involved in this project and there is only one road on which all the trucks arrive. Therefore, the coordination of the arriving trucks is very challenging. There are multiple construction managers on this project. One of the construction managers asked the logistics manager about advice on how to coordinate the delivery and placement of the facades. The crane scheduling tool can show the best arrival time and the capacity of one crane per day. Therefore, the tool was also tested on this project. Figure 22 shows the steps of the data collection for this research. This project was involved late in the research, therefore only 2 steps are taken which were also enough to give useful input to the construction manager.

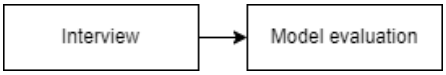

Figure 22 Order data collection methods Amsterdam2

Table 40 shows the results of the questions asked during the introduction meeting for the project. This table shows that the tool has potential to solve the problems of the construction manager, but the subcontractors form a barrier to the effectiveness of the tool.

Table 40 Results of the introduction meeting with one of the construction managers of Amsterdam2

Interview vragen	Answers - Oku House Construction Manager	Factor
In watvoor soort projecten is logistiek extra nodig?	We hebben veel leveringen van materialen die door onderaannemers geregeld worden. Daardoor weten we niet hoelaat die vrachten komen en of we in de knel gaan komen met onze vrachten bij t aanrijden. Daarnaast weten we ook niet wanneer zij de kraan gaan gebruiken. Als we ILips gaan gebruiken is het dus ook noodzakelijk dat zij dat ook gaan doen	Onderaannemers, aankomst tijd onbekend
Watvoor financiele winst wil je uit logistiek halen en wat denk je er nu uit te halen?	Ik ben aangenomen voor een deel van deze logistieke processes met name omdat we een achterstand hebben van 3,5 maand en er een boete clausule is. Daarom is het van belang dat we de komende processen snel uitvoeren	Achterstand inhalen
Watvoor voordeel haal je nu uit het model en wat wil je eruit halen?	Ik wil weten hoeveel vrachten ik kan verwerken in een dag, wanneer de vrachten moeten komen en hoe ik dit zo optimaal mogelijk in kan delen	Optimalisatie schema

After the introduction meeting, version 2 of the tool was tested based on the input given during the meeting. The input was used to fill in the tool on a day level since the construction manager wanted to optimize one day. Table 41 shows the results of the model evaluation. These results show that there are no barriers for this project, but there are a few possible updates. So, after these updates the tool can be used to solve the problems of the construction manager.

Table 41 Results model evaluation Amsterdam2 based on version 2

Oku House V2			
Data analyse vragen	**Antwoord**	**Uitleg**	**Factor**
Is alle data betrouwbaar en beschikbaar?	Ja	Vrachten en elementen zijn zeker, hijsmethode heeft goeie tijden, rijtijd van de kraan is nog variabel maar geen grote factor	Beschikbaar en betrouwbaar
Zijn de resultaten consistent en realistisch?	Ja	De resultaten geven voor iedere dag dezelfde resultaten en komen overeen met de verwachtingen van de uitvoerder, de pauze momenten zijn niet goed doordat er een grote vracht is	**Pauze momenten verkeerd**
Is de tool makkelijk te gebruiken?	Ja	Er was maar 1 regel aan input data nodig, de rijtijden van de kraan waren nieuw, maar konden makkelijk meegerekend worden in de bijplus kolom	Simpel
Zijn de resultaten overzichtelijk?	Ja	De resultaten zijn duidelijk, maar ze zijn per vracht verwerkt en voor dit soort grote elementen wil je deze graag per element	**Element niveau**

This project showed that the tool could quickly give good results. The construction manager saw a lot of potential and the tool gave useful input for the made decisions.

Appendix H Company level

During the research, several employees gave input about the tool which were not involved in a project on which the tool was tested. Therefore, this input is used as results on the company level. The paragraphs below describe who gave input and what they answered.

Table 42 and 43 show answers given by the project organisers. These results were gathered during a meeting with all the project organisers of a suborganization. During this meeting version 0 of the tool was presented and discussed. This presentation was the final presentation of the previous thesis. Therefore, the given input could not be implemented anymore in that thesis, so it is used as input for this thesis. The tables show that all project organisers of both suborganisations would like to get the same advantages from the tool, but they doubt whether the input data is generalizable for all the projects since they have different cranes and different heights.

Table 42 Results Interview project organiser DVBH

Interview vragen	Answers - General project organiser DVBH	Factor
In hoeverre komen de resultaten overeen met je gevoel?	We missen nog onderscheid in type kranen voor de bijvoorbeeld de lostijden	**Onderscheid type kraan**
Watvoor voordeel haal je nu uit het model en wat wil je eruit halen?	We willen weten hoeveel kranen we nodig hebben en hoeveel we daarvoor moeten budgeteren. In de toekomst zou het mooi zijn om te zien watvoor effect het heeft als we iets aanpassen in de planning of in het aantal vrachten	Hoeveel kranen, hoeveel budget, **sensitivity analyse input data**

Table 43 Results Interview project organiser DVBMW

Interview vragen	Answers - General project organiser DVBMW	Factor
Zijn de resultaten realistisch?	We missen nog extra lostijd bij een bepaalde hijshoogte.	**Compensatie lostijd hijshoogte**
Watvoor voordeel haal je nu uit het model en wat wil je eruit halen?	Met deze tool kunnen we meer data-gestuurde beslissingen maken zoals het bepalen van het budget voor kranen.	Hoeveel budget, data-gestuurde beslissingen
Hoeveel tijd heb je voor het invullen van het model over?	We willen geen extra tijd kwijt zijn aan het invullen van het model.	Geen extra invultijd

During the previous thesis one construction manager was involved multiple times. This construction manager already worked a lot on crane schedules by himself. Therefore, he was interested in the tool and could give useful input. He was asked again to give input about version 0 of the tool. Table 44 shows the results of the interview with the construction manager. There are no questions asked about a project and the results of a project, since the project of the construction manager was not in a stage in which the tool would be useful. The table shows the answers given by the construction manager and the factors mentioned in the answer which have the corresponding color code. The table shows that the main barriers are with the integration of tacit and explicit knowledge. It is not the current way of working of construction managers to actively share and document knowledge. The table also shows that there are still multiple possible updates, but the construction manager already sees a broad driver for the future.

Table 44 Results interview general construction manager

Interview vragen	Answers - General construction manager	Factor
Hoeveel kennis haal je uit ervaring en hoeveel uit documenten?	Alle kennis komt uit ervaring, soms vraag je nog eens iemand anders als je toevallig hoort dat deze hier ervaring mee heeft.	Kennis uit ervaring
Hoeveel van je eigen kennis uit ervaring noteer en deel je?	Ik noteer geen kennis en ik deel alleen kennis in samenwerkingsverband.	Geen kennis notatie, kennis wordt niet gedeeld
Wat is nu onduidelijk aan het model? Welke kennis mis je?	Er wordt nu met seconden gewerkt, maar worden deze echt verwerkt in de output, is het nodig?	Secondes lijken te gedetailleerd
Wat zou je verbeteren aan de gebruiksvriendelijkheid?	De documentatie voor bedrijfsbureau heb je weinig nodig in de uitvoering, dus deze zou ik in een ander documentje zetten. De tussenberekeningen heb ik niet nodig, dus deze kun je weglaten.	**Bedrijfsbureau en uitvoering splitten, tussen berekeningen weglaten**
Watvoor voordeel haal je nu uit t model en wat wil je eruit halen?	In de toekomst zou het mooi zijn als de input automatisch uit Kyp gehaald kan worden en de output automatisch in Ilips ingevoerd kan worden.	**Synchronisatie Kyp en Ilips**
Hoeveel tijd heb je voor het invullen van het model over?	Niet meer dan ik nu besteed aan het plannen van de vrachten.	Evenveel als huidige tijd
Wat denk je dat het model in de toekomst kan bieden?	Je kunt veel meer performance gericht sturen en dit kun je per verdieping doen.	Performance gericht sturen

Within DVBH, project leaders manage several projects for which they make sure the delay is minimal and the costs stay within the budget. They are involved both during the preparation and execution phase of a company. Project leaders also decide which tools will be used for their projects. Therefore, it is important that a project leader sees the added value of the tool. Table 45 gives the answers which the project leader gave. He especially saw a lot of potential for the project organisers on the project level. For the day level he was still doubtful because of the needed input and the added value.

Table 45 Results interview project leader

Interview vragen	Answers - General Project leader	Factor
Wat is nu onduidelijk aan het model? Welke kennis mis je?	Kloppen de hijstijden? Verschillen deze niet per kraan? De omsteltijden is een goede toevoeging.	Twijfel lostijden, toegevoegde waarde omsteltijd
Wat zou je verbeteren aan de gebruiksvriendelijkheid?	Momenteel vullen onderaannemers ook zelf dingen in in Ilips, dit moet je dus weer dubbel invoeren bij dit model.	Dubbelop werk
Watvoor voordeel haal je nu uit het model en wat wil je eruit halen?	Ik vind het goed aan Ilips dat ze gegevens verzamelen over leveranciers, daar kunnen we meer mee doen. Ik vraag me af wat het voordeel is voor een uitvoerder om dit model in te vullen tegenover hem een lijstje te geven met de processtijden. Ik denk namelijk dat het tweede sneller is, ik ben bang dat je nu dingen dubbel moet invullen bij dit model en bij Ilips en dat dit onnodige invultijd is. Ik ben het er wel mee eens dat je meer performance gericht kunt sturen zoals andere uitvoerders ook noemden. Voor bedrijfsbureau wil je gewoon die grafiek hebben, dat is mooi, dat is praktisch	Gegevens leveranciers Ilips, twijfel toegevoegde waarde utvoerders, kraanuren grafiek bedrijfsbureau
Hoeveel tijd denk je kwijt te zijn aan het model?	Ik denk dat je veel dubbel moet invullen en daardoor kost het teveel tijd voor de output die je krijgt	Meer dan nu
Wat denk je dat het model in de toekomst kan bieden?	Ik denk dat je voor nu moet zorgen dat je focust op bedrijfsbureau. Je kunt wel eens bij een uitvoerdersmeeting gaan zitten. Zorg dat dan je een project van 1 uitvoerder gebruikt en de rest lekker maakt, maar duidelijk zegt dat ze je model niet mogen gebruiken. Zodra ze naar je model gaan vragen heb je enthousiaste mensen en krijg je het van de grond. Focus nu op laaghangend fruit en kader je updates.	

Since the project leader saw a lot of potential for the project organisers and there were no personal interviews with project organisers of DVBH yet, a meeting was organized with a project organisers of DVBH to give feedback on version 3 of the tool. Table 46 shows the results of this interview. During this interview the results of project Rotterdam were used. He was very positive and saw multiple drivers. There are a few barriers which can be

solved with an update and which make the results more realistic. He was also very curious about the final result of the project.

Table 46 Results interview project organiser DVBH

Interview vragen	Answers - General Project organisor - based on Hefkwartier results	Factor
Hoeveel kennis haal je uit ervaring en hoeveel uit documenten?	(Specifiek onderwerp over onwerkbare dagen)Deze kennis wordt uit ervaringsgetallen gehaald die standaard vastgelegd zijn per jaar.	Onwerkbare dagen standaard getal
Zijn de resultaten realistisch?	Zoals je zegt mis je wel bepaalde buffers en is dit alleen gebaseerd op productieve uren. Je kunt goed gaan kijken naar onwerkbare dagen want dit is een aardig grote factor. Wij zeggen vaak het duurt zoveel dagen voor dit process en dus niet per element niveau zoals jij zegt, maar bij ons zit de pauze en kraanhuur buffertijd er dus wel al bij in. Deze buffers verschillen per type kraan. Kijk ook goed naar het verschil tussen verdiepingsniveau en project niveau, waardoor komt dit? en laat me vooral weten wat daar uitkomt	**Alleen productieve uren, onwerkbare dagen niet meegenomen**
Zijn de resultaten van het model duidelijk?	Tijdens het gesprek was alles gelijk duidelijk en zijn er geen vragen geweest over de duidelijkheid van de resultaen	Duidelijk
In hoeverre komen de resultaten overeen met je gevoel?	Als dit waar is dan twijfel ik aan de keuze voor een torenkraan. Het kan zeker waar zijn, maar je mist nu dus nog wel bepaalde buffers	
Watvoor voordeel haal je nu uit het model en wat wil je eruit halen?	Met dit model kun je in de toekomst makkelijker vaststellen waar het verschil zit tussen uitvoering en bedrijfsbureau. Zo kun je makkelijker leren en de standaardisatie verhogen. Daarnaast kun je hierdoor goed streven naar betere resultaten.	Mogelijkheid voor makkelijk leren, verhogen standaardisatie, betere resultaten
Wat denk je dat het model in de toekomst kan bieden?	Ik merk nu dat ik getriggerd ben door de grafieken om te gaan kijken waar het beter kan. Je ziet veel leegstand en dan ga ik al gelijk nadenken wat nou als ik dit aanpas of dit. Hierdoor ga je wel extra daarover nadenken. Ik kijk zowel naar pieken over de normale kraanhuur als dalen bij leegstand van de kraan	Leegstand verbeteren

The volume model gives important input for the crane scheduling tool. The volume model is filled in by the logistics managers. In the future, the crane scheduling tool should also be used by the logistics managers. Therefore, it is important to have a good cooperation with both logistics managers, so a meeting was scheduled with the logistics manager of DVBMW. Table 47 shows the results of this meeting. This table shows that the logistics manager has a different view on the tool than the other employees. There are multiple small updates which will increase the user-friendliness.

Table 47 Results interview logistics manager DVBMW

Interview vragen	Answers - Logistics Manager	Factor
Watvoor steun geeft de regening in logistieke optimalisatie in de bouw?	De regering geeft alleen maar de wetgeving aan, maar je moet zelf uitzoeken hoe je, je aan deze wetgeving gaat houden	Geen steun, wel wetgeving
In watvoor soort projecten is logistiek extra nodig?	Dit is gebaseerd op bouwplaats, omgeving en volume. We gaan hier ook een scorecard van maken om aan te geven wanneer het logistieke team ingeschakeld moet worden	Bouwplaats, omgeving en volume
Hoeveel kennis haal je uit ervaring en hoeveel uit documenten?	Je kunt de kennisoverdracht verbeteren door heel simpel opmerkingvakken toe te voegen. Hier zijn ze ook heel erg van de lijstjes maken	**Opmerkingvakken toevoegen**
Wat is nu onduidelijk aan het model? Welke kennis mis je?	De eenheid van de verschillende onderdelen van de lostijden moet ik altijd even naar zoeken. Daarnaast is de leverancier vaak niet bekend en hebben ze daar ook niet altijd invloed op. Dit wordt voornamelijk bepaald door inkoop	**Eenheid lostijd beter aangeven**, leverancier onbekend in voorbereidings stadium
Wat zou je verbeteren aan de gebruiksvriendelijkheid?	Ik zou de #N/B weghalen en je kunt om hem sneller te maken eventueel index gebruiken i.p.v. Vlookup.	**Foutmeldingen wegwerken**
Hoeveel tijd heb je voor het invullen van het model over?	Het grootste probleem is wanneer wil je dit model gebruiken. Soms heb je binnen een week al de resultaten nodig zonder dat je alle input hebt, dan moet je dit snel kunnen invullen. Het volume model kost me nu soms erg veel tijd omdat het handmatig moet invullen aangezien de input verder nog niet gemaakt is.	Binnen een week resultaten
Hoeveel tijd denk je kwijt te zijn aan het model?	Vooral het runnen koste me toen heel erg veel tijd	**lange run tijd**
Waar denk je dat we nu de meeste voordeel uit kunnen halen in de logistiek?	We moeten goed gaan nadenken wie dit model gaat invullen. Wij kunnen dit ook doen zodat het tijd scheelt bij de anderen. Je kunt inderdaad ook zelf een eerste opzetje leveren die daarna aangepast kan worden door bedrijsbureau.	

All the suborganisations of DV have an improvement manager who helps with changes and gives advice to the management of the suborganization. Since she is involved with many innovations within the company, she was interviewed to talk more about the culture of DVBH and how she handles the acceptance of new innovations. Table 48 shows the answers she gave during the interview. This table shows that she has multiple ways of improving the acceptance of a new tool by employees. She suggested to show what financial benefit can be gained from the tool and to have minimal effort to increase the acceptance

Table 48 Results interview improvement manager DVBH

Interview vragen	Answers - Improvement Manager DVBH	Factor
Intro	Als verbetermanager ben je niet alleen bezig met veranderingen maar ook met het verbeteren van de cultuur en lean management. Ik adviseer de directie over hoe ze veranderingen kunnen aanpakken en de beslissing is aan hun.	
Wat is de houding van medwerkers tegenover innovatie?	mee te werken. In dat geval heb je verschillende opties. Je kunt het van bovenop opleggen, je kunt het laten gaan in geval een werknemer net voor pension zit, je kunt mensen trainingen laten doorlopen of je kunt kijken of iemand wel echt in dit bedrijf past. Het is belangrijk dat je mensen de urgentie laat zien zodat deze de verandering gaat accepteren. Veel mensen blijven in hun eigen werkwijze dus om te zorgen dat ze meegaan hierin kun je tegen ze zeggen: we gaan dit doen en ik ga je helpen. Dan help je ze de eerste paar keer en groeit het in hun werkwijze. We hebben nu iedere week voor ieder project een PEP meeting. In deze meeting bespreken we de vorige week, wat er fout ging en	Wel eens weigeringen, Urgentie laten zien, persoonlijke aanpak
Zijn de doelen van DV gericht op financiële winst of zijn er ook andere doelen?	Niet alle veranderingen hebben een financieel doel.	Winst niet altijd doel
Watvoor voordeel haal je nu uit het model en wat wil je eruit halen?	Je zou meer kunnen gaan kijken wat zijn mijn kosten en waar kan ik de financiele voordelen uit halen	**Financiele voordeel laten zien**
Komt de tijd voor het invullen die je denkt kwijt te zijn overeen met de tijd je ervoor over hebt?	Een werknemer moet echt minimale inspanning voor dit model nodig hebben, de nodige input moet echt minimaal zijn.	Minimaal invultijd nodig

Division is the umbrella of all the suborganizations of DV working in housing & utility. Division has an information manager which works on the digitalization of the Company. Since the crane scheduling tool has a big digitalization aspect, and interview was scheduled with the information manager to inform him about the tool and to get input from a different part of the company. Table 49 shows the results of this interview. This interview shows that DV is currently focusing on getting the basics of the digitalization in the company right. In the next step, they want to focus on the digitalization of the construction site. The crane scheduling tool already focusses on the digitalization of the construction site. Therefore, the level of the digitalization of the company might not be ready yet for the crane scheduling tool. There is mainly among the younger generation a lot of enthusiasm for new tools which might improve the acceptance of the tool. The information manager saw a lot of potential in the tool and thinks it is a good next step after the new application of the volume model is ready and the transportation management tool is fully working.

Table 49 Results interview information manager

Interview vragen	Answers - Information manager	Excerpt
Hoeveel is DV bezig met innovatie?	We willen niet in het wild gaan innoveren, maar we hebben een strategie ontwikkeld waaronder voor digitalisering. In deze strategie leggen we onder andere uit dat we met data willen het inzetten daarvan. Voor digitalisering hebben we we drie horiozonnen. De eerste is morgen waarbij we de basis zetten. Hier zijn we nu mee bezig, daarna willen we de bouwplaats meer digitaliseren en naar spannendere innovaties kijken zoals VR en AR. Eigenlijk alles wat we doen leggen we naast de strategie om te kijken of het bijdraagt aan de doelstelling. Binnen Dura Vermeer hebben we hele korte lijnen en zijn wel ondernemend en pragmatisch. Dat is een voordeel en nadeel bij innoveren	Strategie doelen, inzet data, digitaliseringsfocus op basis, ondernemend
Wat is de houding van medwerkers tegenover innovatie?	Mensen zijn in hun prive leven nu ook bezig met digitalisering en jonge mensen zijn ook heel erg enthousiast. Daarnaast gaan oude mensen ook al met pensioen. We werken nu veel met koppeltjes tussen oude en jonge mensen. Tegenzin komen we niet tegen, dus het is niet alsof mensen het niet willen, maar mensen vinden het of gewoon moeilijk, anderzijds is het soms ook een beetje onbewuste onbekwaamheid, mensen weten niet dat het beter kan	Enthousiasme jonge generatie, geen tegenzin, onbewuste onbekwaamheid
Zijn de doelen van DV gericht op financiële winst of zijn er ook andere doelen?	Het doel is niet altijd finaniciële winst, maar ook het verbeteren van de samerwerking en het werk leuker maken.	non-finaciële doelen
Hoeveel kennis haal je uit ervaring en hoeveel uit documenten?	Mensen willen de lange documenten niet meer lezen. Dus we werken vooral in koppels zodat de oudere generatie de kennis en ervaring kan delen en de jonge generatie de kennis van de digitalisatie. We hebben wel nog inloopspreekuren voor vragen	Kennis uit samenwerking
Wat is nu onduidelijk aan het model? Welke kennis mis je?	Wat bedoel je precies met elementen per vracht en hoe bereken je deze is nog een beetje vaag. Hier kun je misschien Ibis calculaties nog voor gebruiken	Elementen per vracht, geen ontbrekende kennis
Wat zou je verbeteren aan de gebruiksvriendelijkheid?	Excel heeft beperkingen vooral met de integratie met andere applicaties. Daarom zou het mooi zijn dat je dit ook kunt toevoegen aan de nieuwe applicatie.	Beperkingen Excel, mogelijkheid toevoegen in nieuwe applicatie
Watvoor voordeel haal je nu uit het model en wat wil je eruit halen?	Het dagschema is praktische output voor de hele bouwplaats. Je kunt ervaring gebruiken door bij te plussen, mooi dat je dat hebt meegenomen. Je maakt heel inzichtelijk waar je buffers zitten en je kunt makkelijk zien wanneer iemand het anders/beter doet	Dagschema is praktisch, combi ervaring en data, inzichtelijke buffers, inzichtelijk verbeteringen
Wat denk je dat het model in de toekomst kan bieden?	De mogelijke koppeling met Ilips is zeer interessant. Zodra de applicatie van het volume model af is en het nieuwe Ilips staat, is dit een mooie vervolgstap. Het is belangrijk dat je het daarvoor goed uitwerkt, maar dat heb je volgens mij al gedaan. Verder moet je zorgen dat de acceptatie er is en dat de resultaten realistisch zijn.	Mooie vervolgstap na Ilips en volume model, zorg voor acceptatie en realistische resultaten

One of the project organisers of DVBMW was very enthusiastic about the tool and more input about the tool for the preparation phase was still missing. Therefore, a meeting was scheduled with this project organisers. The logistics manager of the same suborganization filled in the volume model for this project and provided input. Therefore, he also joined the meeting. Table 50 shows the results of this meeting. The table shows that the results were lower than expected by the project organiser. As a result, many possible updates were named to find the cause of the results. Even though the results are lower, they still saw drivers to use this tool after the updates are implemented.

Table 50 Results interview project organisers and logistics manager DVBMW

Interview vragen	Answers - Project Organiser & Logistics manager	Excerpt
Wat is nu onduidelijk aan het model? Welke kennis mis je?	Wat bedoel je met het aantal elementen per vracht? Om 1 wand te plaatsen heb je meerdere hijsjes nodig. Dus je kunt dit beter aanpassen naar aantal hijsjes i.p.v. elementen. Verder is het duidelijk	**Elementen vervangen door hijsjes, duidelijk**
Zijn de resultaten realistisch?	Je hebt de kraan veel langer nodig op een dag. Je verdeelt de uren over teveel dagen. Ik denk dat je de werkbare dagen moet aanpassen naar de activiteitsdagen. Voor het volume model rekenen we nu gemiddeld met 3.74 werkdagen per week.	**Werkbare dagen vervangen door activiteitsdagen, 3.74 werkdagen per week i.p.v. 5**
Zijn de resultaten van het model	Duidelijk	Duidelijk
In hoeverre komen de resultaten overeen met je gevoel?	Ik heb voor dit project 2 torenkranen gepland en ik denk dat dit krap gaat worden. Volgens het model is er maar 0.5 torenkraan nodig, dus dit is veel te laag	1/4 van totaal gevoel
Watvoor voordeel haal je nu uit het model en wat wil je eruit halen?	Je geeft alle resultaten mooi weer. Deze grafieken van het aantal uren en de buffer percentages zijn precies wat we nodig hebben en willen weten.	kraanuren over tijd, bufferoverzichten

During this research, the tool became more valuable because of nitrogen legislation. For this law, the logistics managers needed more information which could possibly be given by the tool . Therefore, a new interview was conducted with the logistics manager of DVBH. Table 51 shows the results of this interview. This table shows that the logistics manager needed new important updates for the new legislation and thus saw new opportunities.

Table 51 Results interview logistics manager DVBH

Interview vragen	Answers - Logistics manager	Excerpt
Wat zou je verbeteren aan de gebruiksvriendelijkheid?	Er komen veel foutmeldingen die verwijzen naar de code doordat informatie mist in het inputform. Dit is niet makkelijk uit te lezen voor de werknemer. Dus missende informatie moet op een andere manier weergegeven worden	**Foutmeldingen missende informatie**
Watvoor voordeel haal je nu uit het model en wat wil je eruit halen?	De output is nu alleen van de kraan, maar in de toekomst zou het mooi zijn als we ook output krijgen van andere resources. Deze kunnen we goed gebruiken voor de stikstofberekeningen.	**Andere resources toevoegen**
Komt de tijd voor het invullen die je denkt kwijt te zijn overeen met de tijd je ervoor over hebt?	De informatie van het volume model is makkelijk te verkrijgen, daarna is het alleen nog nieuwe informatie die toegevoegd moet worden	Volume model lukt

Appendix I Enablers, Drivers, Barriers

This appendix gives an overview of all the enablers, drivers and barriers per data collection method. There are no tables for the drivers of the model evaluation and observations because these data methods showed no drivers. The tables of the barriers also show if they are resolved with an update, enabler or driver.

Table 52 Overview enablers of interviews

Enablers			
Factors	**Company level**	**Project level**	
		Preparation	**Execution**
Rules & regulations	Bouwplaats, omgeving en volume		Weinig (opslag)ruimte, hoge omsteltijd
Culture of innovation	Urgentie laten zien, persoonlijke aanpak, Strategie doelen, ondernemend, Enthousiasme jonge generatie, geen tegenzin, onbewuste onbekwaamheid		DV denkt verder na over berekeningen
Financial benefit	Winst niet altijd doel (2x)		
Cooperation subcontractors	Volledig aanpassen aan klant, DV stuurt		
Integration explicit & tacit knowledge	Gebruik ervaringsgetallen, ervaringsgetallen worden aangenomen		
Employee skills & knowledge of the product	Goede toevoeging van omsteltijd, geen ontbrekende kennis, duidelijk	Duidelijk (2x)	Duidelijk
Output quality		Geloofwaardig op basis van de input	Realistisch
Result demonstratability	Duidelijk	Resultaten compleet (2x), Duidelijke resultaten	Resultaten compleet (2x), duidelijke resultaten
Compatibility	Niet ongeloofwaardig	Verdiepingsniveau is realistisch	Gevoelsmatig kloppen de resultaten(2x), Realistisch na herzien input
Ease of use	Mogelijkheid toevoegen in nieuwe applicatie		
Performance expectancy	Informatie hoeveelheid kranen, Informatie nodige budget (2x), Dagschema is praktisch	Beantwoord nodige vragen	
Effort expectation	Evenveel als huidige tijd (2x)		
Image of product	Focus op laaghangend fruit, voor nu focus op bedrijsbureau, zorg voor acceptatie en realistische resultaten		

Table 53 Overview enablers of model evaluation

Enablers		
Factors	**Project level**	
	Preparation	**Execution**
Data		planning beschikbaar, Beschikbaar en betrouwbaar
Output quality	Realistisch(3x), logisch(2x)	Realistisch, consistent
Result demonstratability	Duidelijk(2x), makkelijk, overzichtelijk	Compleet, overzichtelijk (2x)
Ease of use	Makkelijk(3x), automatisch(2x)	Simpel

Table 54 Overview enabler of observations

Enablers		
Factors	**Company level**	**Project level**
		Execution
Employee skills & knowledge of the product	Begrijpelijk	
Facilitating conditions	Volume model lukt	
Data		De lostijden kloppen grotendeels
Output quality		
Ease of use		
Triability		

Table 55 Overview drivers of interviews

Drivers			
Factors	**Company level**	**Project level**	
		Preparation	**Execution**
Rules & regulations	Logistieke output nodig voor wetgeving		
Culture of innovation	Inzet data		Dagschema nodig voor iedereen op de bouwplaats
Financial benefit			Achterstand inhalen, boete clausule
Cooperation subcontractors	DV denkt verder na		
Integration explicit & tacit knowledge			
Employee skills & knowledge of the product			
Facilitating conditions			
Data			
Output quality			
Result demonstratability			Weten wat je per dag moet doen
Compatibility			
Ease of use			
Triability			
Performance expectancy	Data-gestuurde beslissingen, Makkelijker leren op project niveau, verhogen standaardisatie, aanzet tot betere resultaten, goeie toevoeging grafiek nodige kraanuren bedrijfsbureau (2x), combi ervaring en data, inzichtelijke buffers (2x), inzichtelijk verbeteringen		Automatisch dagschema's, Makkelijker leren, makkelijker standaardiseren, Dagcapaciteit, optimale aankomsttijd vracht, aanzet nadenken omsteltijd strategie, efficiëntie verhogen
Effort expectation			
Image of product	Performance gericht sturen, Aanzet tot betere resultaten van zowel leegstand als overgebruik, Mooie vervolgstap na Ilips en volume model		

Table 56 Overview Barriers of Interviews

Barriers						
Factors	**Company level**		**Project level**			
	Barrier	**Valt weg tegen**	**Preparation**	**Valt weg tegen**	**Execution**	**Valt weg tegen**
Rules & regulations	Geen steun regering	Logistieke output nodig voor wetgeving			Gecombineerde vrachten, Aankomst tijd vrachten en kraantijd onderaannemers onbekend	**Gecombineerde vrachten**
Culture of innovation	Wel eens weigeringen, digitaliseringsfocus op basis	Genoeg middelen voor medewerking				
Financial benefit						
Cooperation subcontractors	Eigen planning, Ervaring gebaseerd	Volledig aanpassen aan klant, DV stuurt				
Integration explicit & tacit knowledge	Kennis uit ervaring, vragen naar andere ervaringen, Geen notatie, delen in					
Employee skills & knowledge of the product	Secondes lijken te gedetailleerd, Twijfel lostijden, twijfel verschillende types kraan nodig, leverancier onbekend in voorbereidings stadium, Elementen per vracht				Skilllevel kraanmachinist	**Skilllevel kraanmachinist**
Output quality	Geen hijshoogte meegenomen in lostijd, Alleen productieve uren, onwerkbare dagen niet meegenomen	**Alleen productieve uren, onwerkbare dagen niet meegenomen**	Anders dan de praktijk, anders dan aannames leverancier		In theorie klopt het, uitzonderingen niet meegenomen, Na meer dagen gaat alles soepeler	
Result demonstratability			Geen vaste dagen voor vaste taken, zelf leveranciers toevoegen	**Geen vaste dagen voor vaste taken, zelf leveranicers toevoegen**	Geen retourvracht meegenomen	**Geen retourvracht meegenomen**
Compatibility	Geen onderscheid type kraan, 1/4 uren van totaal gevoel		Geen overeenkomt op (projectniveau) (2x), twijfel input lostijd			
Ease of use	Dubbelop werk met Ilips, Beperkingen Excel				Uitleggen werknemers	
Performance expectancy	Twijfel toegevoegde waarde utvoerders tegenover alleen procestijden geven	Automatisch dagschema's, Makkelijker leren, makkelijker standaardiseren, Dagcapaciteit, optimale aankomsttijd vracht, Aanzet nadenken omsteltijd strategie				
Effort expectation	Teveel invultijd tegenover toegevoegde waarde, Twijfel resultaten op het juiste , lange run tijd, Minimale invultijd nodig	Evenveel als huidige tijd (2x), **lange run tijd**				
Image of product	Twijfel optimaal gebruik eindgebruiker	Mooie vervolgstap na Ilips en volume model				

Table 57 Overview barriers of model evaluation

Barriers				
Factors	**Project level**			
	Preparation	**Valt weg tegen**	**Execution**	**Valt weg tegen**
Data	Aantal vrachten onbekend(4x), Aantal elementen per vracht onbekend(5x), geen input van veel leveranciers(3x), Onbekende omsteltijd(3x), Hijsmethode onbekend		Tijden hijsmethodes, niet alle hijsmethodes, schatting omsteltijd(2X), planning incompleet,Aantal vrachten onbekend	
Output quality	Inconsistent op verschillende niveau's (4x)		Te nauwkeurig, dagen onafhankelijk, lostijd vrachtwagen verkeerd	**Te nauwkeurig, dagen onafhankelijk, lostijd vrachtwagen verkeerd**
Result demonstratability				
Ease of use			Oorzaak non-feasible onbekend, geen mogelijkheid tot handmatig invoeren lostijd, geen variabele werktijden, Combinatie elementen onnodig, weekschema i.p.v. dag generen	**Oorzaak non-feasible onbekend, geen mogelijkheid tot handmatig invoeren lostijd, geen variabele werktijden, Combinatie elementen onnodig, weekschema i.p.v. dag generen**

Table 58 Overview barriers of observations

Barriers				
Factors	**Company level**	**Valt weg tegen**	**Project level**	
			Execution	**Valt weg tegen**
Employee skills & knowledge of the product				
Facilitating conditions				
Data	Schatting hijsmethode en aantal elementen			
Output quality			Er is geen opstart en afsluittijd gerekend, oorzaken waar je geen invloed op hebt	**Er is geen opstart en afsluittijd gerekend**
Ease of use				
Triability	Niet zelfstandig invullen			

Appendix J Results possible updates

This appendix describes all the possible updates found during the data collection. Table 59 shows all the named possible updates in the first column. This table also shows based on which version of the tool the data was collected and in which version of the tool the update was implemented. The updates are first checked with the logistics manager for their relevance. If it was decided that the update was not relevant there is a – in the column. The table explains how the update was implemented or why the update was not implemented. Lastly, the table shows which indicator of the theoretical framework is improved by the update. If this was an update based on general feedback the indicator has a c for company level and if it was project specific, the indicator has a p.

Table 59 Possible updates for the tool

Genoemde mogelijk updates	Genoemd gebaseerd op versie	Geïmplementeerd in versie	Indicator	Uitleg
Bedrijfsbureau en uitvoering splitten	0	5	Ease of use - c	Bij de laatste versie worden de sheets voor de 2 verschillende gebruikers in verschillende bestanden gezet om het overzichtelijker te maken. Dit kan omdat niet iedere gebruiker alle sheets gebruikt.
Secondes lijk te gedetailleerd	0	5	Employee skills & knowledge of the product - c	De lostijd wordt nu weergegeven in secondes, maar dit lijkt te gedetailleerd voor de werknemers. Daarom wordt er nu afgerond op 1 decimaal in het input form. In de code wordt dit niet afgerond
Tussen berekeningen weglaten	0	2	Ease of use - c	De sheets met tussenberekeningen worden verborgen in het bestand.
Synchronisatie Kyp en Ilips	0	-	Performance expectancy - c	De synchronisatie met Kyp wordt niet uitgevoerd omdat niet iedere uitvoerder alle informatie in Kyp compleet invult. De synchronisatie met Ilips wordt niet uitgevoerd omdat dit programma vervangen gaat worden binnen het bedrijf.
Onderscheid type kraan	0	-	Compatibility - c	Er wordt geen onderscheid gemaakt tussen kranen omdat de lostijden van verschillende kraantypes vergelijkbaar is. Dit is gemeten tijdens een vorig onderzoek binnen het bedrijf. Eventueel kan er door de gebruiken bijgeplust worden per onderdeel.
Compensatie lostijd hijshoogte	0	-	Output quality - c	Er wordt geen extra lostijd toegevoegd bij een andere hoogte. Dit is pas van toepassing bij een veel verdiepingen en het verschil is relatief klein vergeleken met de volledige lostijd. Eventueel kan er bijgeplust worden per element door de werknemer.
Te nauwkeurig	0	1	Data - p	Het dagschema wordt op de minuut precies gegenereerd. Er is een extra input cell toegevoegd aan het inputform waarin de construction manager kan aangeven op hoeveel minuten hij het schema wil afronden
Dagen onafhankelijk	0	3	Data - p	De tool berekende de capacitieit en het dagschema voor 1 dag, maar soms worden er ook vrachten een of meerdere dagen van te voren. Het schema kan dit nu ook verwerken door de eindkolom van het bouwonderdeel te veranderen in de leverdatum
Geen mogelijkheid tot handmatig invoeren lostijd	0	1	Ease of use - p	Er is een extra kolom toegevoegd waarin de gebruiker extra tijd voor het lossen kan toevoegen. Dit kan voor ieder bouwelement en geeft de mogelijkheid om lostijd toe te voegen voor elementen waar nog geen lostijd voor gemeten is zonder formules uit de cell te verwijderen
Geen variabele werktijden	0	1	Ease of use - p	In het dagschema kan nu aangegeven worden wanneer de werkdag begint en wanneer deze eindigt. Hier wordt het schema op aangepast

Oorzaak non-feasible onbekend	0	1	Ease of use - p	Wanneer er door de bouwplaatseigenschappen geen feasible solution gegenereerd kan worden, geeft het model nu ook door welke bouwplaatseigenschap dit is en voor welke dag / week
Lostijd vrachtwagen verkeerd	0	1	Output quality - p	De lostijd van een kraan is nu berekend als een factor van de lostijd van een kraan. Hierdoor hoeven deze niet meer hetzelfde te zijn
Sensitivity analyse input data	0	2	Performance expectancy - c	Het bestand bevat nu een extra sheet waarin de invloed van een verandering in de input data gezien kan worden in een grafiek. Hierdoor kunnen werknemers kijken watvoor invloed het heeft om een aanpassing te doen in bijvoorbeeld de planning, het aantal vrachten of in de leverancier.
Skilllevel kraanmachinist	1	-	Employee skills & knowledge of the product - p	Er is geen compensatie voor skills of productiviteit van werknemers omdat dit geen standaard is.
Gecombineerde vrachten	1	2	Rules & regulations - p	Op dagniveau kunnen elementen nu ingedeeld worden per vracht zodat er meerdere elementen in een vracht kunnen.
Geen informatie soort vracht	1	2	Result demonstratability - p	Het dagschema laat nu ook automatisch informatie over de elementen in de vracht zien.
Pauze niet in dagschema	1	2	Result demonstratability - p	Het dagschema van de kraan geeft nu ook de pauzes aan.
Geen onderscheid tussen nodige uren en minimaal te huren uren	1	2	Result demonstratability - p	De totale grafiek op dagniveu laat nu de nodige uren, de minimaal te huren uren en de geplande te huren uren zien.
Eigen initiatief - overzicht buffers uitvoering	1	3	-	Tijdens heel veel gesprekken viel het op dat iedereen graag overal extra buffers voor inpland. Om te zorgen dat er niet buffer op buffer, krijgt het model nu een overzicht van alle buffers die zijn toegevoegd.
Pauze momenten verkeerd	2	3	Output quality -p	De pauzes worden nu verplaatst als er nog halve vrachten niet verwerkt zijn, maar sommige uitvoerders willen dit op standaard momenten.
Element niveau	2	3	Result demonstratability -p	Bij grote elementen duurt het plaatsen lang. Daarom wil je een schema maken op het plaatsen van elementen in plaats van het plaatsen van de gehele vracht.
weekschema i.p.v. dag generen	2		Ease of use p	Voor dit project was de wens om snel van meerdere dagen een schema te krijgen, maar de tool had deze optie nog niet. Nu kun je voor een langere periode aangeven welke dagschema's je met 1 klik wilt hebben.
Foutmeldingen wegwerken	3	4	Ease of use - c	In het inputform staan soms nog foutmeldingen als bepaalde informatie niet is ingevuld. Dit kan verwarrend zijn voor werkenmeres. Daarom zijn deze meldingen met een als functie weggewerkt.
Eenheid lostijd beter aangeven	3	4	Employee skills & knowledge of the product - c	Een van de werknemers gaf aan dat hij niet wist met watvoor eenheid de lostijd is ingevuld. Dit kwam bij meerdere gesprekken naar boven. Daarom is deze eenheid nu per activiteit aangegeven.

Opmerkingvakken toevoegen	3	4	Integration explicit & tacit knowledge - c	Om beter te leren en om makkelijker uitzonderingen aan te geven zijn er nu opmerkingvakken toegevoegd aan de tool.
Geen vaste dagen voor vaste taken	2	-	Result demonstratability - p	Bij deze update kun je aangeven wanneer welke activiteit sowieso uitgevoerd moet worden. Dit is lastig te implementeren en is maar door 1 werknemer genoemd. Daarom heeft dit geen prioriteit en moet dit voorlopig met de hand gecheckt worden.
Alleen productieve uren	3	4	Output quality - c	Momenteel geeft het model aan de productieve uren aan, maar niet de uren die voor pauze en opstarttijd gebruikt moeten worden. Met deze nieuwe update zijn deze tijden ook weergegeven in de grafiek met nodige uren
Onwerkbare dagen niet meegenomen	3	4	Output quality - c	Er zijn een aantal dagen in het jaar waarop niet gewerkt kan worden door weersomstandigen heden of vakanties. Na deze update zorgt het model dat er geen uren op deze dagen gepland wordt.
Financiele voordeel laten zien	3	5	Performance expectancy - c	Ondanks dat niet alle innovaties financiële doelen hoeven te hebben van DV, kan het wel de acceptatie verhogen om de financiële resultaten te laten zien. Met deze update laat het model zien wat je kunt besparen door machnisten alleen op nodige dagen te laten werken.
Lange runtijd	3	5	Effort expectation - c	In de voorbereiding wordt de betrouwbaarheid van leveranciers meegenomen. In geval er veel mogelijke afwijkingen van de aankomsttijd zijn, zijn er veel scenarios waardoor het model erg langzaam kan worden. Met deze nieuwe update is er een andere strategie gebruikt voor het aantal scenarios waardoor er minder scenarios zijn.
Andere resources toevoegen	4	5	Output quality - c	Voor de stikstofwetgeving moet het aantal uren van meerdere resources berekend worden. Dit model kan voor meerdere resources gebruikt worden als de input wordt aangepast. Daarom is er met deze update een nieuw bestand gemaakt met het model voor bedrijfsbureau waarbij er voor meerdere resources verschillende input forms zijn. Het aantal uren wordt hierbij gesplits per jaar.
Foutmeldingen missende informatie	4	5	Ease of use - c	Zodra informatie niet wordt ingevoerd in het inputformulier onstaat er een foutmelding in de code. De gebruiker kan de code niet lezen en snapt niet wat er fout gaat. Daarom is er een extra code geschreven die eerst checkt of het inputformulier volledig is. Als dit niet het geval is geeft het model aan welke informatie mist.
Elementen vervangen door hijsjes	4	5	Employee skills & knowledge of the product - c	Voor een aantal bouwonderdelen moeten er meerdere hijsjes gedaan worden om 1 element te plaatsen. Daarom is deze verwoording verwarrend en is het aangepast naar aantal hijsjes i.p.v. elementen.
Werkbare dagen vervangen door activiteitsdagen	4	-	Output quality - c	Deze update is niet gedaan omdat hierdoor de berekening niet meer zou kloppen. Het is een gemiddelde over de gehele periode. Het probleem wordt hierbij opgelost door ook een verdiepingsniveau in te vullen.
3.74 werkdagen per week i.p	4	-	Output quality - c	Deez update is ook niet gedaan omdat de berekening hierdoor niet meer zou kloppen. In het volume model is een kortere werkweek genomen om te compenseren voor onwerkbare dagen. Aangezien deze al meegenomen zijn wordt hier nog gerekend met een 5 dagen werkweek
Zelf leveranciers toevoegen	4	-	Result demonstratability - p	Deze update is niet uitgevoerd omdat de output van Ilips beheerd wordt door de logistiek managers. Daarom kunnen deze het makkelijkst ook de informatie over leveranciers invullen. Als een werknemer zelf leveranciers toevoegt is hier waarschijnlijk nog niet genoeg leveringsbetrouwbaarheid data van.

Appendix K Recommendation

Table 60 Overview recommendations

Number	Problems	Possible next steps	Essential	Explanation
1	The digitalisation level of the company is not ready	Cooperate with digitalisation team	no	The digitalisation team has made a flow which shows what digitalisation projects should be prioritized. Therefore, they can give good advise about when to start a new project and at what pace this should be implemented.
2a	The data set is not complete	Perform observations to measure the movement times of more lifting methods	yes	Currently, not all the movement times of lifting methods are known, so an estimation is still used. This research showed that the measured times are reliable. Therefore, it is worth the effort to increase this data set.
2b		Create work instructions for the execution phase	no	The movement times are based on a certain way of working. Therefore, it is important to have work instructions which show on what process the times are based. Additionally, this makes it easier to find deviations or improvements.
2c		Find and document deviations from the model to learn and be able to predict deviations	no	There are a lot of buffers included in the model. By measuring and documentating deviations, the buffers can be based on averages of actual data.
2d		Document and request information about the movements per truck	yes	The elements per truck is on a project level always an estimation while it is know on the day level. By documenting the data on the day level, the estimations on the project level can be replaced by averages of actual data.
3a	Limitations of Excel	Let the logistics manager fill in the input form and let the end-user adjust the input	yes	Originally, the tool was designed for the employees of DV to use it independently. Since there are several instructions due to the limitations of Excel, it is recommended to let the logistics manager fiil it in first who know more about the tool. The employees can afterwards adjust the input.
3b		Add the crane model to the application for the volume model and the transportation management system	yes	Excel is limited in improving the user-friendliness. The volume model also used to be implemented in Excel, but currently a new application is developed which is more user-friendly. The project and floor level part of the crane model can be added to this application after the volume model is implemented. The same is applicable for day level of the crane model to the transportation management system.
4	Depence suppliers	Increase cooperation suppliers	no	The crane schedule is very dependen on the arrival of trucks. Additionally, there are a lot of tasks which need to be done in between by subcontractors. With a schedule they can also improve their processes and increase their reliability. Therefore, it is important to also let them add tasks and have clear agreements.
5a	Sharing knowledge in cooperation	Use the model to optimize projects and not only for logistics challenging projects	no	By using the tool for also logistic simple projects, big improvements can be made with little effort. This way, more can be learned and more people can see benefit from it and share it with other employees.
5b		Create an overview of the goals and next steps for the logistics department	no	By creating a clear overview of the goals and the next steps, this can also be communicated clearly when employees are instructed about the tool.