MSc Thesis

Optimum enlargement of the Eefde lock using a simulation model

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Optimum enlargement of the Eefde lock using a simulation model

by

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Summary

With the development of the inland waterway transport, ship locks become more and more important as infrastructure in waterway network. Currently, there are a lot of studies about the capacity of locks, but the impact of the chamber's horizontal dimensions on the passing time and the costs-benefits should be studied more. In order to study the method of selecting optimum scenarios of enlarging locks, Eefde lock is taken as a case. The thesis is aimed to determine the optimum enlargement scenario for the Eefde lock. Furthermore, the relationship between the horizontal dimensions of chambers and costs-benefits is also found and suggestions are given to other locks with insufficient capacity.

Eefde lock is located in the east of the Netherlands, which is important to the transport on the Twente canal. It also plays an important role in the economy of Twente region. However, the current lock does not have sufficient capacity because the waiting time of individual ship is more than 30 minutes which is too long for vessels. Thirty minutes is the maximum waiting time for commercial vessels. The responsible authority of the Eefde lock has already decided to expand the capacity of the lock. Therefore, the study of the optimum enlargement scenarios is necessary. In the thesis, the method of simulation is used to get the relevant values of passage.

The information and data are collected and analysed first. The data are mainly from Rijkswaterstaat. Data are about the vessels and passage at the Eefde lock. Part of data is the prediction for the future. In order to calibrate the data of passing time, personal field study at the Eefde lock is taken to record passing time.

Before simulation, different scenarios are made. The control variables of scenarios are the length, the width and the number of chambers. Scenarios are divided into two types, current scenarios and future scenarios. For both current and future situations, base scenarios are established and only one indicator is changed everytime. In the current situation, the enlargement method is to extend the length, the width of the chamber and build the second new chamber. In the future situation, the methods are enlarging length or width of the original chamber or building the second chamber and changing the dimensions of the second chamber.

In the thesis, SIVAK (Simulation model for Waterways and Infrastructures) is used for simulations. Data after analysis are put into SIVAK. Then, models of the Eefde lock are made. The models are proved to be true by scenarios with data from RWS. Simulations of different enlargement scenarios run in the environment of PROSIM. According to the outputs of simulations, passing time and the capacity of the Eefde lock can be obtained. The results of simulations are studied and analyzed in detail by tables and graphs. Scenarios which meet the requirement of passing time are selected. The requirement of passing time that passing time should be less than 50 minutes is obtained by calculation.

Selected scenarios are used to calculate the costs and benefits. Costs contain construction costs, operational costs and maintenance costs. Benefits are the reduction of waiting costs. Finally, the net

costs and waiting time are combined to get the optimum scenarios.

The study results in relationships between the horizontal dimensions of chamber, passing time and the cost-benefits. The enlargement of width is more effective to reduce waiting time than the enlargement of the length. The construction of the new chamber becomes the most efficient method. However, the most effective method of reducing passing time does not mean having the least costs. Net costs and waiting time are combined and the costs of per unit reduced waiting time are calculated. The optimum current scenarios and future scenarios for the Eefde lock are determined at last. Under the prediction from other different sources, there will be a large increase of ship number in 2050. The second chamber which RWS is going to build is not large enough. The optimum scenario shows that in order to have enough capacity in 2050, the new chamber should have the width of 18.5 meters which is wider than RWS's plan.

After the study of the Eefde lock, the approach to the optimum enlargement scenarios is generalized. The results and principles found in the study of the Eefde lock are applied in the generalized approach.

Based on the study, recommendations are provided for the Eefde lock and, in principle also for other locks which need enlargement. In order to improve the simulations in the future, recommendations are also given to the study method. For example, because the input data have some assumptions, in the further study, work should be done to improve the accuracy of input data for the enlargement of the Eefde lock. More real cases should be studied further in order to find more general regulations.

Preface

This graduation thesis marks an important milestone in my studying career at the Faculty of Civil Engineering and Geosciences, the Delft University of Technology. The thesis is completed at TU Delft with the help of many persons.

Firstly, I would like to thank the members of my graduation committee. They are prof. Tiedo Vellinga, ir. Henk Verheij and Dr.ir Winnie Daamen. Ir. Henk Verheij is my supervisor who is very responsible. Thank ir. Henk Verheij for helping me adjust the topic, for checking the thesis before meetings meticulously, and for answering many questions with great patience. He is so warm-hearted and spent much precious time helping me with the thesis. I am also appreciated for the instructions of prof. Tiedo Vellinga and Dr.ir Winnie Daamen. Their suggestions are highly helpful to my graduation thesis.

The topic of the thesis is chosen based on my personal interest and the provided topic from ir. Henk Verheij. Though there were many difficulties, I learn a lot during the time of thesis.

Last but not the least, I also would like to thank my family and my friends. They encourage me a lot and give me the confidence to finish the thesis.

Jing Shi

Delft, October, 2017

Contents

List of figures

List of tables

List of abbreviations

POT	Port of Twente
RWS	Rijkswaterstaat
PPP	Public-Private Partnership
SIVAK	Simulation model for Waterways and Infrastructure

1 Introduction

Chapter 1 contains the background and overview of the thesis. Background includes the general information of the Eefde lock. After background, the overview of the thesis is given. It focuses on the objectives, research question, research methodology, indicators, criteria, research significance, research scopes and assumptions. Finally, the outline of the thesis is introduced.

1.1 Background

Eefde lock is located in Eefde, the Netherlands. The lock complex is located on the Twentekanaal (Twente Canal) and is a national monument that was built in 1933. The location of Eefde lock is shown in figure 1.1. According to Port of Twente (2013), it is used by the department of Waterways and Public Works for water management and shipping.

Figure 1.1 Location of Eefde lock (adapted from: Worldatlas, 2017)

The chamber of the Eefde lock is 12 meters wide and 140 meters long (POT, 2013). Along length direction, 133 meters is the available length for accommodating vessels (Rijkswaterstaat [RWS], 2011). For the economic development of the Twente region, there is a plan of enlarging Eefde lock, which is going to start construction in 2017. The enlargement method is to build a second lock chamber at the north of the old one (figure 1.2).

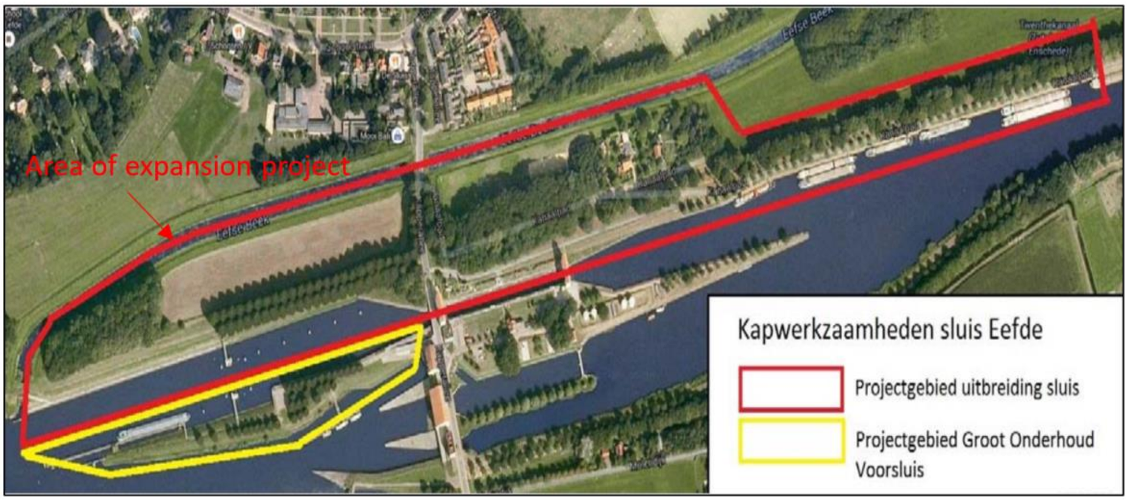


Figure 1.2 Plan of new chamber (Rijkswaterstaat [RWS], 2016)

The dimensions of the second chamber is 125 meters long and 12.5 meters wide. The estimated cost of the Eefde lock PPP (Public-Private Partnership) project is EUR 100 million (IJGlobal, 2016).

Though the expansion plan has been chosen by the responsible authority of the Eefde lock, it is also meaningful to check whether the plan is the optimum or whether there is a better plan of enlargement considering waiting time and costs-benefits. At the same time, the study of Eefde lock can provide theory basis to projects of enlarging other locks.

1.2 Objectives and research question

1.2.1 Objectives

The main objective of the research is to determine the optimum enlargement layout of the Eefde lock. The optimum scenarios are based on the combination of waiting time and costs-benefits. In reality, the waiting time is related to costs. When the waiting time becomes less, the construction costs will increase. The thesis is aimed to find the approach to balance waiting time with net costs and find the optimum scenarios. Then, the exact dimensions of enlargement can be determined at last. The relationship between the dimensions of chambers, passing time and cost-benefit is found. Useful principles will be applied to other locks which are going to be enlarged.

1.2.2 Research question

Currently, there are some enlargement projects of locks in the Netherlands. Before the construction of projects, many plans of projects are given by bidders. The authorities of locks mainly take into account of quality, price, environmental influence and social benefits when they select the plan of enlargement. The thesis does not consider all factors which will be described in the scope of research.

Eefde lock needs to be enlarged. The optimum enlargement is selected based on the waiting time and costs-benefits. The responsible authority of the Eefde lock has decided that the capacity will be increased because the waiting time is too long. The plan of enlargement is expected to be finished in 2020. It makes sense to study enlargement scenarios of the lock. Compared to possible enlargement plans, whether the 2nd chamber is the optimum choice will be considered. The method of simulation is used. The results of simulation will be analysed. At the same time, when the factors (number of ships, ship types) change in the future, the scenarios of enlarged lock need to be studied as well. By studying the Eefde lock, the method of choosing the best enlargement plan of ship lock will be given, and recommendations may be given to other locks.

Thus, the main research question of this thesis is defined as:

What is the optimum enlargement scenario of the Eefde lock with increasing capacity based on costs-benefits analysis?

Except the main questions, some questions will be answered first to support the main research questions.

- What are possible enlargement scenarios for the Eefde lock?
- What are criteria to choose the plan of enlargement based on simulation results?
- How to select optimum scenarios according to costs-benefits analysis?

1.3 Research methodology

Based on the above research question, the research approach is built up in this section. Initially, literature study is needed to find the possible topic and gaps about enlarging locks and find the significance of the thesis. Information and data are collected from publications to give adequate information on the research topic. Part of information comes from government and agency.

Except literature study, the data can also be collected by personal field survey. During the field survey, the process of locking at Eefde lock is observed. Time points of locking are recorded. The data from field survey are real but rough, so there exist some errors to some extent. When data need to be forecast, it should be based on information already known well.

Subsequently, a simulation model is used to get the waiting time and the capacity of Eefde lock based on the data collected and assumed. The simulation model is a digital process to create and analyze the physical model. By using simulation models, designers do not need to repeat building multiple physical prototypes. Locking is a complex process so that using simulation model can get the waiting time and the capacity of lock more conveniently. However, external validity is limited due to insufficient data. And part of the model is possible to be out of sight for users.

In the thesis, SIVAK is taken as a simulation model. SIVAK (Simulation model for Waterways and Infrastructures) is a program which has been widely used in the Netherlands. SIVAK simulation program is made to analyze traffic flows of ships and road traffic at bridges, locks, narrowing of waterways and waterway compartments. In this research, the SIVAK program is mainly used to analyze the ship traffic through the Eefde lock. PROSIM is the main part of SIVAK program which offers simulation environment to models. In SIVAK program, models are established first and then simulated. The results are obtained at last. Both input and output information will be introduced in detail in simulations.

The results then will be analysed and compared with each other. The optimum design scenario will be selected according to the waiting time and the costs-benefits analysis.

Detailed research methods and steps are introduced as follows.

- Collecting information

The first step is to collect information. The information can be from paper, education thesis, report of the company, as well as field survey. They should be collected as much as possible which include the general information about the conditions of the present Eefde lock, ship size and intensities, the cost of lock enlargement etc. Some information needed can be summarized as follows.

① *The reasons of enlarging the Eefde lock.*
② *Dimensions and number of ships in Twente Canal (current and future)*
③ *Locking process (arrangement of locking ships)*
④ *Vessels through the Eefde lock*

- Analysis of information

A collection of information is possible through the whole process of research. Then, it is important to classify and analyze the information. First, the challenge of present Eefde lock chamber should be clear. Secondly, several elements are determined in this phase. Ship size and intensities should be known. The number of ships is also important. What is more, the initial representative lock dimensions after the expansion is identified. The existing expansion method of lock chamber is studied.

- Scenarios

Initial scenarios of the enlarged Eefde lock are determined based on collected information. Scenarios are the horizontal dimensions of ship lock but changing the length, width and the number of the chamber. The scenarios will be modified gradually during the simulations. In general, scenarios are divided into current scenarios and future scenarios.

- Simulations

After analysing amounts of information, initial estimation for the enlargement of lock chamber is made. In order to compare different scenarios with each other, the dimensions of lock chamber is modified. Simulations are divided into two parts, current scenarios and future scenarios. For each part, base scenarios and enlargement scenarios are simulated. In current scenarios, the reference scenario is the existing lock chamber. In future scenarios, the Eefde lock with one chamber and two chambers is simulated. The data of ships will be put into the program. For current scenarios, real data are input. For future scenarios, the predicted number of ships are used. Before simulations of enlargement scenarios, SIVAK models are proved to be right by scenarios with data from RWS. Then, SIVAK program is used to get the passing time and capacity of lock chamber with different dimensions. SIVAK should be applied to each scenario respectively.

- Analysis of simulation results

After simulations, results can be obtained directly by the output of SIVAK. Different results will be analyzed and figures are made to show the possible principle clearly. The analysis of results will also be separated into the current situation and future situation.

- Analysis of costs and benefits

For each selected scenario, it is necessary to calculate the costs of extended construction. The costs should take into account of the fee of investment, maintenance and operation. In another aspect, profit of Eefde lock after the expansion is calculated. Profit is the decrease of the waiting cost. At last, cost and profit need to be considered at the same time to get the net profits. The net profits are taken as one of basis to choose the optimum scenario. The construction time needs to be taken into account. However, the rate of money is assumed to be consistent during construction time. In reality, estimated costs of enlargement projects can be used for convenience.

- Generalized approach to optimum scenarios

After the study of the Eefde lock, the generalized approach will be provided to other locks which also have the problem of insufficient capacity. The generalization process is modified based on the study of the Eefde lock and the results of the Eefde lock will be applied in this process.

- Conclusions

The main conclusion is based on the objective of the study. The whole research is summarized first. Then, the optimum expansion layout of lock chamber is determined. The optimum scenario results from the comparison between the enlargements of lock chamber based on the original ship lock and new lock chamber next to the old one. Whether the challenge of the capacity of the present Eefde lock has been reduced will be illustrated.

- Recommendations

Based on the results of the study, recommendations are given to the Eefde lock and other locks. Recommendations about thesis will be also described. The purpose of recommendations for the thesis is to improve the simulation in the future. It will also make the conclusions and principle more applicable for other locks.

The process of research is shown explicitly in the following figure 1.3.

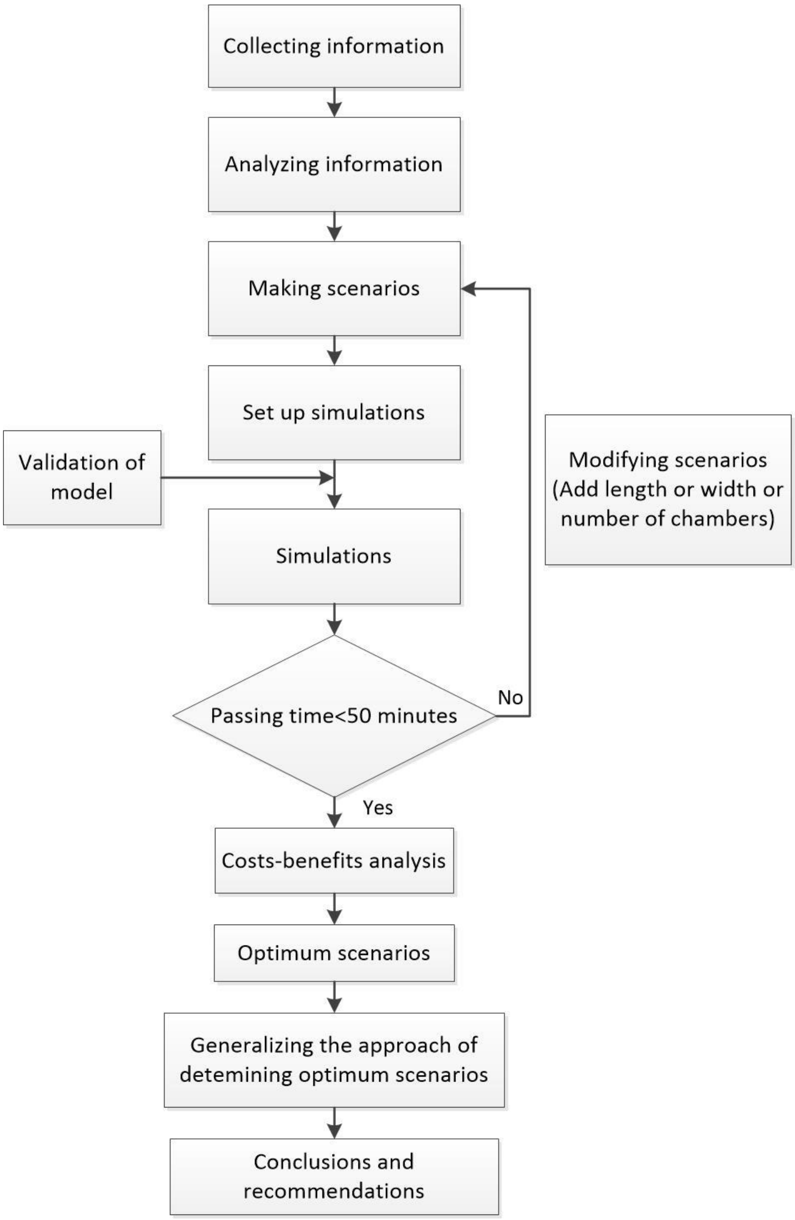


Figure 1.3 Flow pattern of research

1.4 Variables and criteria

As known from above sections, the process of research is in line with the judgment of the optimum scenarios. The scenarios have control variables. They are the length, the width and the number of chambers. When scenarios are made, only one indicator will be changed in every scenario.

Variables of scenarios:

- Length
- Width
- Number of chambers

After simulations, scenarios are selected according to criteria. One of criteria is the limit of waiting time. According to Waterway guidelines 2011 (Rijkswaterstaat [RWS], 2011), the waiting time of commercial vessels should be smaller than 30 minutes. Furthermore, the passing time for the Eefde lock should be smaller than 50 minutes which is calculated in section 2.3.2 (Locking process) later. The scenarios which meet the requirement of waiting time will be used to calculate the cost and benefit. In all, the criteria are as follows.

- Waiting time< 30 minutes; Passing time< 50 minutes
- Costs and benefits

1.5 Research significance

As introduced in Section 1.1 background, the case study of Eefde lock will get optimum scenarios for the enlarged ship lock. The optimum scenario is at the equilibrium point between the net costs and the waiting time. The thesis takes into account of both logic study and economy. The conclusions and recommendations are helpful to the enlargement of the Eefde lock.

The method of selecting the optimum scenario will also be generalized and applied to other locks. For example, the relationship between the dimensions of chamber and the benefits should be considered when other locks are going to be enlarged. Furthermore, the indicators in the thesis may be taken into account especially when other locks need enlargement. Because the topic is about the dimensions of the chamber which is not relevant to the local situation, the principle of choosing the optimum scenarios may be applied to many other locks. However, the costs and benefits depend on the local situation. In all, the thesis may be helpful for studying the enlargement of other locks.

1.6 Research scopes and assumptions

As mentioned in the above section, the main effort is focused on the real case, Eefde lock. For some factors in research, reasonable assumptions have to be made.

In order to solve the problem of research effectively, efforts should focus on the determined field. Information and data are collected from the local department, websites, paper etc. As some information is hard to collect, reasonable assumptions shall be made.

Eefde lock is located on Twente Canal. The water sections including west and east part of the Eefde lock are studied. The detailed length of water sections will be determined in the part of the simulation program.

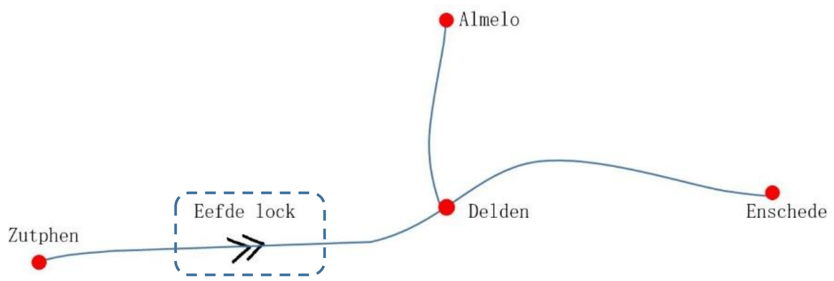


Figure 1.4 Simplified Twente canal and Eefde lock

Besides the Eefde lock, there are some bridges, ports and other infrastructures on the canal. The thesis only takes into account of the Eefde lock. Other infrastructures are neglected because the comparisons are only between scenarios of the Eefde lock. Moreover, the dimensions of locks which are put into simulation are the size of lock chamber indeed.

Furthermore, the optimum scenario is selected based on the consideration of economy. The environmental and social influences are not discussed here.

When chambers are enlarged, the locking time will be affected and is possible to be longer. In the thesis, locking time is assumed to be not affected by the dimensions of chambers. It is related to the vessels only.

When the future conditions are talked about, next 40 years until 2050 is discussed. The European Union has the objective that a "modal shift" of 30% road transport converts to rail and water in 2030, and 50% in 2050 (EUROPESE COMMISSIE [EC], 2011). Thus, 2050 can be taken as a time point to be studied which has larger and more obvious changes than 2030.

The thesis is aimed to compare the scenarios with each other. Thus, the interest rate can be assumed to be the same until 2050. It means that the change of economy scale is not taken into account.

Simulation program: using SIVAK. Rijkswaterstaat has different IWT models with different characteristics. Both tools of BasGoed and BIVAS focus on the prediction of traffic demand and volumes. SIVAK can simulate the traffic conditions in detail. Furthermore, SIVAK is dynamic simulation model which can be applied to specific locations. Thus, SIVAK is used as simulation program which can obtain the results clearly and quickly, such as passing time and capacity.

1.7 Outline of thesis

The thesis is aimed to find the optimum enlargement layout for the Eefde lock and offer reference to the future study of other locks. The sequence of the report chapters is in line with simulations. The flow of chapters is demonstrated in figure 1.5.

First, Chapter 1 introduces the background and overview of the thesis. This chapter is based on the research proposal. In Chapter 2, detailed data are collected and studied. The selection of data is also in this chapter. Based on the data and information from Chapter 2, data are analyzed, and several scenarios are made in Chapter 3. Then, parameters are given to SIVAK program. The detailed process of simulation can be found in Chapter 4. Chapter 5 discusses the validation of the model which proves the correctness of the model in the thesis. The results of the simulation are analyzed in Chapter 6. Chapter 7 is about the costs and benefits of each scenario which is the principle of optimization. Chapter 8 generalizes the approach of determining optimum scenarios for other locks. Finally, the conclusions of the optimum layout of locks and recommendations are elaborated in Chapter 9.

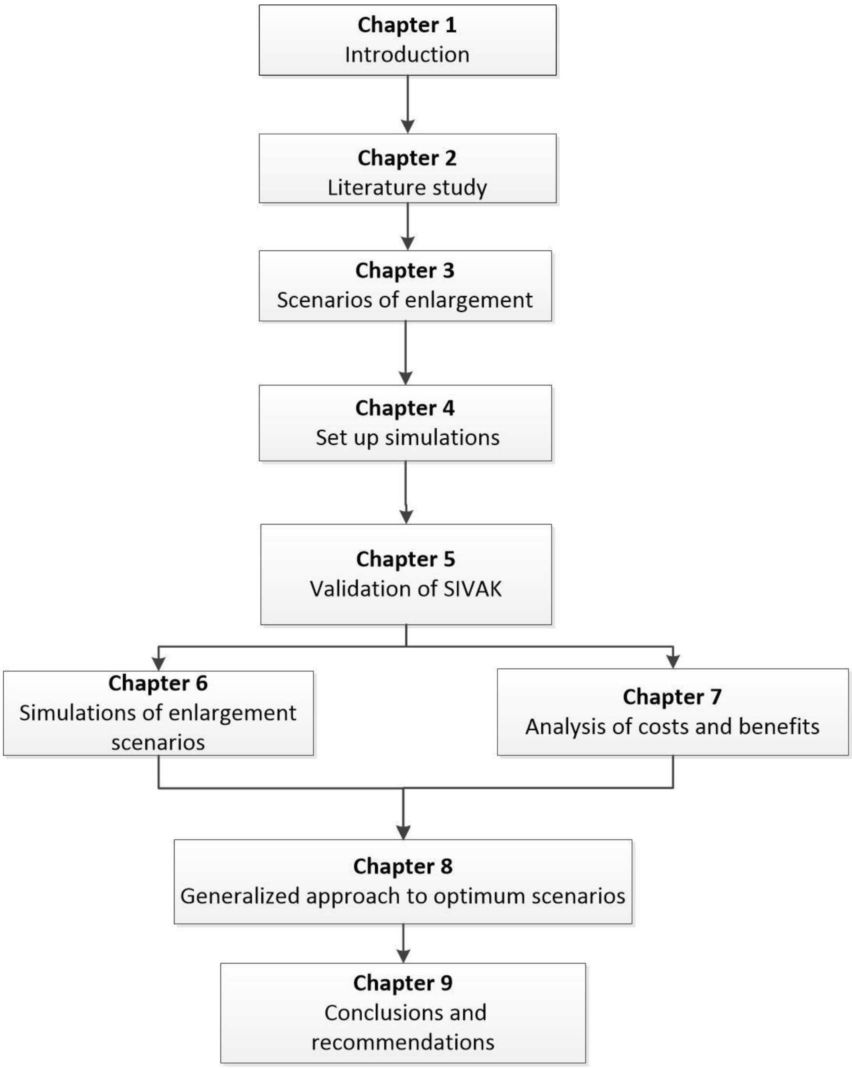


Figure 1.5 The flow of chapters

2 Literature and information

Literature study shows the related work already done by others. Then, related information is collected and analyzed. Information is about Twente canal, the Eefde lock and vessels. The related knowledge is introduced in the Appendix A, Appendix B and Appendix C.

2.1 Literature

Locks need enlargement when they cannot reach the requirement of traffic anymore. All around the world, many locks have been enlarged due to different reasons. Many researchers have paid attention to the topic of lock enlargement. However, many types of research are about the enlarged capacity of locks (Appendix B.2). There is not much literature about the selection of the optimum scenarios of lock enlargement.

There are some real cases in China about lock expansion. For example, according to Ma (2011), the enlargement of YunDong lock in Jiangsu province has four scenarios which have different placements of the new chamber. Advantages and disadvantages are listed for all scenarios. Engineering quantities and cost are calculated. The final selection of the scenario consider all the factors, such as the cost, geological condition and the situation of fleet.

The old BaoYing lock (Xia, 2012) at the Grand Canal need capacity expansion. Except the selection of horizontal layout, it also considers the water-carriage system and structure of upstream channel to improve the efficiency of lockage.

One simulation system is proposed by Xie (2014). The system is used to evaluate the enlargement of lock. It mainly contains model of traffic flow, scheduling model of ship lock and the model of lock gear.

The functional flexibility of lock design is also studied by R.J.A. de Groot (2009). The study shows that it is possible to construct a functional inland navigation lock that is able to cope with the changing ship sizes and intensities for the next 100 years. When the costs and benefits are calculated, Whole Life Costing (WLC) is used. Cost variables, initial construction costs and benefits and costs over the lifetime are included in WLC. Under the analysis of WLC, functional flexibility of lock design is the least expensive option for ‘Sluis Sambeek’, compared with a structural flexible lock. The structural flexible lock is a relatively easy extendable navigation lock, which can be enlarged when it is required. Furthermore, the detailed design of floated head is also introduced.

In Belgium, due to the increase in traffic and the upscaling of ship sizes, locks at the Albert canal need enlargement. IMDC was awarded to perform a study. A model was developed to study the capacity of locks. The study also contains the consideration of macro-economic development.

With respect to the SIVAK simulation, Chen (2014) and Liu (2015) have experience of using SIVAK to simulate the capacity of inland waterway and three gorges ship lock. These two cases can be taken as references for the thesis.

There is also some other literature but the relationship between the enlargement scenarios of lock and dimensions of the chamber can be studied further. As mentioned above, different studies have different principles to learn the enlargement of locks, such as structure improvement and the location of chambers. Though there are many indexes to judge the scenarios, attention is paid to the horizontal dimensions of chamber and cost-benefit in the thesis.

Actually, different locks are analyzed based on their own situations. It is hard to get a uniform rule for different locks. Therefore, the conclusion and recommendation of the thesis will offer theoretic reference to other locks but the particular situation of different locks should be analyzed as well.

2.2 Twente canal (Twentekanaal)

Twente canal (52°10′ N, 6°20′ E) is one of important water systems in the Netherlands. The main part of the canal which is from Zutphen and Enschede was completed in 1938. Then, there was a connection to Almelo port in 1953 (POT, 2013). The total length of Twente canal is 65km. The depth is about 3.5-5 meters. The water level difference is large which is approximately 21 meters between Zutphen and Enschede. The width of all sections of the canal is between 50 and 53 meters. The design of Twente canal expansion is still in phase. According to 'INNOVATION AND NETWORKS EXECUTIVE AGENCY' (2013), TEN-T project will upload the last section of Twente canal to make it suitable for larger vessels (class Va). The plan to upload the Twente canal can be found in table 2.1 (Bückmann , Gun , & Harmsen , 2012).

Table 2.1 Classes of canal sections（2010） (Bückmann , Gun , & Harmsen , 2012)

Alternatief	Referentiealternatief	Voorkeursalternatief
Sluis Eefde incl. voorpand	Va / 2,80	Va / 3,50
Eefde -Bolksbeek (fase 1)	Va / 2,80	Va / 3,50
Bolksbeek - Delden (fase 1)	Va / 2,80	Va / 2,80
Delden -Hengelo	IV* / 2,60	Krap Va / 2,80
Hengelo - Enschede	IV* / 2,60	Krap Va / 2,80
Zijtak naar Almelo	IV* / 2,50	Krap Va / 2,80
Almelo - De Haandrik**	II / 2,50	II / 2,60

* Voor de kanaalpanden Delden-Hengelo-Enschede en de zijtak Almelo geldt dat nu al wel schepen van klasse Va worden toegelaten, maar met een extra beperking in breedte en/of diepgang.

** Dit traject wordt verruimd zodat het bereikbaar is voor schepen met 2,60m diepgang. Dit is een autonome ontwikkeling (geen onderdeel van de planstudie), maar de voordelen (baten) hiervan treden pas op als de zijtak Almelo ook bereikbaar is voor schepen met een grotere diepgang dan 2,50m.

Bron: Grontmij & Ecorys (2010), Onderbouwing voorkeursalternatieven: Capaciteitsvergroting sluis Eefde en verruiming Twentekanalen; Ecorys (2009), KBA Almelo - De Haandrik

There are three locks on Twente canal in total. Eefde lock is located on Twente canal, and bridges about 6 meters according to Loenen, Xu and Enge (2014). The graph which shows the bridge between locks on Twente canal is as follows (figure 2.1).

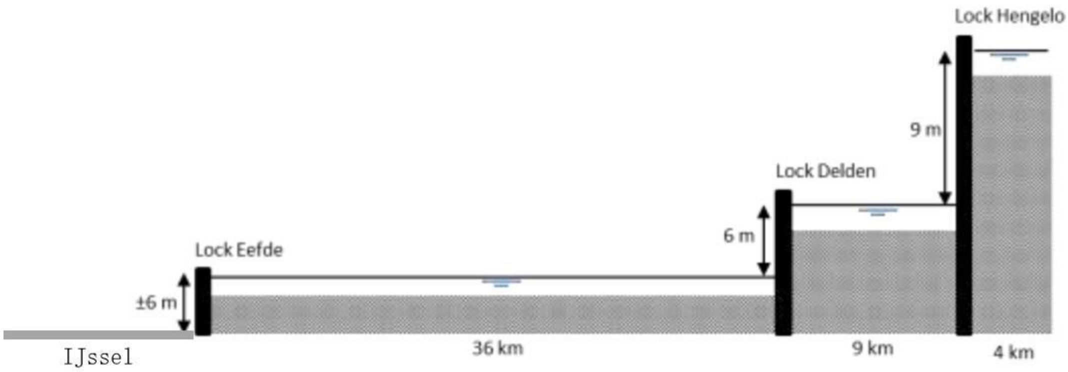


Figure 2.1 Longitudinal cross-section of the canal system (Loenen, Xu and Enge, 2014)

According to Waterway guidelines 2011 (RWS, 2011), before determining reference vessels, the class of the waterway should be selected. Based on the horizontal dimensions, waterways are divided into five classes which are accepted by CEMT (the Conférence Européenne des Ministres des Transports). However, the classification of CEMT is no longer representative of the current West European inland navigation fleet. Thus, Rijkswaterstaat (RWS) 2010 classification is used currently for the design and construction. The details of classification can be found in Appendix A.1. The cargo carrying commercial vessels are divided into three types in Waterway guidelines 2011: motor cargo vessels, pushed convoys and coupled units. They are described in Appendix A.2. The recreational vessels are introduced simply in Appendix A.3. In the research, inland vessels on Twente canal are recorded in reality by RWS.

2.3 Eefde Lock

2.3.1 General information

Figure 2.2 Eefde lock (Jing Shi, 2017)

Currently, Eefde lock has only one chamber. The capacity of the current lock is a limit of the increasing traffic. It has some problems so there is a plan to build a new lock chamber. There are mainly three problems (RWS, 2010):

① Waiting time at Eefde lock now is more than 30 minutes. The navigation time becomes unpredicted.

②If the lock needs maintenance or there is in an emergency, one lock will make navigation inconvenient. The lock has to be closed temporarily.

③The lock chamber is too small to accommodate the increased water transport.

In current enlargement plan of Eefde lock, the new chamber is located at the north of existing chamber, which is shown in figure 2.3. The construction of a second lock chamber will be completed in 2020.

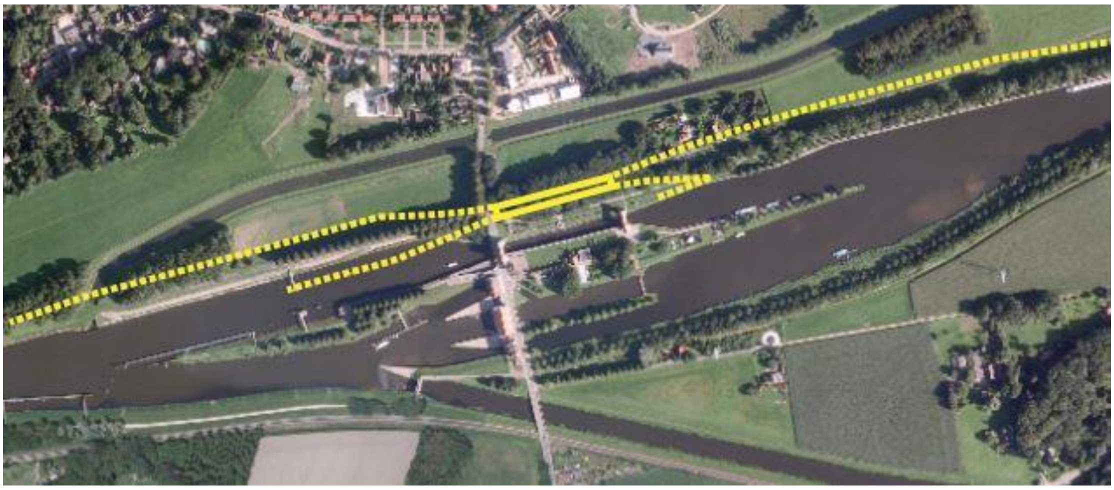


Figure 2.3 Location of the second new chamber of Eefde lock (De Binnenvaartkrant, 2014)

The dimensions of the second chamber is 125*12.5*3.5 meters, which is shown in figure 2.4 (RWS, 2010). The new lock is suitable for the ships of 11.4 x 110 meters and with navigation depth which is up to 3.50 meters (RWS, 2016). This is the largest vessel which is allowed to navigate in Twente Canal after widening the canal. The dimensions of the new chamber originate from the minimum capacity lock (i.e.one governing ship per locking cycle, see Appendix B.3).

As seen in figure 2.1, on Twente canal, there are also other two locks, Delden lock and Hengelo lock. The enlargement of the Eefde lock is aimed to help more ships arriving inland ports. Furthermore, Delden lock and Hengelo lock are located at the east of the canal section to the Almelo port. Thus, part of vessels through the Eefde lock will go to Almelo port. So, the enlargement of the Eefde lock will not affect a lot to the other two locks.

Figure 2.4 Dimensions of new chamber (RWS, 2010)

Figure 2.5 Diagram of new chamber (RWS, 2016)

Above graph 2.5 shows the diagram of the new chamber after construction. The number of passing shipping traffic each time a barge passes through the Eefde lock is recorded. Combining different sources of data, table 2.2 is made to analyze the number of passages.

Table 2.2 Intensity and shipping tonnage on the Twente canal

Year	Number of passages	Bulk in mln.ton	Containers in TEU
2010	12.500[1] (commercial)	6.1[1]	96.000 TEU[1]
2011	13.845[2] (commercial)	-	1467SHIPS[2]
2012	10.661[3] (commercial)	-	-
2014	13.095[4] (total)	-	-
2015	13.066[4] (total)	-	-
TM 2020	14.800[1] (commercial)	7.3[1]	140.000 TEU[1]
TM 2040	16.900[1] (commercial)	8.2[1]	252.000 TEU[1]

*1. Capaciteitsvergroting sluis Eefde en verruiming Twentekanalen (Bückmann, Gun & Harmsen, 2012) for commercial vessels

*2. MER Capaciteitsuitbreiding sluis Eefde (Peerdeman, 2013)

*3. The power of inland navigation (Redacties)

*4. RWS (data documents) total vessels

According to *3, the number of passages in 2011 is 13801 which is similar to the data from *2. Thus, in 2012, the obvious decrease of the passage is credible. It may result from the decrease of demands or unsuitable weather conditions. Comparing 2010 with 2020, the increase of container is larger than the number of passages, which means the vessels are getting bigger in the future. Generally, the number of passages keeps increasing though some fluctuations occur in several years.

The forecast of ship number is important to the construction of the Eefde lock. Above table 2.2 shows the prediction in 2020 and 2040. RWS also has predicted data of commercial ships on Twente canal. The following graphs are made based on data from Rijkswaterstaat. The ship number is estimated until 2050. For every ten years, both low and high numbers are forecast.

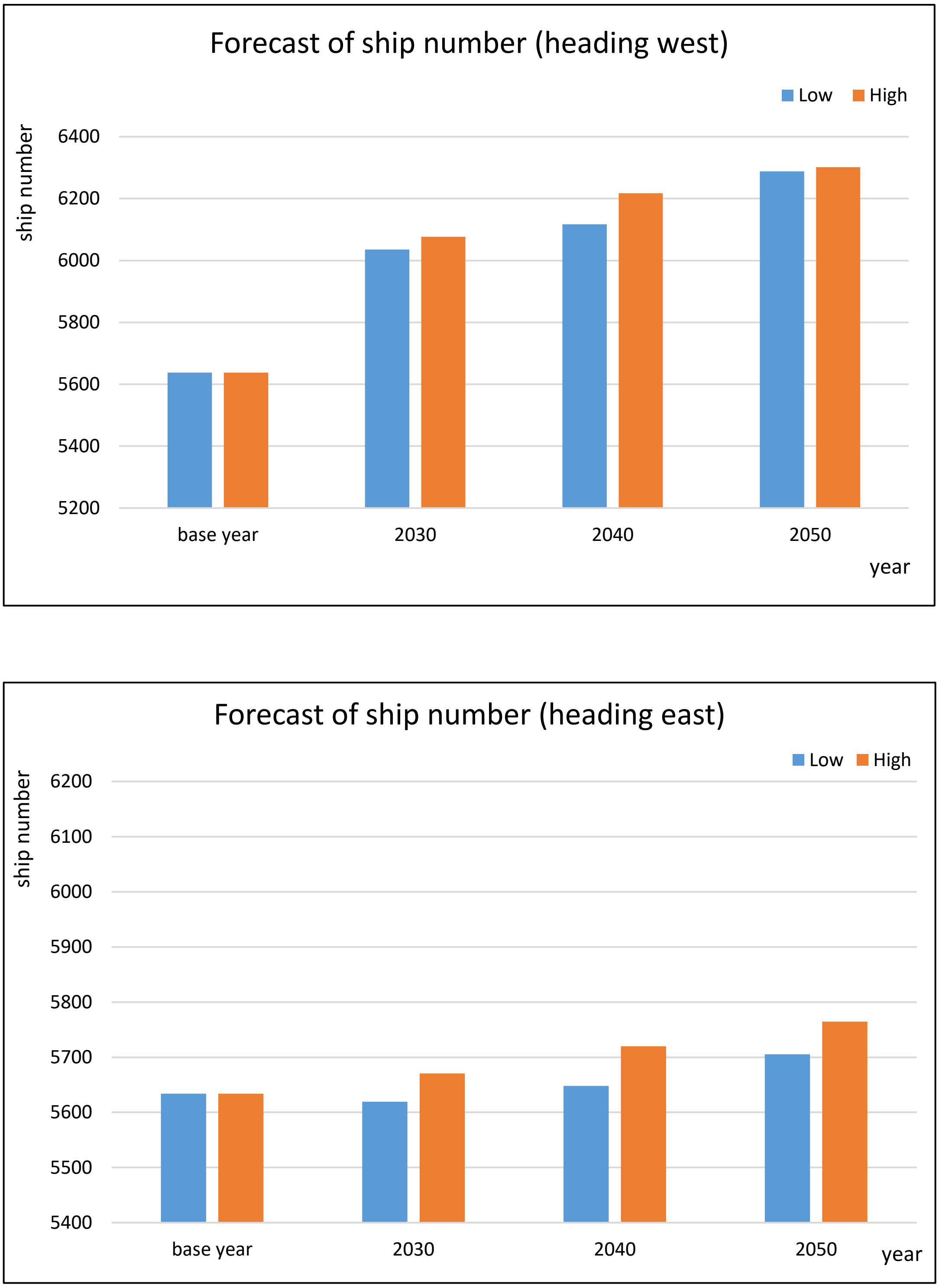


Figure 2.6 Forecast of ship number (two directions) (data source: RWS)

From figure 2.6, it is found that more ships head west through Eefde lock than that head east. Heading west means ships come from harbors in the east and are aimed to reach Ijssel. It means the vessels heading west are possible from other places. No matter what the direction of heading is, the number of ships is increasing in the future. However, the increasing rate is decreasing. The general tendency is described in following figure 2.7.

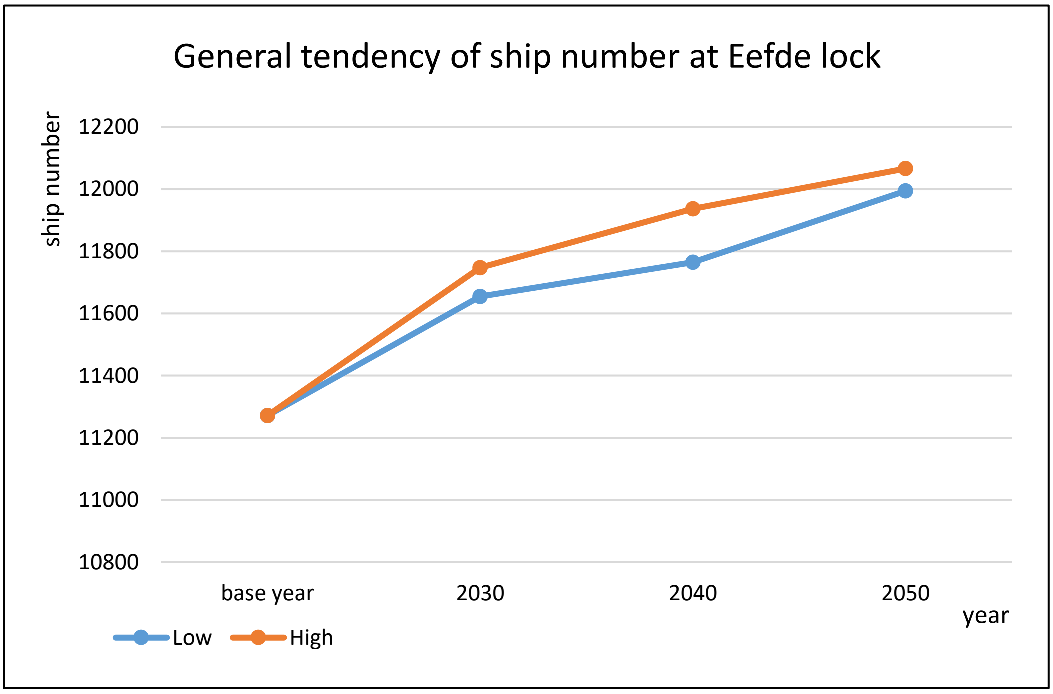


Figure 2.7 General tendency of ship number at Eefde lock (data source: RWS)

In figure 2.7, Rijkswaterstaat predicts that there will be about 11900 commercial vessels in 2040, which is less than 16900 (table 2.2) predicted by Bückmann, Gun & Harmsen (2012). Also, the prediction for 2020 by RWS is less than what is shown in table 2.2. And so on, the commercial vessels in 2050 predicted by RWS are possible to be less than the prediction by other sources. The prediction for 2050 by other sources will be described in Section 4.2.2 when data are put into the model.

The increasing ship numbers may be due to the plan of new terminals (figure 2.8). The demand of total terminals is increasing so that ships are demanded as well. When the supply and demand are close to the equilibrium point, the increasing of ships are slower.

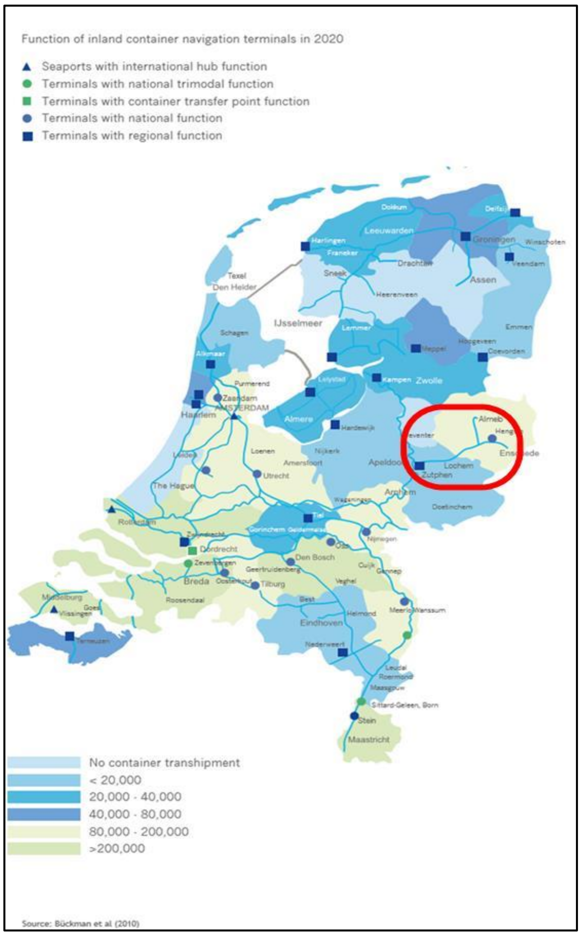


Figure 2.8 Impression of Dutch inland container navigation terminals in 2020 (Redacties)

As we can see in figure 2.8 (Redacties), in 2020, there will be one terminal with regional function and one terminal with national function on Twente canal. The area of Twente canal is possible to have container shipment over 200,000 TEU. New plan of terminals will lead to the increase of ships.

2.3.2 Locking process

(1) Factors influencing the capacity of lock

The factors discussed here are the length and the width of the chamber. There is a relationship between the lock capacity and the length of the chamber. When the length is increased, the capacity increases but the increase is on a declining scale. Based on the graph from Kooman and Bruijn (1975), when the length of the chamber increases 40 meters, the capacity has an obvious increase (figure 2.9). When scenarios are made in next chapter, 40 meters is possible to be used to modify scenarios if nothing else is taken into account.

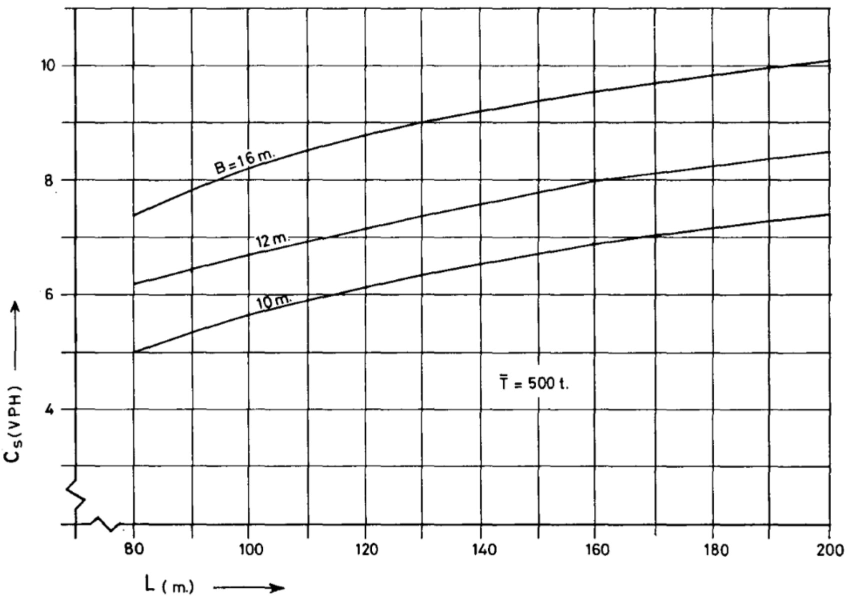


Figure 2.9 The relation between lock capacity (Cs) and the effective length of the chamber (L)

(Kooman & DE Bruijn, 1975)

The relationship between lock capacity and the width of the chamber is also described by Kooman and Bruijn. They got the conclusion that the locks with a width of less than about 12 m have a relatively small capacity. The capacity computations were made for locks with length from 80 m to 160 m. The existing Eefde lock has the length of 133 m so the principle in figure 2.10 will be applied to the Eefde lock. For every two meters, there are obvious changes of lock capacity (figure 2.10). When scenarios are made later, two meters are added to the previous scenario each time during modification.

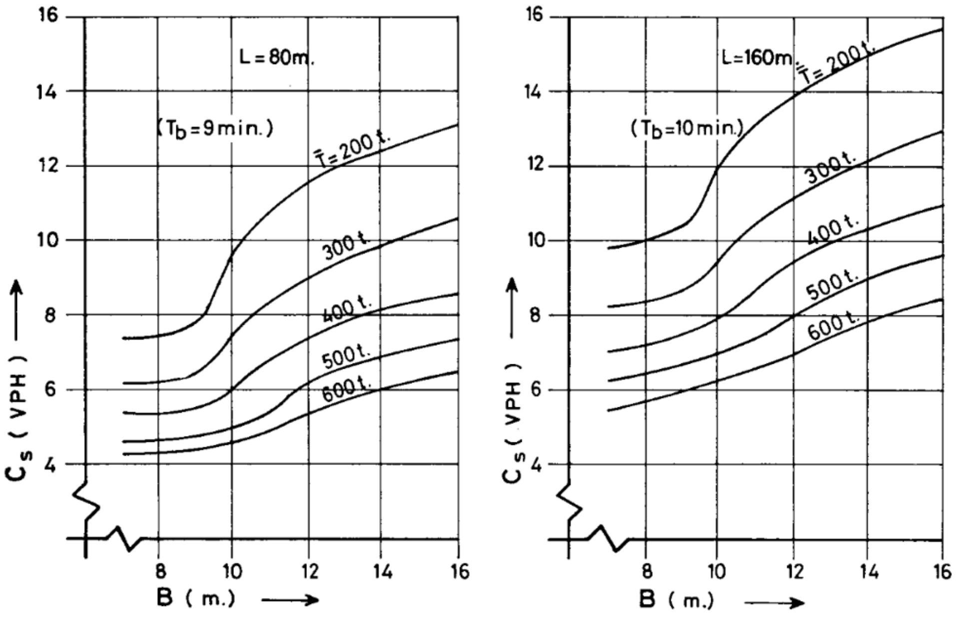


Figure 2.10 The relation between lock capacity (Cs) and the effective width of the chamber (B)

(Kooman & DE Bruijn, 1975)

(2) Passing time

According to waterway guidelines 2011 (RWS, 2011), the reasonable time of waiting time at locks on main waterways should be 30 minutes at maximum for commercial vessels.

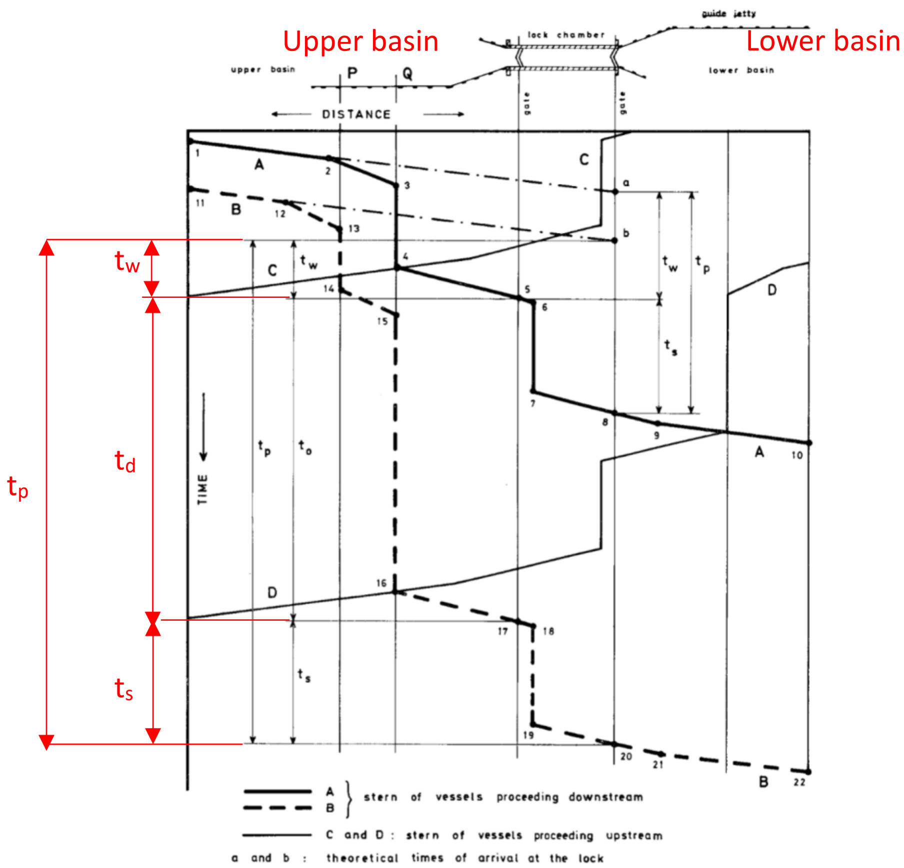


Figure 2.11 Time-distance diagram showing transit through lock (RWS, 2011)

In figure 2.11, ship A and ship B go downstream. Ship C and ship D go upstream. The full line and dashed line stand for the placement of stern of vessels. Based on above figure 2.11, the whole passage time (t_p) consists of waiting time (t_w), locking time (t_s) and delay time (t_d).

$$t_p = t_w + t_s + t_d \tag{2.1}$$

The passing time of an individual ship means the total additional time that a ship spends on passing a lock, compared with an imaginary situation without a lock (Groenveld, Verheij and Stolker, 2006). t_d is additional waiting time that arises if the vessel arriving at the lock cannot be included in the first lockage because the chamber is already full. In the thesis, the delay time has already been included in the total waiting time. Because we will get passing time (t_p) from the output of SIVAK simulation, we need to know the locking time (t_s) in order to calculate the waiting time (t_w) at last.

Locking time t_s includes closing gates (t_c), filling or emptying the chamber (t_{fe}), and opening the gates (t_o), which consist of operating time Tb. Locking time also includes time ships exit out of the chamber. In other words, locking time comprises operation time and part of total exit time. According to Kooman, in the case of a lockage with one vessel, the locking time is given by

$$t_s = T_b + t_u \tag{2.2}$$

$$T_b = t_c + t_{fe} + t_o$$

t_s= Locking time

T_b =Operating time

t_u= Exit time

t_c= Closing gates

t_{fe}= Filling or emptying the chamber

t_o= Opening the gates

The theoretical values of parameters in above equations are calculated first. Then, the results of observation are used to be compared with theoretical values. As seen in table 2.3, the data of observations are in the range of average time of inland navigation shown in table 2.4. Furthermore, by standard deviation, it can be found that the data of sailing out time have a large deviation. Therefore, when sailing out time is calculated, more attention should be paid to literature. With respect to gate maneuvering time, filling and emptying time, the final results are obtained by calculating the average of theoretical and observational values.

Table 2.3 Data of observation (personal observation data at the field) (Jing Shi, 2017)

	Ship 1(EW)	Ship 2(WE)	Ship 3(EW)	Ship 4(WE)	Average	σ
Closing gate (min)	1.38	1.72	1.62	1.83	1.64	0.19
Opening gate (min)	1.70	1.82	1.92	1.77	1.80	0.09
Gate maneuvering (closing and opening)	3.08	3.54	3.54	3.60	3.44	0.24
Filing/emptying (min)	9.87	9.57	9.83	9.28	9.64	0.27
Sailing out (min)	3.00	1.00	1.57	2.62	2.05	0.92

In the lecture notes of hydraulic structures (Molenaar, 2011), the average time of navigation is also known as the following table.

Table 2.4 Average locking time (Molenaar, 2011)

List of Events	Average time Inland Navig.	% of the total time	Average time Sea lock	% of the total time	Possibilities for optimisation to reduce the total time
TOTAL LOCKING (1/2 cycle)	28 min (20 – 40 min)	100%	45 min (*) (40 – 90 min)	100%	
Entrance / Exit	5 min (3 to 10 min)	18%	15 min (*) (10 to 20 min)	33%	Medium
Mooring	5 min (3 – 10 min)	18%	7 min (*) (3 – 10 min)	15.5%	High
Gate manoeuvring	3 min (2-4 min)	11%	3 min (*) (2-5 min)	7 %	Low
Filling / Emptying	15 min (8 – 20 min)	53%	20 min (*) (10 – 25 min)	44.5%	High

Following sections give the estimation of the parameters in equation 2.2 in order to calculate the locking time.

Opening and closing the gate (t_o and t_c)

Opening and closing gates cost some time which depends on the types of gates. The time of typical chamber is given. However, in reality, time should be identified according to different locks.

Table 2.5 Time of opening and closing gates (Groenveld, Verheij and Stolker, 2006)

Gate type	Chamber width(m)	Closing gate(min)	Opening gate(min)	Total(min)
Rolling gate	12	1.2	0.7	1.9
Vertical lift gate	14 to 18	3 to 3.3	2 to 2.3	5 to 5.6
Mitre gate	16 to 24	1.3 to 2.5	1.2 to 1.6	2.5 to 4.1

The above table is given by book 'Capacities of Inland Waterways' (Groenveld, Verheij and Stolker, 2006). Eefde lock has two vertical lift gates. The time of opening and closing gate is assumed to be 5 minutes in total as the width of the chamber is small.

By observation (table 2.3), the time is about 3.5 minutes that is a little shorter than the theoretical value. The average value, 4 minutes are taken at last.

Filling and emptying the chamber (t_{fe}) (Groenveld, Verheij and Stolker, 2006)

$$\mathrm{T} = \frac{2 \times O_k \times H}{m \times A_{sl} \times \sqrt{2gH}} \tag{2.3}$$

O_k : Horizontal chamber area

H : Head of water.

m : Energy loss coefficient.

A_{sl} : sluice opening area

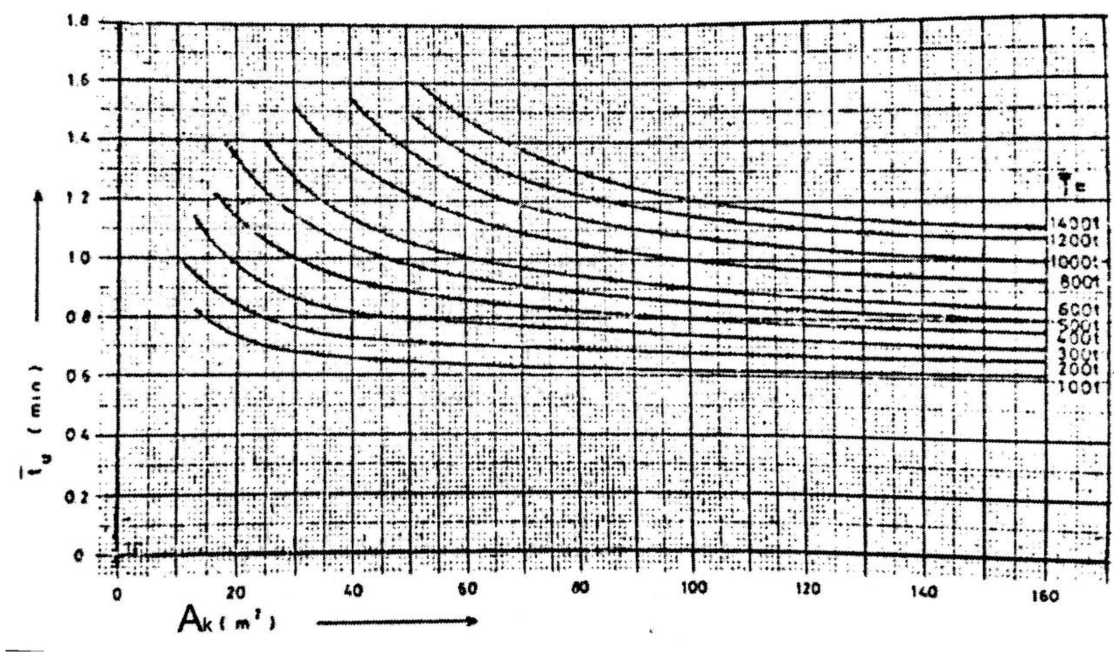
For the Eefde lock, H is 6m and m is taken as 0.9. There are six valves on the gates to empty and fill the chamber. The area opening area is about 6 m^2. By calculation according to equation 2.3, the time of filling and emptying the chamber is about 9 minutes.

By observation, the average time of filling and emptying the chamber is about 9.6 minutes which is corresponding to the theoretical value. Finally, 9.5 minutes is used.

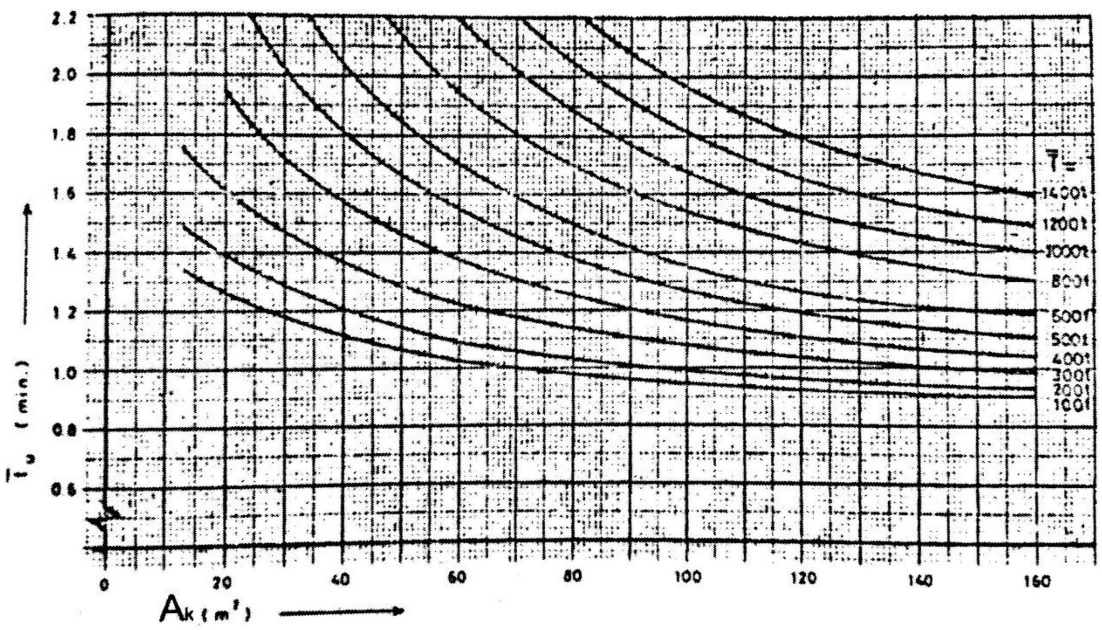
Exit time (t_u)

Exit time is different according to the dimensions of the chamber and the dead weight of ships. Various measurements and observations have been done to study the relationships between exit time and cross-sectional area of the chamber A_k for different dead-weight capacities. The relationships are also distinguished between laden and unladen ships. (Groenveld, Verheij and Stolker, 2006)

According to the data of vessels in April of 2014, there were 589 laden ships and 696 empty ships. Because the dead weight of each ship is known, the average exit time with dead-weight below 1400t can be calculated according to following graphs 2.12. The average exit time of these ships is 2 minutes. The results according to these graphs are inaccurate because it was developed many years ago. Finally, the exit time is taken as 5 minutes according to table 2.4.



(Unladen)



(Laden)

Figure 2.12 Relationship between exit time and the cross-sectional area of the chamber for different dead-weight capacities (unladen and laden ships)

Therefore, the total time for locking is around 20 minutes. Because the waiting time should be smaller than 30 minutes, the whole passing time should be less than 50 minutes. Table 2.6 shows the limitation of different time.

Table 2.6 Limit of passing time

<table>
<tr><td rowspan="5">t_p</td><td rowspan="4">t_s</td><td rowspan="3">T_b</td><td>t_c</td><td rowspan="2">4 min</td><td rowspan="5"><50 min</td></tr>
<tr><td>t_o</td></tr>
<tr><td>t_{fe}</td><td>9.5 min</td></tr>
<tr><td>t_u</td><td colspan="2">5 min</td></tr>
<tr><td>t_w</td><td colspan="3">< 30 min</td></tr>
</table>

2.4 Vessels on Twente canal

The analysis of ship characteristics is an important part before simulations. The data of vessels passing through Eefde lock have been collected in 2014 and 2015 by RWS. Information of locking is studied by data. The navigation direction, navigation time, numbers of vessels and types of vessels are shown in the document of data. By the analysis of vessels, the characteristics of vessels through Eefde lock are known. The busiest month will be selected and the main types of vessels will be obtained.

After dealing with data, firstly, we compare the number of vessels of two years (see table 2.7).

Generally, the total number of vessels through Eefde lock had a little decrease in 2015, compared with 2014. In 2014, the lowest amount of vessels appeared in December. The lowest point in 2015 was in January. The low number of locking is due to the seasonal factor.

Table 2.7 Vessels passing through Eefde lock in 2014 and 2015 (data source: RWS)

	Number of vessels 2014	Number of vessels 2015
January	1055	764
February	831	826
March	1015	939
April	1285	881
May	1233	1112
June	1183	1270
July	1459	1500
August	1183	1277
September	1000	1108
October	1143	1188
November	950	1188
December	758	1013
Total	13095	13066

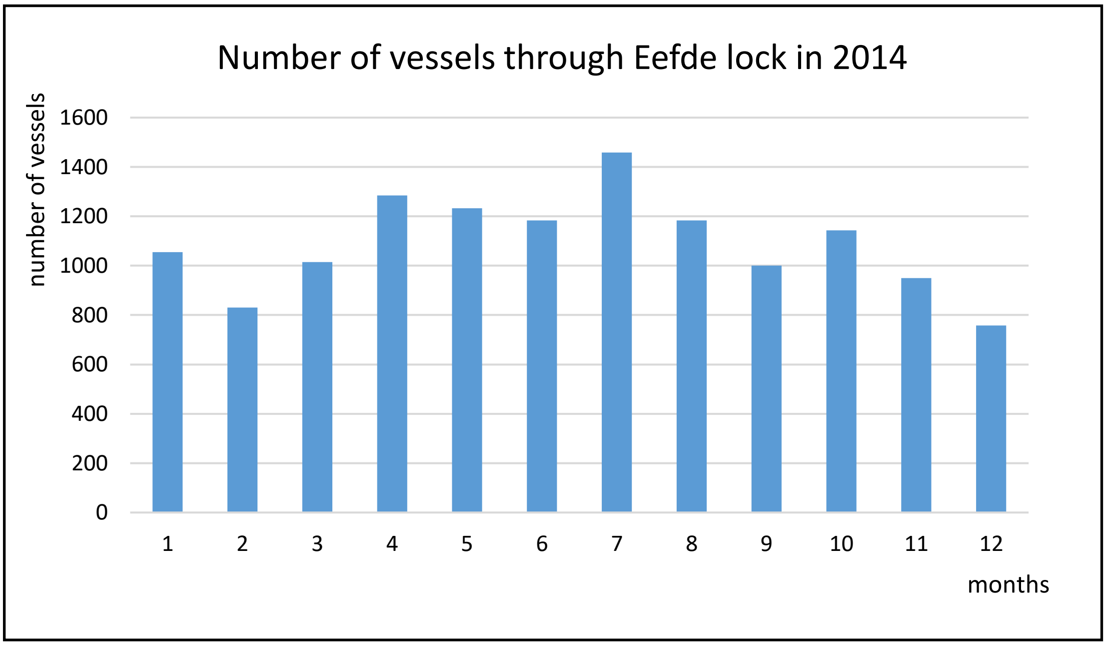


Figure 2.13Number of vessels through Eefde lock in 2014

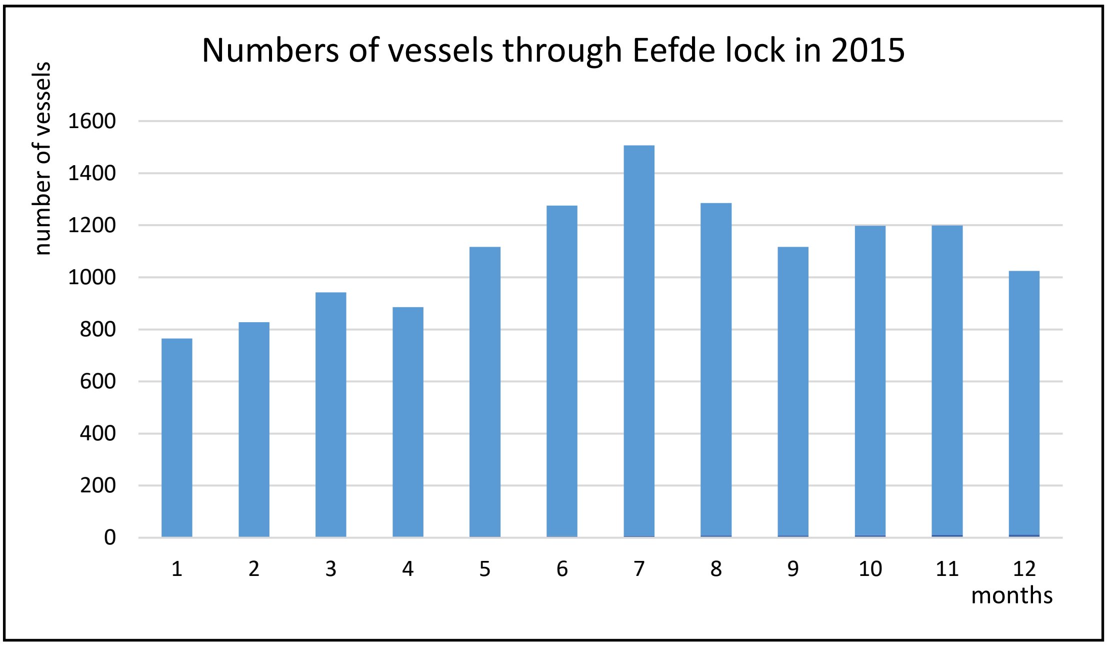


Figure 2.14 Number of vessels through Eefde lock in 2015

According to above diagrams (figure 2.13 and figure 2.14), it can be found that 2014 and 2015 have the similar distribution in different months. July was the busiest month. In July, 2015 has 1500 vessels which were 41 vessels more than that of 2014, though the total amount in 2015 is less than 2014. Thus, the situation in July should be analysed especially because it has most possibility to cause a traffic jam at lock point. However, there are holidays in July. April in 2014 should also be analysed because it has no holiday but the amount of vessels is also large.

2.4.1 Data of 2015

Table 2.8 Vessels through Eefde lock in July 2015 (data source: RWS)

RWS-Coding of ship type	RWS class	Number of vessels
1,2,3,21	M1	42
	M2	83
	M3	127
	M4	81
	M5	143
	M6	269
	M7	118
	M8	166
	B01	2
	B04	4
	BI	2
40,43,44,45,80,82 85,89	Others	463
	Total	1500

In July 2015, the number of vessels reached the peak which was 1500. Most of these vessels are categorized into RWS class. Some recreational vessels are not in RWS class. They are known by RWS coding which is shown in table 2.8. According to SOS form by RWS, the identified types of vessels are found in consistent with RWS-coding, shown in table 2.9.

Table 2.9 Details of other types of vessels

RWS-Coding of ship type		Name	Number
Others	40	Tug: losvarend	11
	43	Pusher: losvarend	3
	44	Passenger inland	12
	45	Service vessel	2
	80	Motor yacht	417
	82	Yacht sailing on (help) engine	1
	85	Large recreational ship>20m	14
	89	Other recreational craft	3

Next, the dimensions of vessels in different classes are organized in Appendix D. The distribution of vessels based on types is described in figure 2.15. According to figure 2.15 and figure 2.16, in both 2014 and 2015, motor yacht took the most percentage of all. The size of motor yacht is not available in the data document. In Waterway guidelines 2011(RWS, 2011), the dimensions of the motor yacht are 15*4*1.5 m (length*beam*draught) set by the United Nations Economic Commission for Europe. Following motor yacht, vessels in M6 are also the main component. Reference vessels in M6 class are described as Rhine-Herne Vessel (L <= 86 m) in waterway guidelines 2011. Considering large vessels which are longer than 100 meters, 2015 is more than 2014. Vessels with length between 20 and 80 meters has an increasing trend but lower than the number of vessels in M6.

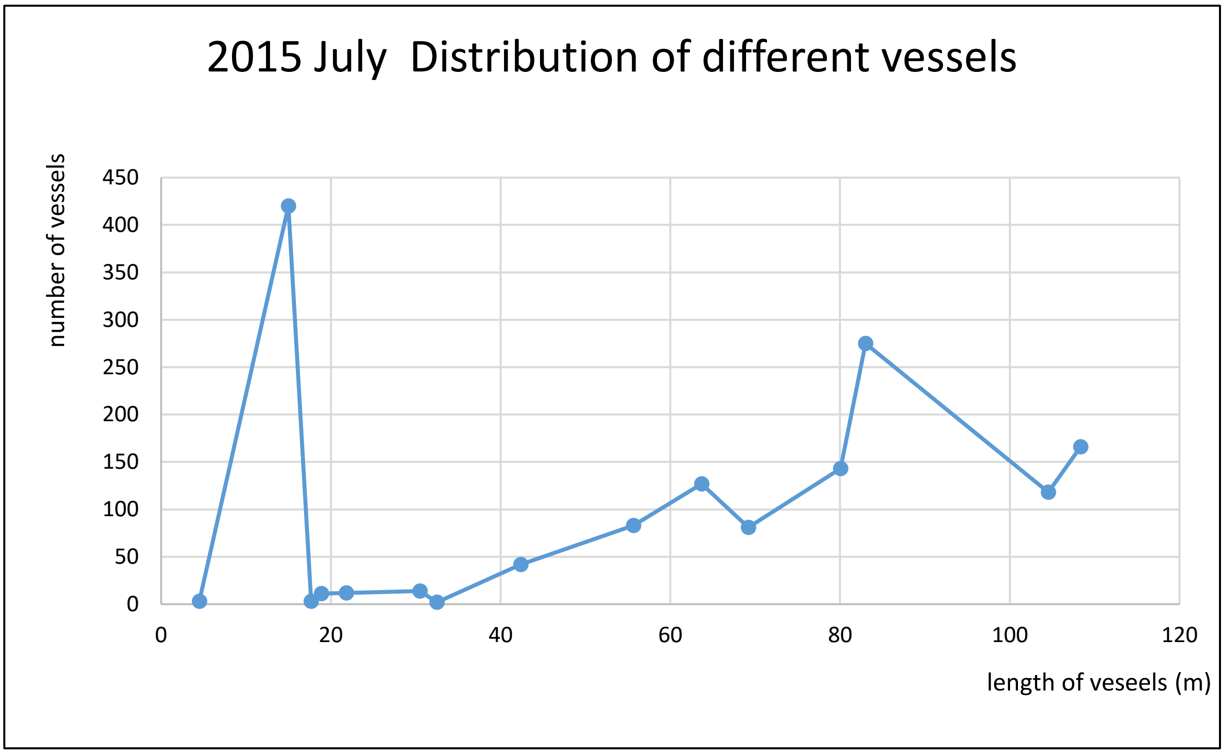


Figure 2.15 Distribution of different vessels (July 2015)

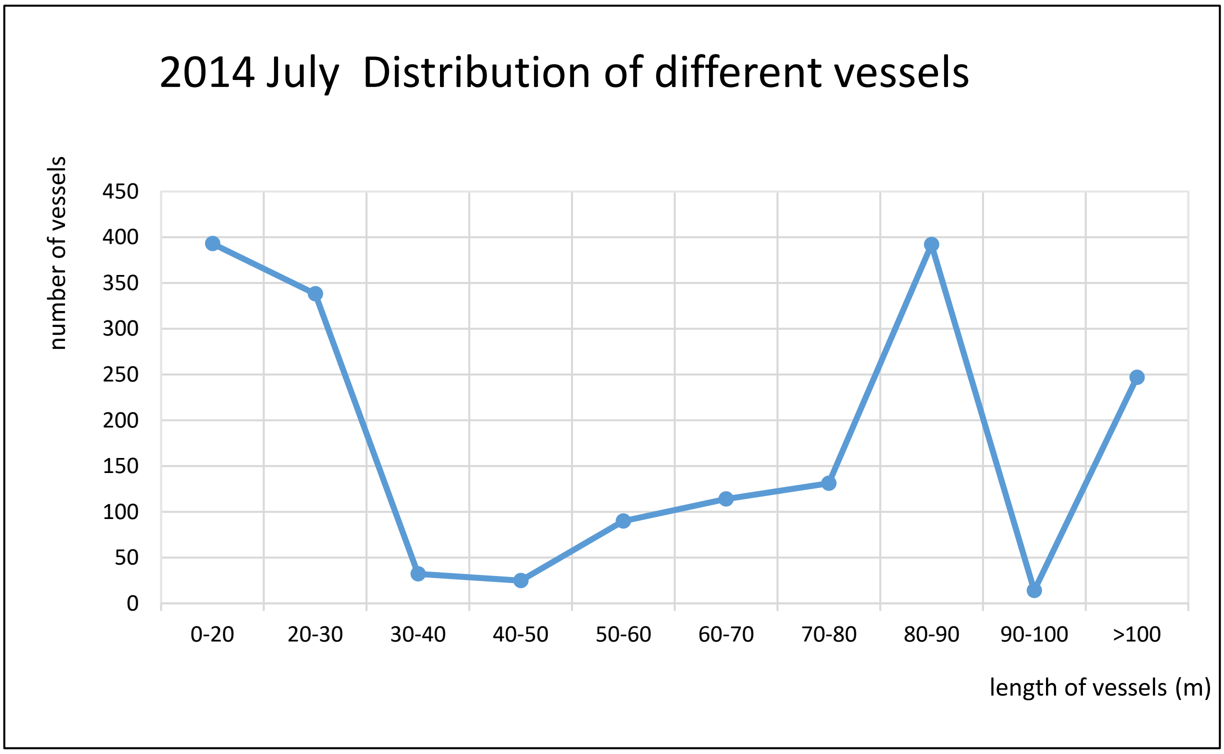


Figure 2.16 Distribution of different vessels (July 2014)

Moreover, vessels can be also classified based on two opposite navigation directions. To the east is upstream direction, while to the west is opposite. In July 2015, the vessels to east nearly have the same amount of vessels as that to the west based on data provided by RWS.

Passing time recorded by IVS90 is also known by the data document. IVS90 is a ship reporting system used by the Dutch waterway authorities. It supports lock planning, vessel traffic services, calamity abatement and statistics. Except missing data, the average passing time in July 2015 is calculated to be 76.81 minutes. According to the data document, the time of opening doors is 2 minutes. Closing doors takes 2 and 3 minutes separately for the upstream and downstream side.

In July 2015, there are totally 1047 lockings, counted from files of data. Thus, 1500 ships passed the Eefde lock in the 1047 lockings of July. The number of ships per locking inside is 1.43ships.

2.4.2 Data of 2014

July becomes the busiest month mainly because of the summer holiday. The distribution of vessels in July 2014 is shown in above figure 2.16. Actually, recreational vessels are not important factors which influence the dimensions of the lock chamber, because the size of most recreational vessels can fit the lock chamber. Except July, April became the busiest month in 2014 and October followed. Different types of vessels in April, 2014 are studied now because the original data in SIVAK is the April of 2012, provided by RWS. Data from SIVAK and document of RWS can be compared with each other. The information of ships in April of 2014 is given in Appendix D. Total number of vessels in April is 1285. The distribution of vessels is shown in figure 2.17 and figure 2.18.

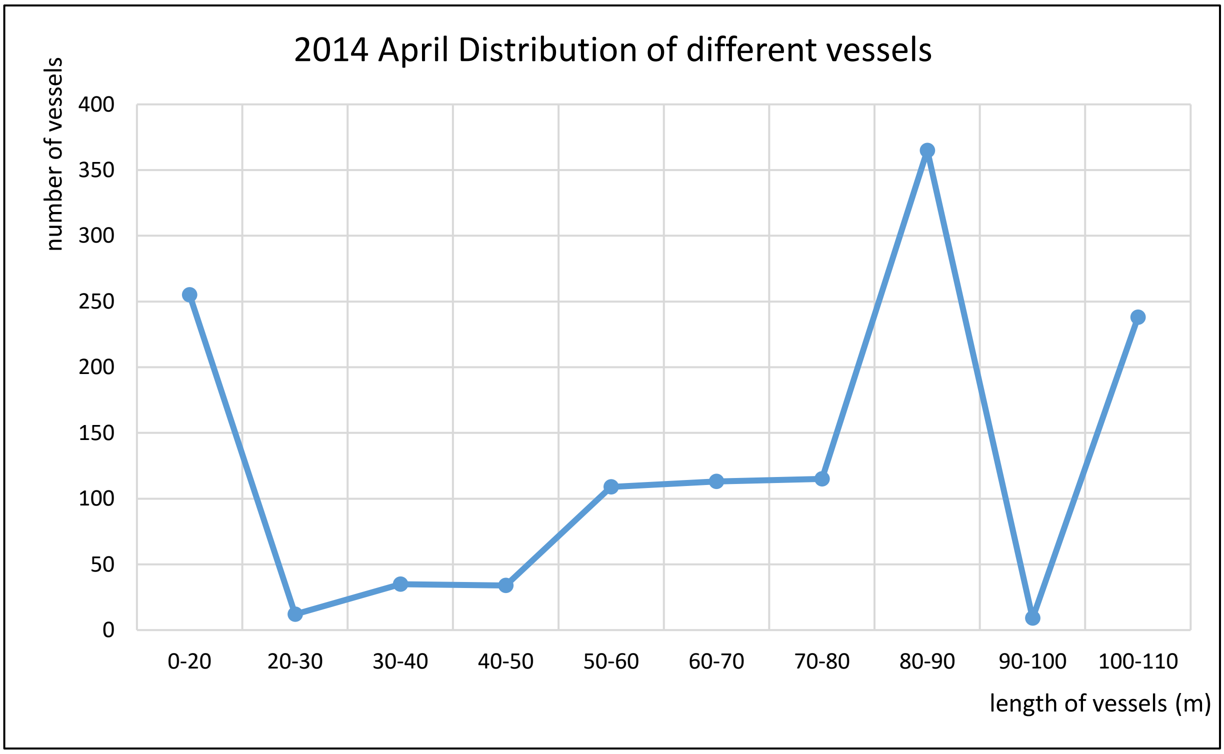


Figure 2.17 Distribution of different vessels (April 2014)

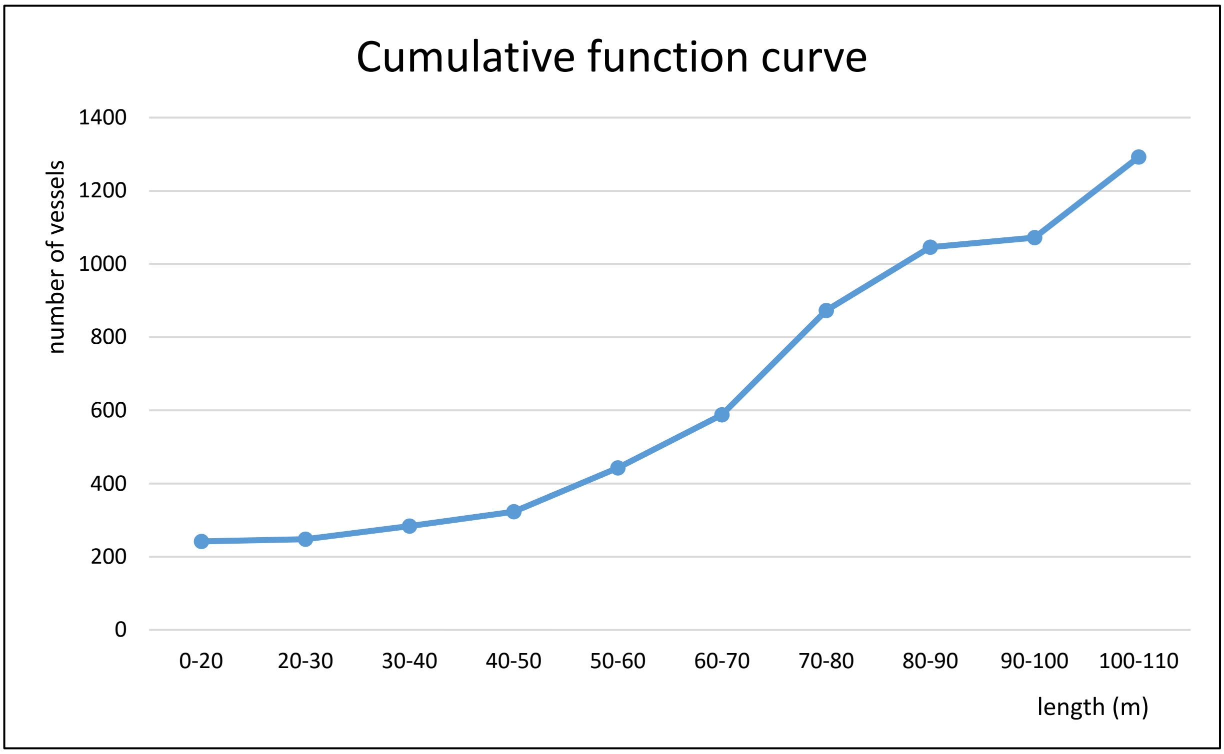


Figure 2.18 Cumulative curve of different vessels (April 2014)

According to figure 2.17, the ships with the length in the range of 80~90 meters reach the peak number which is more than 350. Furthermore, small vessels which have length smaller than 20 meters also have large numbers. Most of them are recreational vessels.

In summary, comparing 2014 and 2015, the typical vessels are vessels whose length are within 80 and 90 meters. In other words, vessels in M5 and M6 class are the main types.

In this section 2.4, the data of vessels in 2014 and 2015 from RWS are analyzed. It can be seen that July is the busiest month considering all types of vessels. If ignoring holidays and commercial vessels are focused on, April of 2014 and March of 2015 are busy months. Last but not the least, by analysing the proportion of vessels, M5 and M6 become the main ship types.

3 Scenarios of enlargement

In this chapter, different scenarios are made before simulations. Scenarios are made for current and future situations respectively. In scenarios, the length or width of the chamber is changed. The change of width and length at the same time is not taken into account since the variables should be controlled in research. Also, the number of chambers will be changed. The diagrams in this section are not to scale.

3.1 Scenarios for lock enlargement-Current situation

In Chapter 2, information and data are collected and analysed for the input of simulation model. We also need scenarios before simulations. Scenarios are made initially and will be modified in the process of simulation.

① Base scenario 1 (S1)-existing Eefde lock

Base scenario is what the further study should be based on. Thus, the existing Eefde lock is taken as base scenario.

Figure 3.1 Diagram of base scenario S1

② Scenario 2 (S2) -the longer chamber

If the lock chamber is lengthened, more ships will pass through the lock at one time. The lengthened part of the chamber is assumed first. According to the study of Kooman and Bruijn, there is an obvious increase of capacity when the length of the chamber increases 40 meters, shown in figure 2.9. Moreover, the length of smallest commercial vessels is around 40 meters. At first, 50 meters are added to the length of existing chamber, also considering the required space between ships. However, mixed locking should be taken into consideration. Except commercial vessels, small recreational ships should also be taken into account. Thus, 25 meters are added to length for every simulation until the requirement of passing time will be met. Small tolerance will make the tendency accurate.

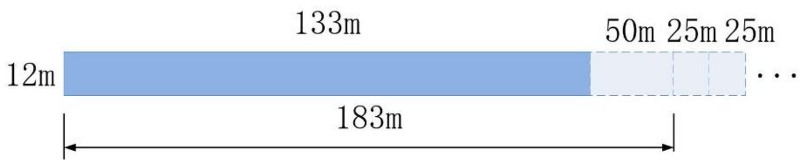


Figure 3.2 Diagram of scenario S2

③ Scenario 3 (S3) -the wider chamber

Upon existing lock chamber, the width of the chamber can be enlarged. The wider lock chamber can influence the arrangement of vessels in the lock. The capacity is changed. Similar to scenario 2, the width of new chamber is assumed first to be 6m which is around the width of smallest vessels and there is a requirement that the space between vessels should be larger than 5m. Then, the width will be modified gradually. After the first simulation, each 2 meters are added because for every two meters, there are obvious changes of lock capacity (figure 2.10). The width is enlarged until the requirement of passing time can be met. According to Molenaar (2011), for a first 'rough' selection of gate alternatives, different types of gates have their own applicable situations. The selection of lock gate depends on the type of navigation lock and the width of lock chamber. Therefore, the applicability of width will be check at the end of the thesis if the optimum scenarios are making chamber wider.

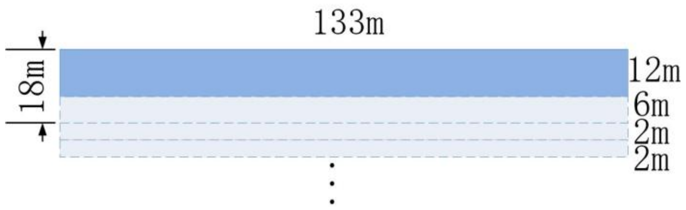


Figure 3.3 Diagram of scenario S3

④ Scenario 4 (S4) -constructed extra new chamber
One method of enlarging existing Eefde lock is to build a new lock chamber next to the old chamber. In fact, this method is what the responsible authority of the Eefde lock is going to take. The plan of the second chamber is shorter but a little wider than the existing chamber (125*12.5m).

Though the dimensions of the planned new chamber are known, we also assume that the new lock chamber has other dimensions to study the problem in the future, because the problem of delays may appear again in the future.

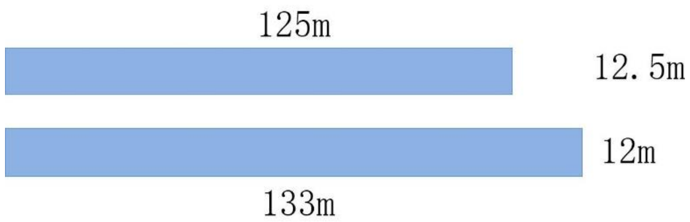


Figure 3.4 Diagram of scenario S4

3.2 Scenarios for lock enlargement-Future situation

For the future situation, the sign SF is used to stand for the future scenarios.

① Base scenario 1 (SF1) -Eefde lock with one chamber
The diagram of base scenario is the same as figure 3.1. However, the number of vessels through the lock is the predicted value in the future.

② Scenario 2 (SF2) –existing Eefde lock but longer chamber
The horizontal layout of SF2 is the same with the S2 (figure 3.2) but for predicted vessels in the future.

The process of modifying the extra length is the same as the current situations.

③ Scenario 3 (SF3) –existing Eefde lock but wider chamber

Similar to the S3 (figure 3.3), in the future, the width of the old chamber will be enlarged. The predicted vessels will be applied to the scenario.

④ Scenario 4 (SF4) -Eefde lock with two chambers

In the future, when the extra lock now being constructed is ready, this situation will be checked for future predictions of vessels. The figure is the same with figure 3.4.

⑤ Scenario 5 (SF5) -make the second chamber longer

The enlargement of Eefde lock in the future will change the dimensions of the second chamber. First, the length of the second chamber is increased. Similar to the current situation, 50 m is assumed to be added to the length initially. Then, 25 meters are added to the length every time until the requirement of passing time is met.

Figure 3.5 Diagram of scenario SF5

⑥ Scenario 6 (SF6) -make the second chamber wider

In the future situation, the width of the second chamber will also be enlarged. Two meters will be added to the width every time. However, six meters can be added initially because there is a requirement that the space between vessels should be larger than 5m (RWS, 2011).

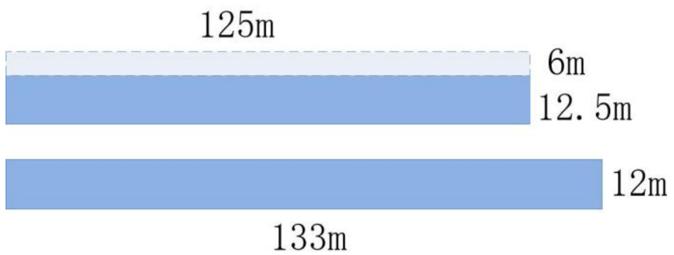


Figure 3.6 Diagram of scenario SF6

Above scenarios are about the dimensions of ship locks. For simulations, the conditions of ships should also be given. Considering the sustainability of waterway structures, situations in the future should be taken into account. Thus, when scenarios are simulated by SIVAK, the conditions of ships should be used for two aspects, current data of ships and predicted data of ships in the future. In the future, the number of ships will increase and the dimensions of ships are possible to be larger. Finally, scenarios for ship locks and conditions of ships are combined together and shown as follows.

stands for the final combinations which are simulated by SIVAK.		Lock chamber					
		Base scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Ships	Current	S1	S2	S3	S4		
	Future	SF1	SF2	SF3	SF4	SF5	SF6

Figure 3.7 Combinations of locks and ships

4 Set up simulations

4.1 Model description

The simulation model SIVAK is made to analyse traffic flows of ships at locks. The features of SIVAK program are:

- The process is a discrete and stochastic process.
- Ships are considered as individual navigation participants. They have their own dimensions and arrival patterns.
- It is useful for a large diversity in vessel dimensions and sailing behaviour.
- Complexes with more than one chamber can be simulated with it.

SIVAK model runs in Prosim environment which is out of sight for users. The animation of Prosim is displayed in SIVAK. The basic units are blocks. There are different blocks where information is put in. Then, blocks make up the project. Finally, the network and route network is set to determine the waterways of navigation.

SIVAK simulation can be separated into two parts, model setting in Sivak and running in prosim . Firstly, the model of the lock should be established in SIVAK. Projects consist of different blocks. Each block is defined in the program as well. Some information of blocks is provided by Rijkswaterstaat. Other blocks can be set by users. For example, in the block of the chamber, information of Eefde lock is filled in. Information includes the dimensions of Eefde lock and ship class. Operation schedule has been set in another block so that it needs to be selected in the block of the chamber.

There are also data of fleet share at Eefde lock. The information of fleet was collected from week13 to week16, which means the month of April in 2012. Other input data are listed in details (Appendix E).

Generally speaking, when the model is established, two aspects (model setting and model running) need to be completed.

INPUT

Input parameters contain information of waterway systems, such as the layout of ship locks, operation regulation of locks, operation time, the length of waterways etc. Besides, input parameters also include ship information, such as a component of ship groups, the dimensions of ships, shipping time etc. The input information can be divided into two parts.

①The network: Layout, process times, regimes, working times, locking times, lock dimensions
②The ships: Arrival numbers, arrival pattern, sizes, ship classes, sailing times, sailing speeds

Figure 4.1 Network of Eefde lock (RWS)

OUTPUT

Outputs include the capacity of locks, number of vessels in the lock, passing time, cost of passing etc. The capacity of locks and passing time are most important parameters in the thesis. The selection of scenarios in Chapter 6 depends on the requirement of passing time. The function of passing time is not used and waiting costs will be calculated especially later in the thesis.

The process of setting up models are described in detail in Appendix F.

4.2 Blocks in the model

In order to simulate the model of the Eefde lock, some data need to be put into SIVAK necessarily. Data mainly serve for the blocks, such as blocks of *Arrival pattern*, *Chamber*, *Lock*, *Fleet* and *Fleet share*. These blocks and others will be introduced in current scenarios and future scenarios respectively as follows.

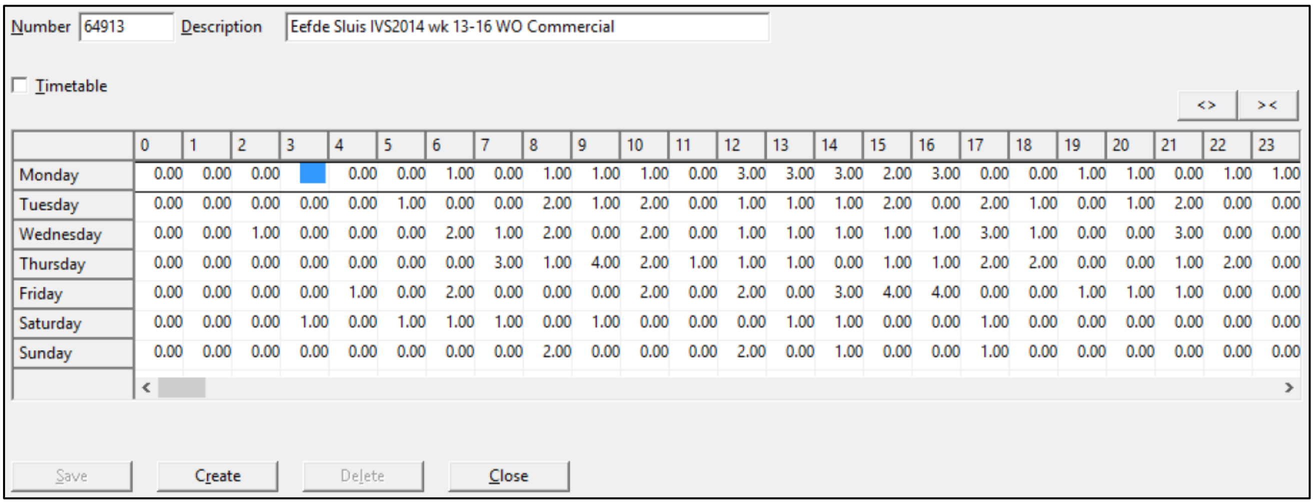
Data is partially collected from Rijkswaterstaat (RWS). The data of ships and lock of 2012 is given in the user library of SIVAK. There are also records of vessels passing through the Eefde lock in 2014 and 2015. The direction of heading, type of ships, the number of ships, RWS-coding of ships, dimensions of ships, the status of loading, the capacity of ships, transported cargos of ships, RWS-class of ships and time of locking are recorded in detail. Except historical data, there is also forecast data of vessels. The predicted numbers of ships in different RWS-class are from base year to 2050. The data of base year is in accordance with the data of 2014.

4.2.1 Current scenarios

Scenarios of current situations use the data of 2014, because the data of ships in 2014 shows the similar monthly distribution of vessels to 2012 which is given by RWS in SIVAK directly. Furthermore, as mentioned above, 2014 seems to be the base year of prediction of future scenarios. Thus, the data of 2014 is used for current scenarios. The busiest month in 2014 is April without holidays. Blocks of models are described now. In blocks, directions are represented by sign WE and EW. WE is the direction from west to the east. EW is opposite to WE.

(1) Arrival pattern

The arrival pattern gives the intensity per hour of the week. Both commercial and recreational ships should have their own arrival pattern. Numbers in the tables are related to each other to show the intensity (figure 4.2). The table means the constant arrival pattern over a week. The data of the busiest week in April are used for this table. It seems that the intensity of ships on weekends is smaller than that during working days.

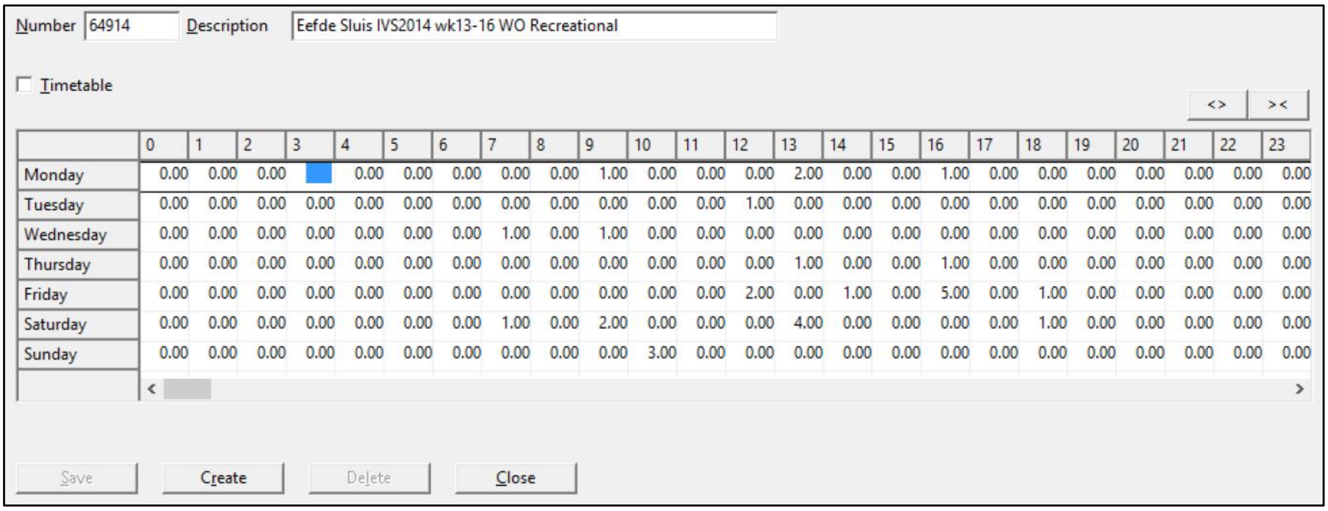


Number 64913 Description Eefde Sluis IVS2014 wk 13-16 WO Commercial

Timetable

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Monday	0.00	0.00	0.00		0.00	0.00	1.00	0.00	1.00	1.00	1.00	0.00	3.00	3.00	3.00	2.00	3.00	0.00	0.00	1.00	1.00	0.00	1.00	1.00
Tuesday	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	2.00	1.00	2.00	0.00	1.00	1.00	1.00	2.00	0.00	2.00	1.00	0.00	1.00	2.00	0.00	0.00
Wednesday	0.00	0.00	1.00	0.00	0.00	0.00	2.00	1.00	2.00	0.00	2.00	0.00	1.00	1.00	1.00	1.00	1.00	3.00	1.00	0.00	0.00	3.00	0.00	0.00
Thursday	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	1.00	4.00	2.00	1.00	1.00	1.00	0.00	1.00	1.00	2.00	2.00	0.00	0.00	1.00	2.00	0.00
Friday	0.00	0.00	0.00	0.00	1.00	0.00	2.00	0.00	0.00	0.00	2.00	0.00	2.00	0.00	3.00	4.00	4.00	0.00	0.00	1.00	1.00	1.00	0.00	0.00
Saturday	0.00	0.00	0.00	1.00	0.00	1.00	1.00	1.00	0.00	1.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Sunday	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	2.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00

Save Create Delete Close



Number 64914 Description Eefde Sluis IVS2014 wk13-16 WO Recreational

Timetable

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Monday	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	2.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tuesday	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wednesday	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Thursday	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Friday	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00	1.00	0.00	5.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
Saturday	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	2.00	0.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
Sunday	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Save Create Delete Close

Figure 4.2 Arrival patterns in direction of WO for commercial and recreational vessels

(2) Operation schedule

Time schedule used in block shows that working time of the Eefde lock. The working hours of working days (from 6.00 to 20.00) are longer than that of weekends (from 9.00 to 17.00) (Appendix C).

(3) Chamber

According to different scenarios, the data of chamber need to be changed. Figure 4.3 shows the chamber of base scenario. The length, width, waterplane length and lock head width are filled in in the left column.

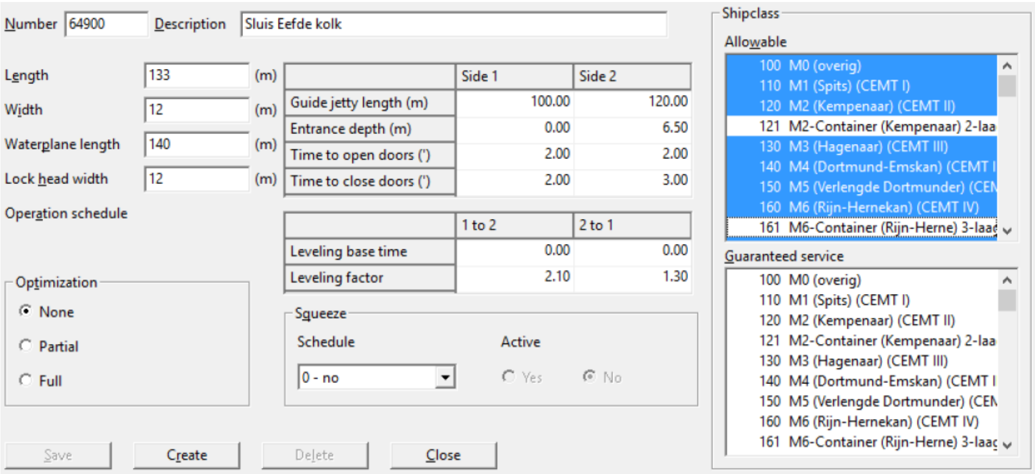


Figure 4.3 Block of chamber

Then, length or width of the chamber will be enlarged. The second chamber is also established in this block. The list of chambers is as follows (figure4.4) that different chambers for different scenarios are made.

64900	Sluis Eefde kolk
64901	Sluis Eefde chamber +longer 50
64902	Sluis Eefde chamber+longer 80
64903	Sluis Eefde chamber+longer 100
64904	Sluis Eefde chamber+wider 6
64905	Sluis Eefde chamber+wider 8
64906	Sluis Eefde chamber+wider 10
64907	Sluis Eefde 2nd kolk
64908	Sluis Eefde 2nd kolk 133*12
64909	Sluis Eefde 2nd kolk 125*12

Figure 4.4 Part of lists of chamber blocks

In the right column of the block of the chamber (figure 4.3), allowable ship classes should be selected according to the data from RWS. This is corresponding to the ship class in the next block.

(4) Ship class

The data of different ship class are provided by RWS directly by excel sheets. The types of ships used in Eefde lock mainly are M0, M1, M2, M3, M4, M5, M6, M7, M8, B01, B02, B04, BI, motor yacht, sailing ships.

(5) Lock

The block of *Lock* should be updated according to the change of the chamber. Chamber priority has three options, availability, surface and filling of the chamber. The option of availability is chosen here. When the scenario has two chambers, all two chambers should be inserted in the table of 'chambers'.

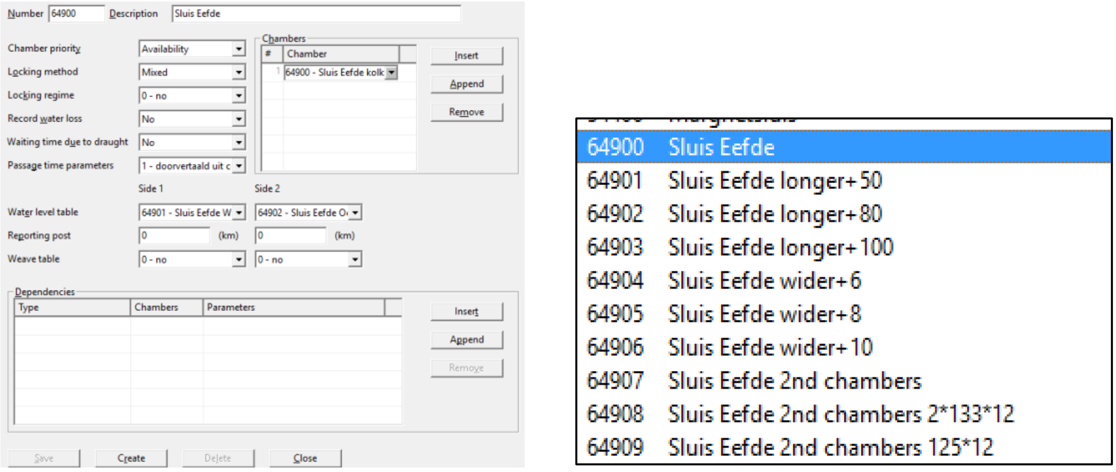


Figure 4.5 The block of lock and the list of *lock* block

In figure 4.5, the list of locks is different from the list in figure 4.4 because they are for different blocks of the model.

(6) Waterway section

Four sections of waterways are defined by RWS in this block which are used directly (as shown in figure 4.1). They are the west section (①-②), the west section before the lock(②-③), east section (④-⑤) and east section near the lock (⑤-⑥). The differences between two sections at one side are their length and their position related to the chamber. The waterway for waiting is close to the lock which is 0.8km long. Normal waterway for navigation is set as 1.5km long. The length of the waterway is provided by RWS, which can be used directly.

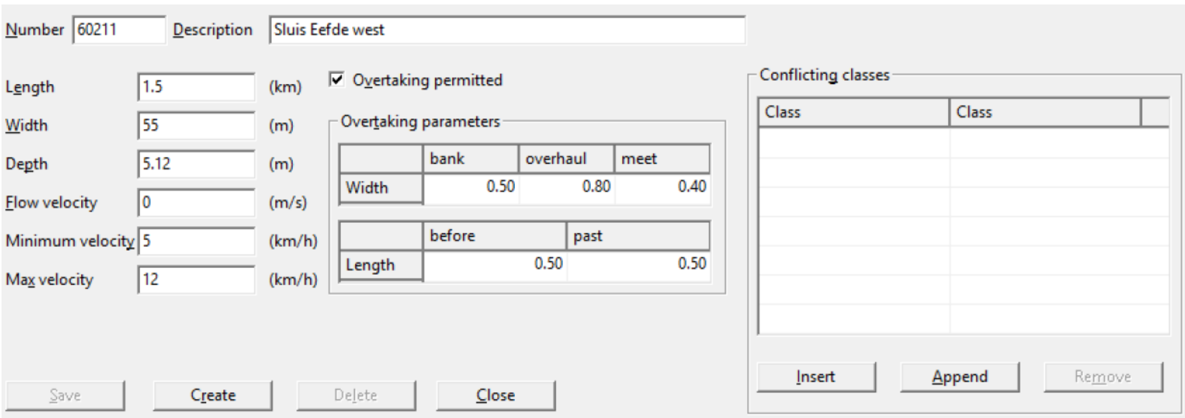


Figure 4.6 Block of waterway section

(7) Fleet

Blocks of *Fleet* are built based on the data of 2014. Navigation in different directions has their own fleet. EW and WE are also used to distinguish directions. In this part, fleet share needs to be selected. Condensing factor and extent are filled in.

Fleet share will be inserted in next block. Condensing factor is used to vary the amount of incoming vessels. The numbers of ships per week will be multiplied with condensing factor. The extent is the amount of weeks that the model of Eefde lock runs for. Too many weeks will increase the time of simulation. Thus, four weeks are filled in here as the data are for one month which stands for the busiest situation.

(8) Fleet Share

Information on different vessels is put in table 4.1, including the percentage of loaded, loaded level, and numbers of ships per week. They are calculated by equation 4.1, equation 4.2 and equation 4.3.

In view of recreational vessels, only motor yacht and sailing yacht are considered. Other types of recreational vessels lack information and they account for a small proportion of total vessels. Thus, the information of motor yacht and the sailing yacht is put in. Data are shown in table 4.1 based on two directions.

$$\text{\%loaded}= \frac{Loaded\ ships}{Loaded\ ships+Empty\ ships} \times \% \tag{4.1}$$

$$\text{loaded level}= \frac{Transported\ weight}{Load\ capacity} \times \% \tag{4.2}$$

$$\text{\#/week}= \frac{Number\ of\ vessels}{4\ weeks} \tag{4.3}$$

Table 4.1 Data of fleet share

April of 2014 (EW)			
RWS-Class	%loaded	loaded level (%)	#/week
M0	0	0	0.25
M1	14.29	69.95	5.25
M2	4.17	87.40	12
M3	26.23	13.32	15.25
M4	20.83	31.04	12
M5	17.67	84.09	21.25
M6	49.04	79.05	26
M7	64.71	77.83	12.75
M8	75	41.37	19
B01	0	0	0.75
B02	100	46.67	0.25
B04	100	81.57	0.25
BI	0	0	0.25
201 motor yacht(RWS-coding 80)	0	0	39
202 sailing yacht(RWS-coding 82)	0	0	4

April of 2014 (WE)			
RWS-Class	%loaded	loaded level (%)	#/week
M0	0	0	0.5
M1	75.00	97.36	5
M2	96.00	84.09	12.5
M3	100	66.76	15.75
M4	93.88	75.12	12.25
M5	91.76	88.09	21.25
M6	60.91	77.71	27.5
M7	39.22	68.77	12.75
M8	75.95	34.65	19.75
B02	0	0	0.25
B04	100	90.21	0.25
BI	100	90	0.25
201 motor yacht (RWS-coding 80)	0	0	16.75

In the block of fleet share, %cert means the percentage of ships sailing with a certificate. %1 cone stands for the percentage of ships sailing with one cone. They are not key factors and lack information so they are ignored.

4.2.2 Future scenarios

The scenarios of future are made in view of increasing fleet in the future. The process is the same as current scenarios but the data need to be changed.

(1) Arrival pattern

Arrival pattern is taken as same as that of current scenarios. The number in each time doesn't mean the number of vessels but they stand for the intensity. Thus, the same arrival pattern as 2014 are assumed.

(2) Fleet share

Data of 2050 provided by RWS are numbers of different types of vessels in total except recreational ships. In order to get monthly data, the tendency of ship numbers monthly is assumed to be same as 2014. Following equation 4.4 and equation 4.5 show the method of calculating the monthly data of 2050. Factor 1 stands for the mathematical relationships between the year 2014 and 2050.

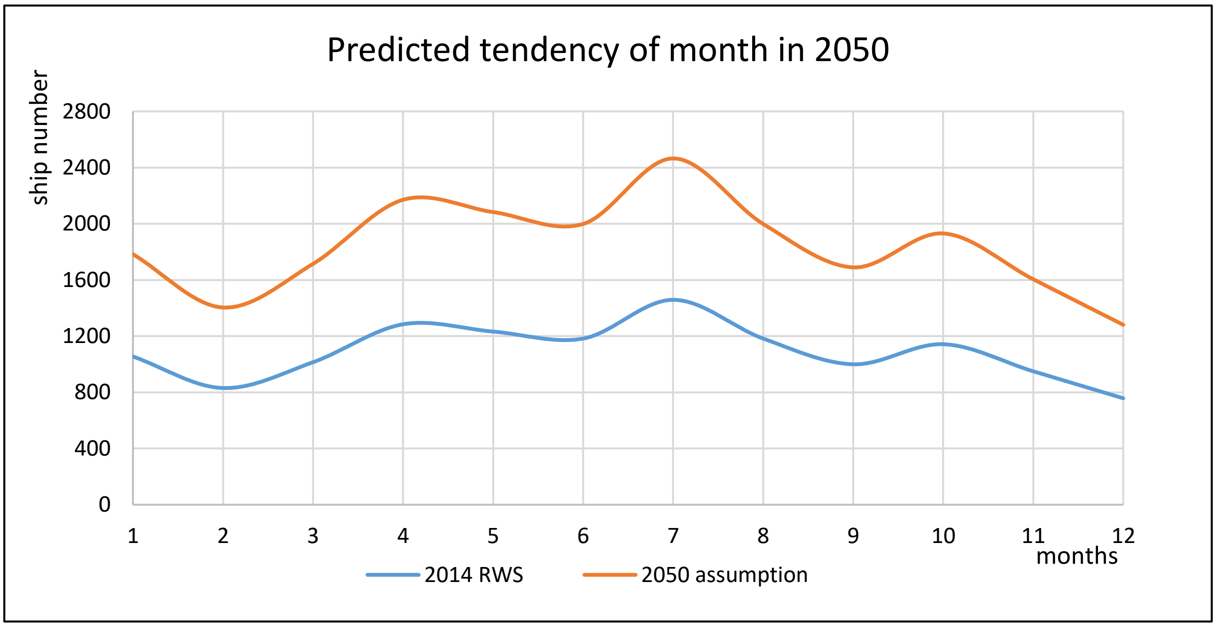


Figure 4.7 Assumed tendency in 2050 (data source of 2014: RWS)

$$2050\ yearly = 2014\ yearly \times Factor\ 1 \tag{4.4}$$

$$\sum 2050\ months = \sum 2014\ months\ \times Factor\ 1 \tag{4.5}$$

As shown in following figure 4.8, the blue line is identified with data of commercial vessels in table 2.2, and the red line is identified with data in figure 2.7. When data are without recreational vessels, the predicted amount of ships in 2050 by RWS is 12066. Based on the blue line and the data in table 2.2 from other sources, the prediction of 2050 is around 19000. RWS predicts that there will be a little increasing tendency of vessels. The prediction by RWS is less than the prediction by other sources.

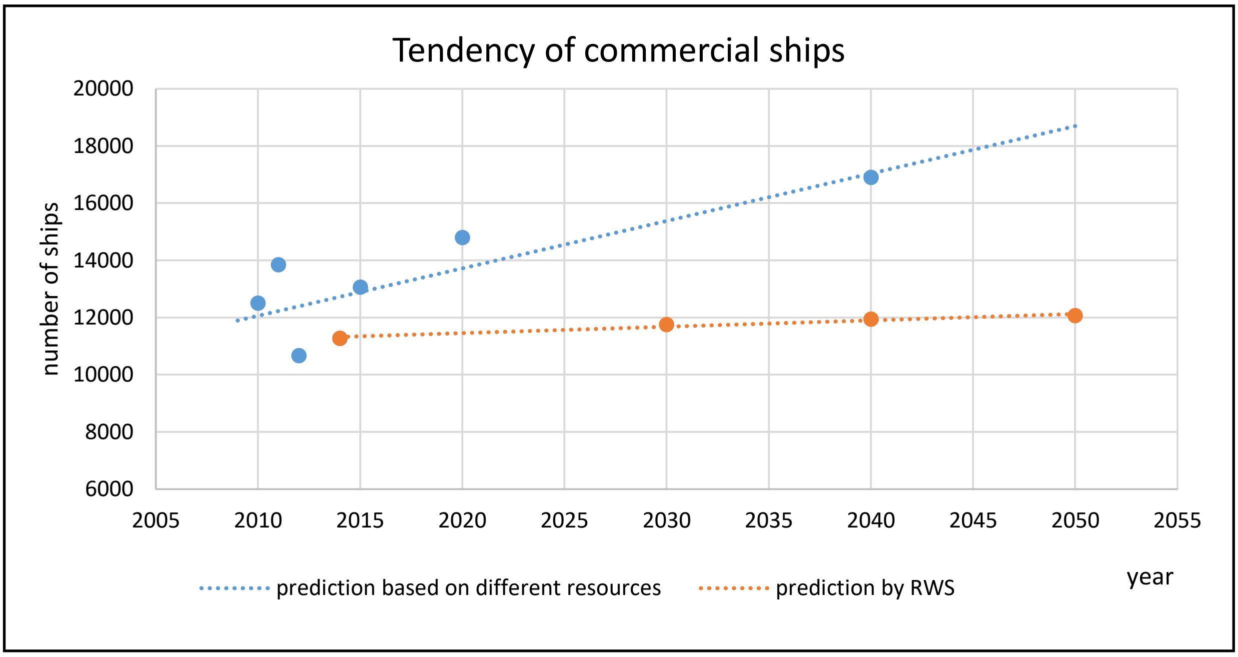


Figure 4.8 Tendency of commercial ships

In SIVAK, input data of vessels should be one month for each direction. However, according to above prediction, only total numbers is got. Therefore, the detailed prediction for one month in each direction is calculated as follows.

Prediction 1

There are deviations around the main trend line (blue line in figure 4.8). Growing trend of vessels shows that 2050 is predicted to have 19000 commercial vessels. More vessels will make waiting time longer so using high prediction is conservative for estimating waiting time. The number of commercial ships is 11272 in 2014. Therefore, factor 1 is calculated which is the amplitude factor.

$$Factor\ 1 = \frac{19000}{11272} = 1.69 \quad (4.6)$$

2050 monthly data (April) in direction EW (WE) = 2014 monthly data(April)*Factor 1 *Factor EW(WE)

(4.7)

The ships in direction of WE are predicted to account for 52%, and the direction of EW will have 48% of total ships in 2050. The proportion of vessels in 2014 is around 50% in both directions. It seems that proportions in 2014 and 2050 have little differences. Therefore, the data of fleet in April, 2014 in one direction can be used directly for equation 4.7.

At last, the monthly data of vessels in different directions can be calculated as following equation 4.8. 2014 data in April (EW) has already included the factor EW mentioned above, same for the 2014 data in April (WE).

2050 monthly data (EW)= 2014 data in April (EW) * 1.69

2050 monthly data (WE)= 2014 data in April (WE) * 1.69 (4.8)

Table 4.2 Fleet share of 2050 (prediction1)

2050 EW(prediction1)		
RWS-Class	%loaded	#/week
M0	0	0.42
M1	1.57	8.87
M2	2.84	20.28
M3	29.85	25.77
M4	25.48	20.28
M5	12.43	35.91
M6	34.70	43.94
M7	64.02	21.55
M8	68.49	32.11
B01	0	1.27
B02	16.41	0.42
B04	6.27	0.42
BI	0	0.42

2050 WE(prediction1)		
RWS-Class	%loaded	#/week
M0	0	0.85
M1	87.96	8.45
M2	97.34	21.13
M3	98.06	26.62
M4	96.80	20.70
M5	94.48	35.91
M6	77.00	46.48
M7	49.89	21.55
M8	87.56	33.38
B02	21.22	0.42
B04	88.68	0.42
BI	87.41	0.42

In the block of *FLEET SHARE*, the percentage of loaded, load level and the number of vessels per week are important and need inputs. Although data of the whole 2050 can be put in, total data cannot stand for the busy situation and will slow down the simulation speed. In other words, data of one month in 2050 is used which is safer for the design of the lock.

In 2050, the proportion of loaded is given by the data of whole year. In the block, the data of one month is needed which is assumed to be the same as the whole year. In reality, the percentage of loaded for the whole year is lower than the busiest month. This error of assumption may reduce the waiting time to some degree.

The amount of vessels per week is calculated according to above equations. The input numbers are listed in table 4.2.

Prediction 2

In the case of RWS prediction, the predicted value of 12066 for the whole year of 2050 will be used directly.

$$Factor\ 1 = \frac{12066}{11272} = 1.07 \tag{4.9}$$

Therefore, the monthly vessels in two directions predicted by RWS are:

2050 monthly data (EW)= 2014 data in April (EW) * 1.07

2050 monthly data (WE)= 2014 data in April (WE) * 1.07 (4.10)

Compared with prediction 1, only the numbers of vessels per week are different because of different factor 1. The fleet share of prediction 2 is shown as following table 4.3.

Table 4.3 Fleet share of 2050 (prediction2)

2050 EW(prediction2)		
RWS-Class	%loaded	#/week
M0	0	0,27
M1	1,57	5,62
M2	2,84	12,84
M3	29.85	16,32
M4	25.48	12,84
M5	12.43	22,74
M6	34.70	27,82
M7	64.02	13,64
M8	68.49	20,33
B01	0	0,80
B02	16.41	0,27
B04	6.27	0,27
BI	0	0,27

2050 WE(prediction2)		
RWS-Class	%loaded	#/week
M0	0	0,54
M1	87.96	5,35
M2	97.34	13,38
M3	98.06	16,85
M4	96.80	13,11
M5	94.48	22,74
M6	77.00	29,43
M7	49.89	13,64
M8	87.56	21,13
B02	21.22	0,27
B04	88.68	0,27
BI	87.41	0,27

The prediction of recreational ships

There is little information about recreational vessels. At locks, recreational vessels cannot be predicted easily since recreational ships have limited communication with the lock master. And recreational ships are easily affected by factors, such as weather and water conditions. Therefore, the total number of recreational vessels is assumed to be the same as 2014 which is about 2000. The loaded pattern and the number of ships per week in different classes are also assumed to be the same as 2014.

5 Validation of SIVAK

In the thesis, SIVAK is used to determine the optimum configuration for increasing the capacity of the Eefde lock. SIVAK is a model which is used by RWS for a long time and has proven to be an accurate simulation model for the capacity of navigation locks. In this chapter, the way that the model is used will be verified to be correct.

5.1 Scenarios for validation

Following four scenarios are used for verifying the simulation model. The data of vessels are all from RWS.

- Scenario S1 with ship numbers according to RWS 2014

As mentioned in Chapter 3, scenario 1 is the existing Eefde lock with the dimensions of 133*12 m. The data of vessels through the Eefde lock in 2014 is provided by RWS.

Figure 5.1 Scenario 1 with vessels of RWS 2014

- Scenario S4 with ship numbers according to RWS 2014

Scenario 4 is the enlargement plan of Rijkswaterstaat. They are going to build a new chamber on the north of the existing chamber. The dimensions of the new chamber is 125*12.5 m.

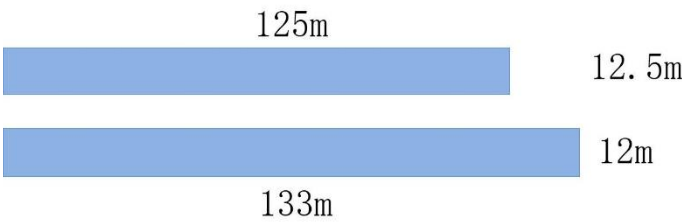


Figure 5.2 Scenario 4 with vessels of RWS 2014

- Scenario SF1 with ship numbers according to RWS 2050

Scenario SF1 has the same layout as scenario 1 but the ship number is predicted by RWS for 2050.

- Scenario SF4 with ship numbers according to RWS 2050

Scenario SF4 has the same layout as scenario 4 but the ship number is predicted by RWS for 2050.

5.2 Results of scenarios

By using SIVAK, the results of above four scenarios are obtained. Attention is paid to the capacity of locks and average passing time.

- Scenario S1 with ship numbers according to RWS 2014

Table 5. 1 Scenario S1 & RWS2014 vessels

Project: Eefde lock 2014 simulation – base scenario (S1)		
Direction	WE	EW
Mean Nmax in chamber	1.26	1.47
Locks in two directions (number/month)	612	611
Total locks (number/month)	1223	
Capacity of lock		
Capacity of lock(tons/hour)	2232.97	2392.44
Capacity of lock(number/hour)	1.77	2.07
Mean passing time		
Mean passing time(minutes)	99.26	94.38
Average passing time of both directions(minutes)	96.64	

The average passing time of existing one chamber is much larger than 50 minutes. The existing Eefde lock has traffic problems in the current situation.

- Scenario S4 with ship numbers according to RWS 2014

Table 5. 2 Scenario S4 & RWS2014 vessels

Project: Eefde lock 2014 simulation –two chambers (S4)		
Direction	WE	EW
Capacity of lock		
Capacity of lock(tons/hour)	4362.42	4654.36
Capacity of lock(number/hour)	3.39	3.50
Mean passing time		
Mean passing time(minutes)	37.06	37.48
Average passing time of both directions(minutes)	37.28	

When the second chamber (125*12.5m) is built according to the plan of RWS, the problem of long passing time is solved in the current situation.

- Scenario SF1 with ship numbers according to RWS 2050

Table 5. 3 Simulation of scenario SF1 & RWS2050 vessels

Project: Eefde lock 2050 simulation (SF1)		
Direction	WE	EW
Mean Nmax in chamber	1.31	1.50
Locks in two directions (number/month)	616	709
Total locks (number/month)	1325	
Capacity of lock		
Capacity of lock(tons/hour)	2209.19	2353.48
Capacity of lock(number/hour)	1.82	2.09
Mean passing time		
Mean passing time(minutes)	105.19	100.70
Average passing time of both directions(minutes)	102.79	

RWS predicts that the number of vessels will increase a little in 2050 (figure 4.8). The simulation result of RWS prediction is in above table 5.3. The passing time will not meet the requirement.

Compared to the current situation (table 5.1), the passing time increase in 2050. It means no matter the current situation or future situation, Eefde lock with one chamber will have a traffic problem. That is also the reason why the responsible authority plans to enlarge the Eefde lock.

- Scenario SF4 with ship numbers according to RWS 2050

Table 5.4 Scenario SF4 & RWS 2050 vessels

Project: Eefde lock 2050 simulation –base scenario (two chambers)		
Dimensions of the second chamber (m)	12.5*125	
Direction	WE	EW
Capacity of lock		
Capacity of lock(tons/hour)	4526.68	4522.46
Capacity of lock(number/hour)	3.59	3.42
Mean passing time		
Mean passing time(minutes)	38.01	37.09
Average passing time of both directions(minutes)	37.52	

In 2050, because there is not much increase of vessels under RWS's prediction, the average passing time of both directions is 37.52 minutes which is smaller than 50 minutes. It means there will be no traffic problem in 2050 according to the RWS's prediction.

It explains why the new chamber with dimensions of 125*12.5 m is going to be built by the lock authority. The plan of the 2nd new chamber is reasonable under the prediction of RWS.

5.3 Summary

By the simulation of four scenarios, the summary is given as follows.

First, according to the simulation of scenario S1 with vessels of RWS 2014, the existing of Eefde lock has insufficient lock capacity and the passing time is much larger than the limit situation (50 minutes). Therefore, the responsible authority has to take measures to solve the problem of insufficient capacity so the enlargement of the Eefde lock is necessary. By simulation of scenario SF1, if no measurements are taken to solve the traffic problem, passing time becomes larger in the future which makes traffic problem more serious.

Then, by the simulation of scenario S4 with RWS 2014 vessels and scenario SF4 with RWS 2050 vessels, it can be found that the results of scenarios in the thesis are corresponding to the plan of RWS who is going to build one new chamber with the dimensions of 125*12.5 m. Thus, the way of the SIVAK model used in the thesis is correct. More scenarios of enlargement will be simulated in the next chapter to study the optimum scenarios.

6 Simulations of enlargement scenarios

There are mainly three documents in the output of SIVAK. They are the records of ships, records of the lock operation and report. The records of ships and lock contain the detailed moment of every operation. In the report, the input of waterway sections is shown first. Then, data of chamber, numbers of locking, the capacity of lock and the mean passing time are given. Especially, the capacity of lock and passing time is important to the analysis.

In this chapter, the results of simulations are analyzed. Scenarios of 2012 and 2014 are compared with each other in different situations. Then, future scenarios are simulated and analyzed as well. At last, scenarios are selected according to the criterion 1 that the passing time should be less than 50 minutes. Scenarios which meet the requirement will be selected to the next costs-benefits analysis.

6.1 Current scenarios

There are data of 2012 and 2014. The data of 2012 are provided by RWS directly in SIVAK. And the data of 2014 are offered by RWS in form of documents. Both data of two years are put into SIVAK. In general, there are four types of scenarios, base scenario (S1), increasing the length of the chamber (S2), increasing the width of the chamber (S3), and building the second chamber (S4). Results are shown in different graphs. At last, different scenarios are compared with each other.

6.1.1 Base scenario S1

Table 6. 1 Simulation of base scenario 2012

Project: Eefde lock 2012 simulation		
Direction	WE	EW
Mean Nmax in chamber	1.11	1.14
Locks in two directions (number/month)	649	648
Total locks (number/month)	1297	
Capacity of lock		
Capacity of lock(tons/hour)	2165.35	2217.86
Capacity of lock(number/hour)	1.54	1.59
Mean passing time		
Mean passing time(minutes)	83.81	73.39
Average passing time of both directions(minutes)	78.55	

In the case of one chamber and based on the data of vessels, the passing time of April in 2012 got from the model is 78.55 minutes (table 6.1). The passing time of 2014 increased to 96.64 minutes which has already been obtained in table 5.1. The problem of Eefde lock became clear from 2012 to 2014.

Comparing 2012 and 2014, except the number of locking times, all other numbers in 2014 increased. In the limited time (one month), if the waiting is longer, the number of lockings will decrease.

According to original data documents from RWS, vessels in the direction of WE are less than that in the direction of EW. However, the passing time in the direction of WE is longer than that in direction of EW. WE is the upstream direction. The velocity of vessels in the upstream direction may have lower velocity and need more time to exit. The different passing time may be due to the difference between filling and emptying chamber as well. Other reasons are not clear.

In the base scenarios, passing time is larger than 50 minutes which cannot meet the requirement (section 1.4).

6.1.2 Increasing the length of chamber S2

As mentioned in Chapter 3 about scenarios, during simulations, 50 meters are added to the length initially. Then, 25 meters are added to each simulation until the passing time can meet the requirement.

The results of passing time are organized in following graph 6.1. The red line is 50 minutes which is the limit situation of passing time.

Overall, as the length of the chamber is longer, the passing time becomes shorter, but the rate of decrease is lower and lower. The passing time in 2012 is lower than that of 2014 because the vessels through the Eefde lock in 2012 were less than that in 2014. The trends of 2012 and 2014 are similar.

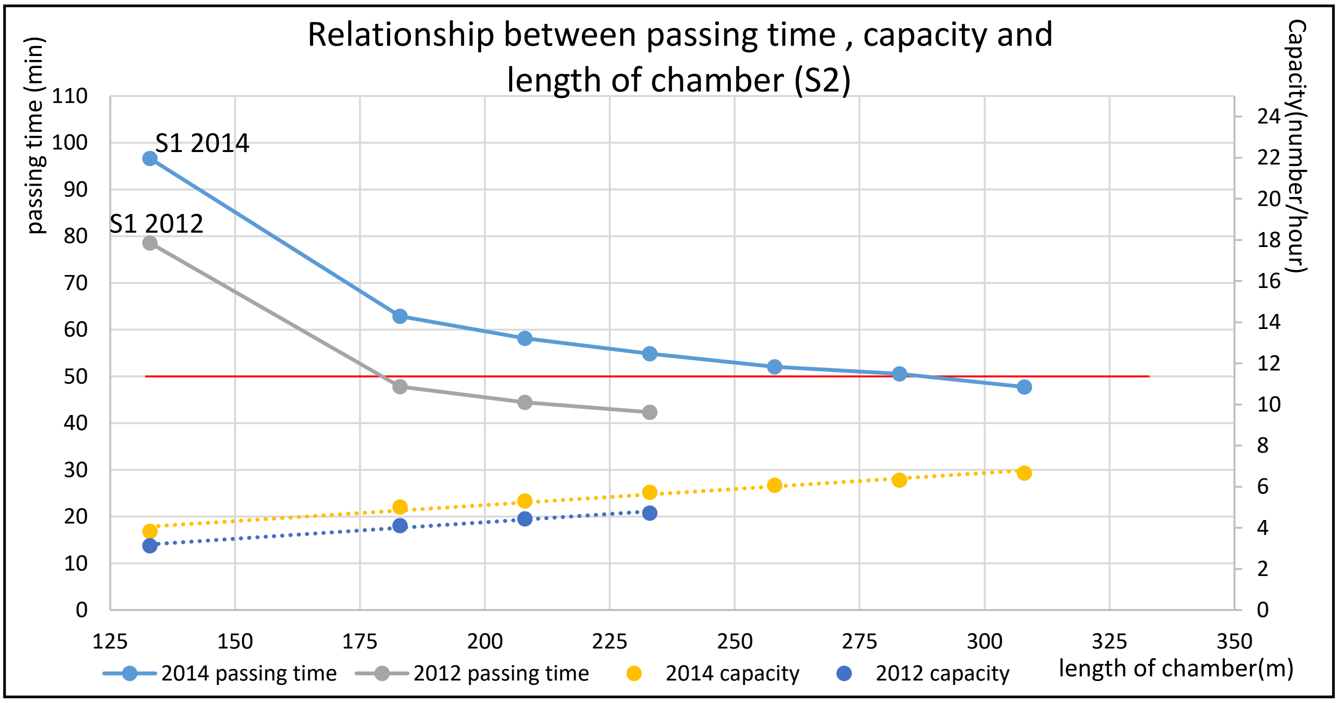


Figure 6. 1 Relationship between passing time, capacity and increasing length of chamber

The simulation of 2014 data shows that when the length of chamber reaches about 308 meters which is 175 m longer than the current chamber, passing time is 47.4 minutes which is less than 50 minutes. Waiting time can meet the requirement that it should be smaller than 30 minutes. Therefore, the enlarged chamber with the dimensions of 308*12 m will reduce waiting time to the critical value.

Two lines at the bottom of the graph are the relationship between capacity in total and the length of chamber. The chamber is longer, the capacity is larger. The relationship is almost linear. When the length is extended 200 meters, the capacity of lock does not increase a lot that the added value is around three vessels.

6.1.3 Increasing the width of chamber S3

The relationship between lock capacity and the width of the chamber is also described by Kooman and Bruijn. Their study was based on locks with lengths of 80 m and 160 m. It can be assumed that the Eefde lock with the length of 140 m has a similar regulation. For every two meters, there are obvious changes of lock capacity (figure 2.10). Therefore, when making scenarios of increased width of the chamber, two meters are taken as intervals.

The results of passing time are organized in following graph 6.2. There is a decreasing tendency of the passing time but the rate of decline becomes smaller.

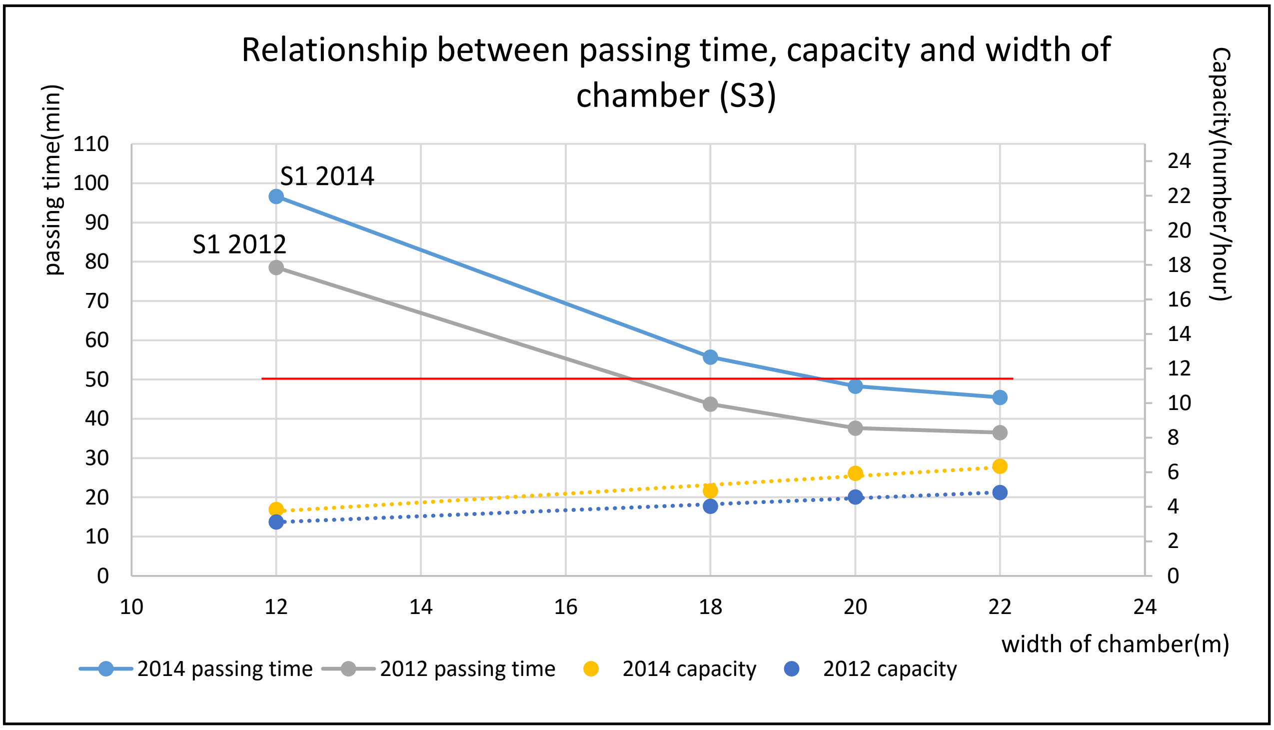


Figure 6. 2 Relationship between passing time and increasing width of chamber

In 2012, when the width is larger than about 17 meters, the passing time is lower than 50 minutes. In 2014, when the width of chamber becomes larger than 20 meters, the passing time is smaller than 50 minutes and the waiting time is smaller than 30 minutes. Therefore, the enlarged chamber with the dimensions of 20*133 m in 2014 will reduce waiting time to the critical value.

The capacity of lock changes linearly. The increasing rate of capacity in 2014 is larger than that in

2012. In 2014, when the capacity is 6 ships per hour, the passing time meets the requirement.

6.1.4 Building the 2nd new chamber S4

The second chamber of the Eefde lock is going to be built. Data of two chambers can be found separately in the output documents of SIVAK. The dimensions of the second chamber are determined according to CVB guidelines for a ‘minimum lock’ (Appendix B.3). This method is suitable for the locks with little navigation and has a low economic advantage (RWS, 2011). The dimensions of the second new chamber are 12.5*125 m. Thus, when the navigation increases and economic interest becomes larger in the future, the locks may need to be improved. This will be discussed in the future scenarios.

Table 5.2 in Chapter 5 has already shown the simulation results of the Eefde lock with two chambers. The passing time is reduced to 37.28 minutes in 2014. The passing time of S4 for 2012 is 28.46 minutes.

In general, the construction of a new chamber seems to be the most effective way to enlarge the lock in view of the reduction of passing time. In the following figure 6.3, the dashed line does not have meaning since it is impossible to have a half chamber. The detailed comparison of different scenarios will be discussed in next section. However, the optimum scenario needs to consider cost and benefit as well which will be discussed in next Chapter 7.

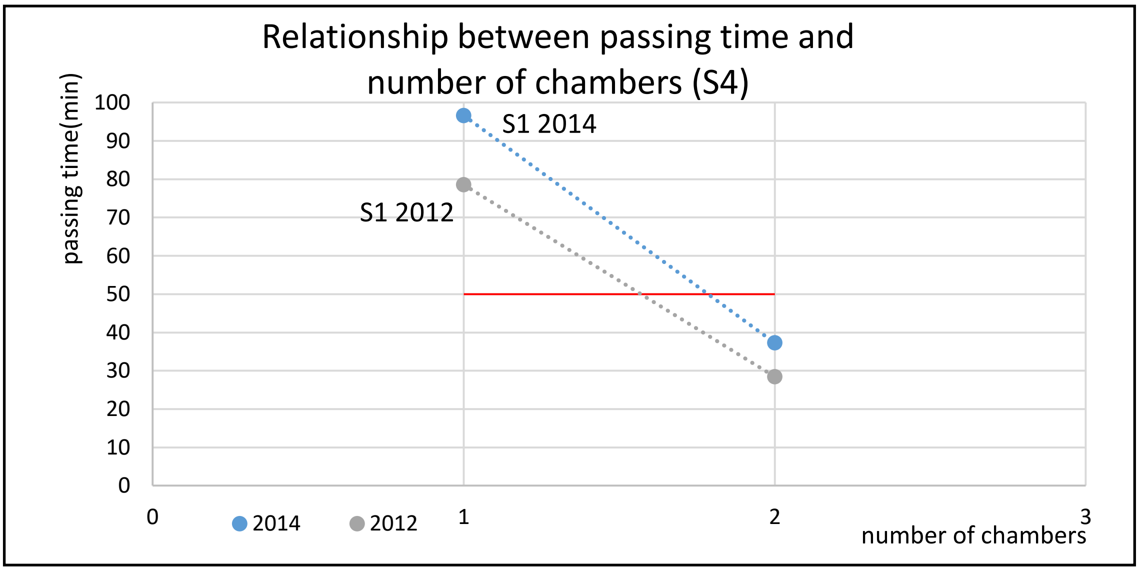


Figure 6. 3 Relationship between passing time and number of chambers

6.1.5 Summary of current scenarios

In the above part, the current scenarios are simulated. The results of 2012 and 2014 simulation are compared with each other. The simulation of different scenarios is analyzed as well.

When the extension is based on one chamber, the results are as following figure 6.4. First, results of 2012 and 2014 are compared. In general, the trend of decline is similar in two years and the differences of two years do not change a lot. Furthermore, the decline is quick at first but becomes slower and slower later. However, the passing time meets the requirement after one simulation in 2012 while 2014 needs several simulations. Therefore, the scenarios of 2012 meet the requirement of waiting time more easily than 2014. Generally speaking, the passing time of 2012 is less than that of 2014. The possible reason for differences between 2012 and 2014 is that 2014 have more vessels than 2012 and no effective measurements were taken to reduce the passing time. This is corresponding to the fact that until 2017, the new chamber is going to be built to solve the problem.

In order to compare scenario S2 (longer chamber) and scenario S3 (wider chamber), length, width and passing time are normalized by the method Min-Max scaling. Base scenarios S1 is taken as reference standard. According to following figure 6.4, making chamber wider is more effective than making chamber longer after the first simulation.

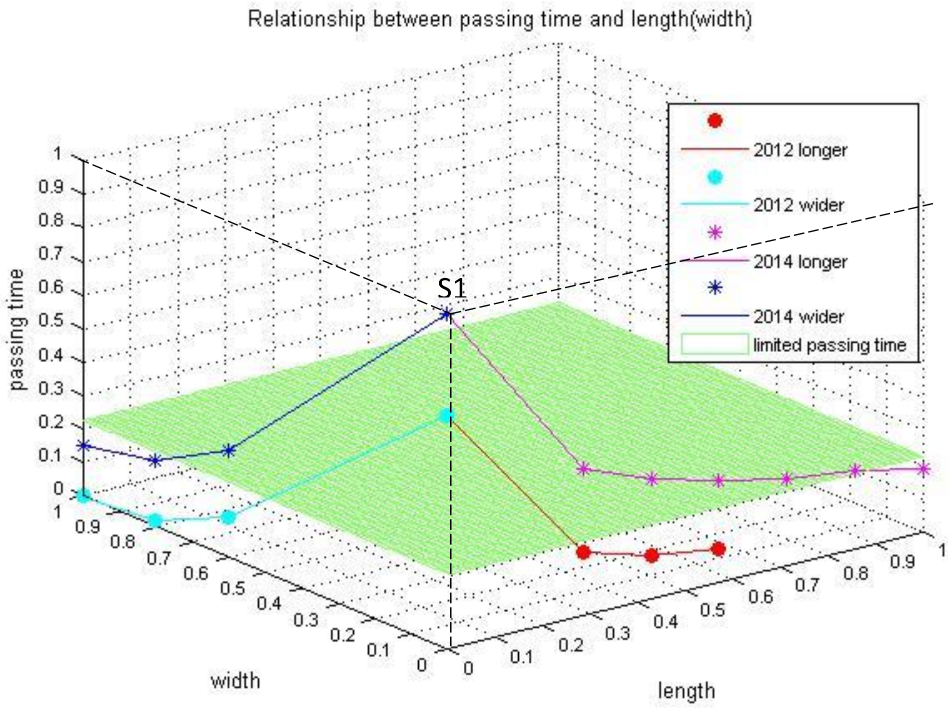


Figure 6. 4 Relationship between passing time and length(width) of chamber

Since the new chamber is going to be built, scenarios of two chambers are simulated necessarily. The most different aspect of two chambers is that the total area of the chamber is improved obviously. Thus, the horizontal area of chambers in case of increasing length and increasing width is calculated as well and shown in the following graph 6.5.

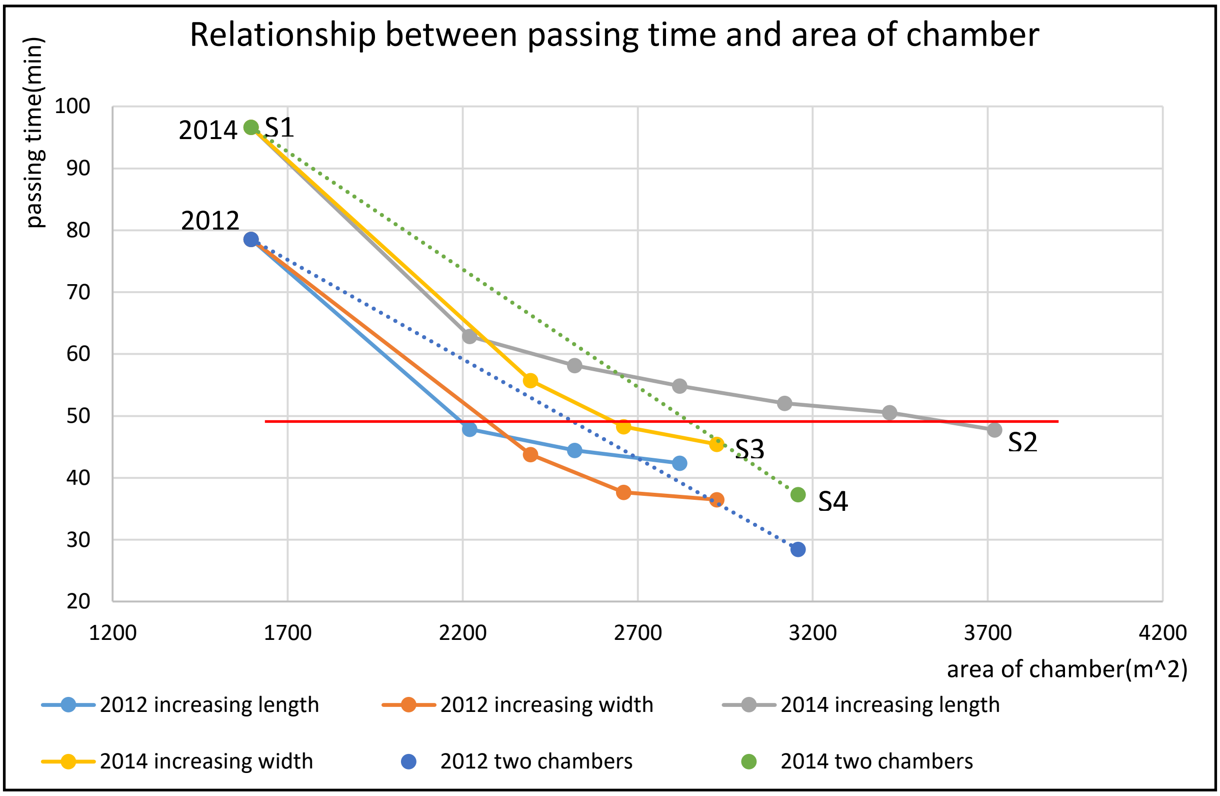


Figure 6. 5 Relationship between passing time and area of chamber

For example of 2014, there are some differences between different scenarios.

In the initial phase of simulation, the scenario of increasing length (S2) has less passing time than the scenario of increasing width (S3) though the horizontal area of the chamber is the same. After the second simulation, the passing time of increasing width scenario (S3) falls quickly and becomes lower than the scenario of increasing length (S2). In the tail of the curve, the lines of increasing length (S2) and increasing width scenarios (S3) are nearly parallel as the rate of decline becomes smaller and smaller.

According to figure 6.5, it can be also found that increasing the width of chamber (S3) is more effective than increasing the length of chamber (S4) after the first simulation.

However, the most effective way of enlargement is to establish the new chamber (S4). When the area of the chamber is the same, the passing time of lock with two chambers is less than other scenarios obviously.

So far, simulations are based on data of current situation. Considering increasing vessels in the future and other factors which affect the passing time of vessels, scenarios of future are going to be simulated as well (see next Section 6.2).

6.2 Future scenarios

The future scenarios have the same base scenario (existing one chamber) as the current scenarios but the vessels increase in the future. Moreover, the second chamber will be built with the dimensions of 12.5*125 m by the authority of the Eefde lock. There are two types of prediction for vessels because of the different forecast documents as mentioned in Section 4.2.2. Prediction 1 will be used in this section because the high prediction means more vessels in the future. It is conservative to select the optimum scenarios which can guarantee the enough capacity in 2050.

The dimensions of the second chamber will be changed because the lock will not fit the predicted navigation by other sources in the future.

6.2.1 Base scenario SF1

In the base scenario, the vessels in the future will pass through the Eefde lock with only one chamber. Since the vessels of prediction1 are larger than the provided number from RWS, it will lead to the large passing time at the Eefde lock in the future.

Table 6.2 Simulation of scenario SF1

Project: Eefde lock 2050 simulation (SF1)		
Direction	WE	EW
Mean Nmax in chamber	1.35	1.54
Locks in two directions (number/month)	931	1019
Total locks (number/month)	1950	
Capacity of lock		
Capacity of lock(tons/hour)	2327.69	2352.98
Capacity of lock(number/hour)	1.82	2.08
Mean passing time		
Mean passing time(minutes)	298.81	315.04
Average passing time of both directions(minutes)	307.29	

From the above table, in 2050, the Eefde lock will have serious problems if there is no enlargement. The locking time is more than five hours which means that there will be a traffic jam at the lock. Measurements should be taken to solve the problems. Compared to table 5.3, the simulation result of RWS prediction is obviously less than the simulation results by other sources.

6.2.2 Make the old chamber longer SF2

Similar to current scenario S2, the length of the chamber is increased gradually but the amount of vessels is more than current scenarios.

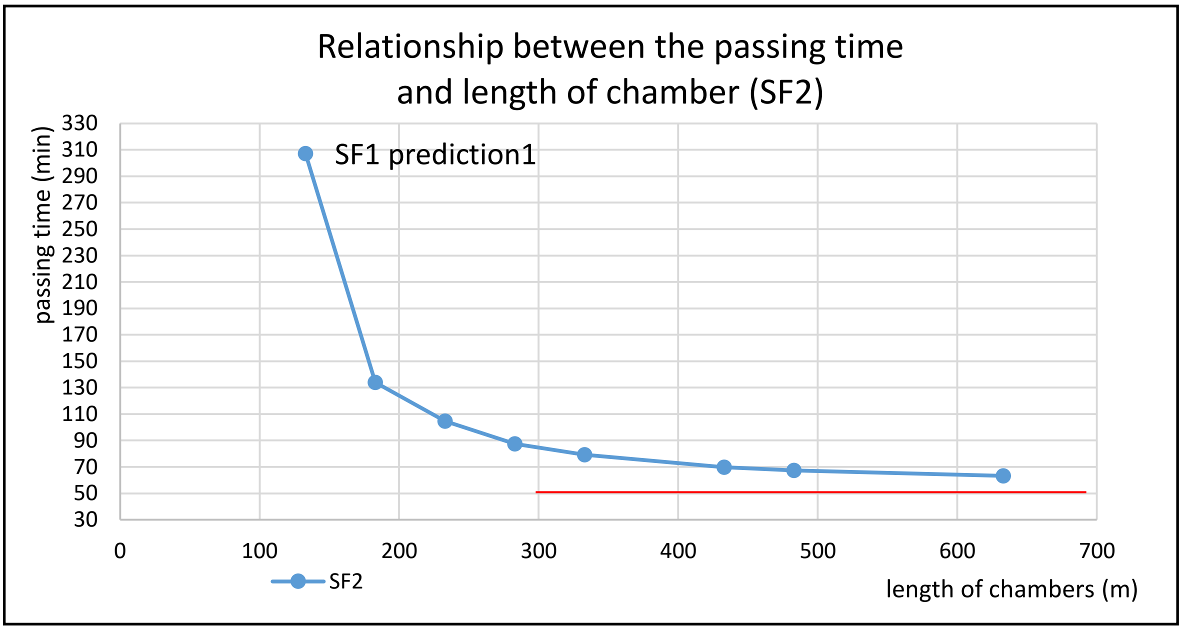


Figure 6.6 Relationships between length and passing time (2050)

Based on the results shown in the above graph, the passing time is hard to be lower than 50 minutes even when the length of chamber reaches to 600 meters. Therefore, the method of enlarging the length of the existing chamber is not efficient.

6.2.3 Make the old chamber wider SF3

The width of the Eefde lock can also be enlarged in the future, which is similar to S3. The results are as follows.

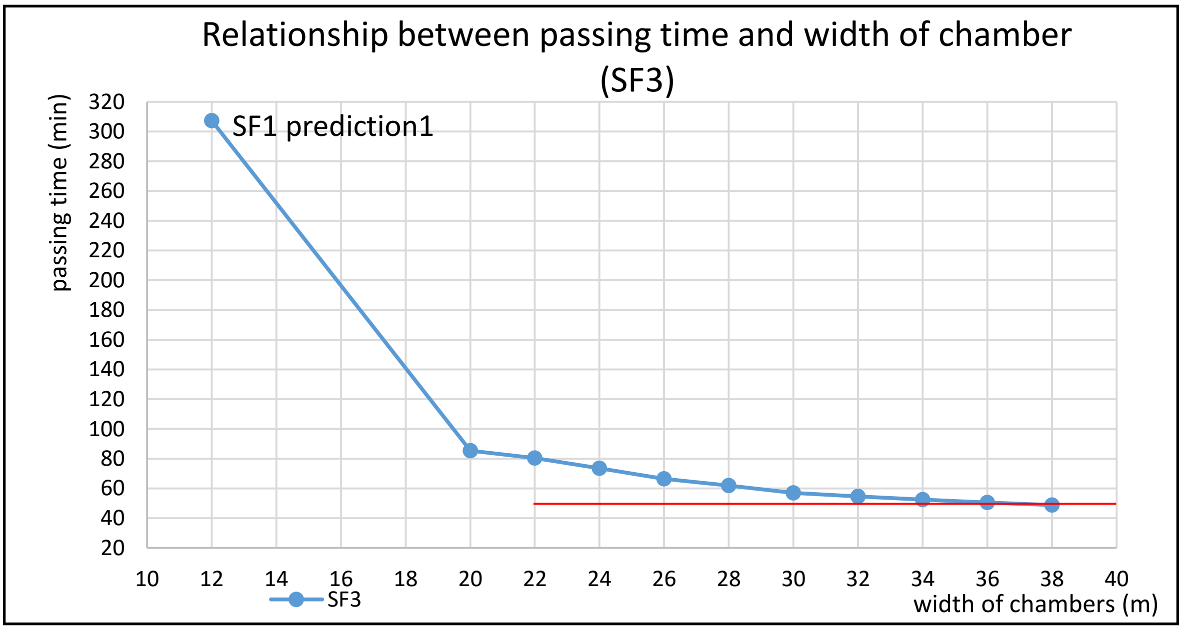


Figure 6. 7 Relationships between width of chamber and passing time (2050)

In the initial simulation, the change is quickly when eight meters are added to the width. The passing time will be lower than 50 minutes when the width is larger than about 35m.

6.2.4 Two chambers SF4

The scenario SF4 is currently what the responsible authority of the Eefde lock is going to take. Prediction 1 (other sources) is still used in this section.

In the future, the second chamber has minimum lock capacity. The result of simulation is shown in following table 6.3.

Table 6. 3 Simulation of 2050 scenario (two chambers & prediction 1)

Project: Eefde lock 2050 simulation –base scenario (two chambers)		
Dimensions of the second chamber (m)	12.5*125	
Direction	WE	EW
Capacity of lock		
Capacity of lock(tons/hour)	4500.4	4499.5
Capacity of lock(number/hour)	3.46	3.60
Mean passing time		
Mean passing time(minutes)	66.35	56.05
Average passing time of both directions(minutes)	60.97	

According to the results, because of increasing number of ships, the passing time is more than 50 minutes. Measurements should be taken in the future to enlarge the lock under the prediction 1.

The thesis focuses on the enlargement of locks and uses costs-benefits analysis to select the optimum scenario. Changes happen on the second new chamber in following simulations (section 6.2.5 and section 6.2.6). Furthermore, ships tend to be bigger in order to have larger loading capacity (Sys, & Vanelslander, 2011). Thus, the distribution of different vessels may change in the future. Because the distribution in the future is not forecast well, it is hard to simulate such scenarios since the data of ship size and ship numbers for each ship type are not sufficient to be put in the program.

6.2.5 Increasing the length of the second chamber SF5

In the future, the possible method of enlarging the lock is to increase the length of the second chamber. The result of simulation is shown in figure 6.8.

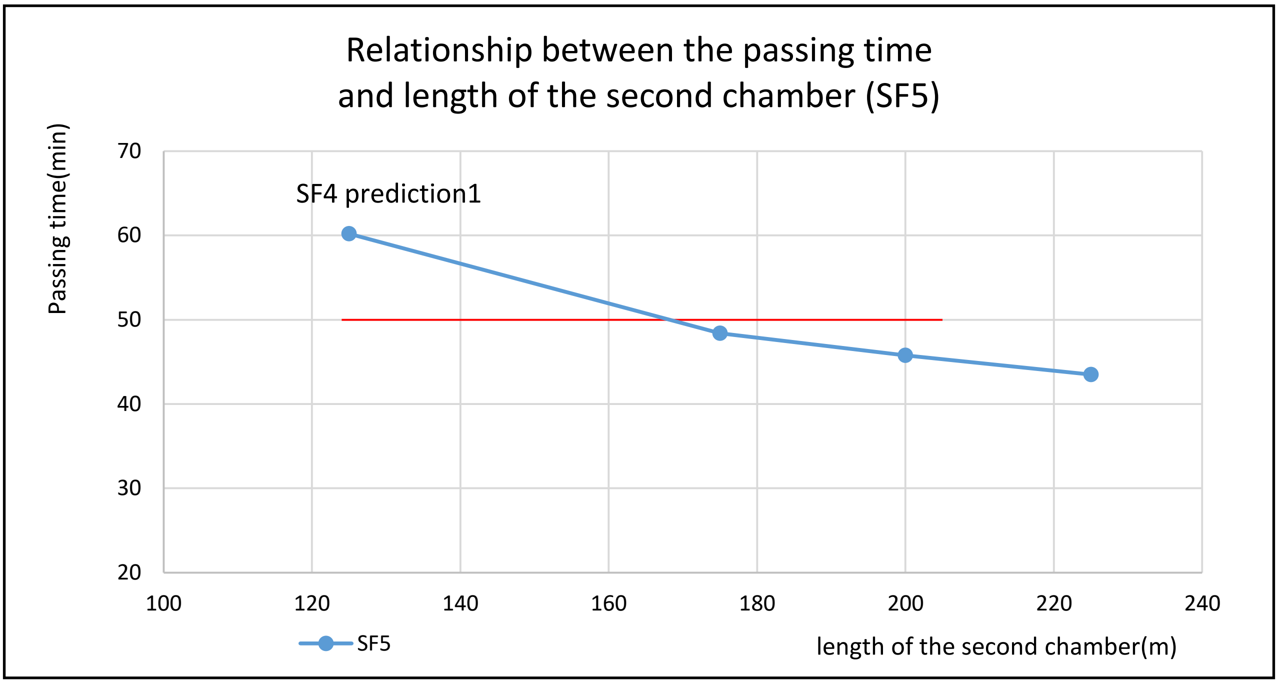


Figure 6. 8 Relationship between passing time and increasing length of the second chamber

When 50 meters are added to the length of the second chamber, the passing time can meet the requirement. The rate of decline becomes smaller and smaller.

6.2.6 Increasing the width of the second chamber SF6

The width of the second chamber is increased in this scenario and two meters are taken as intervals.

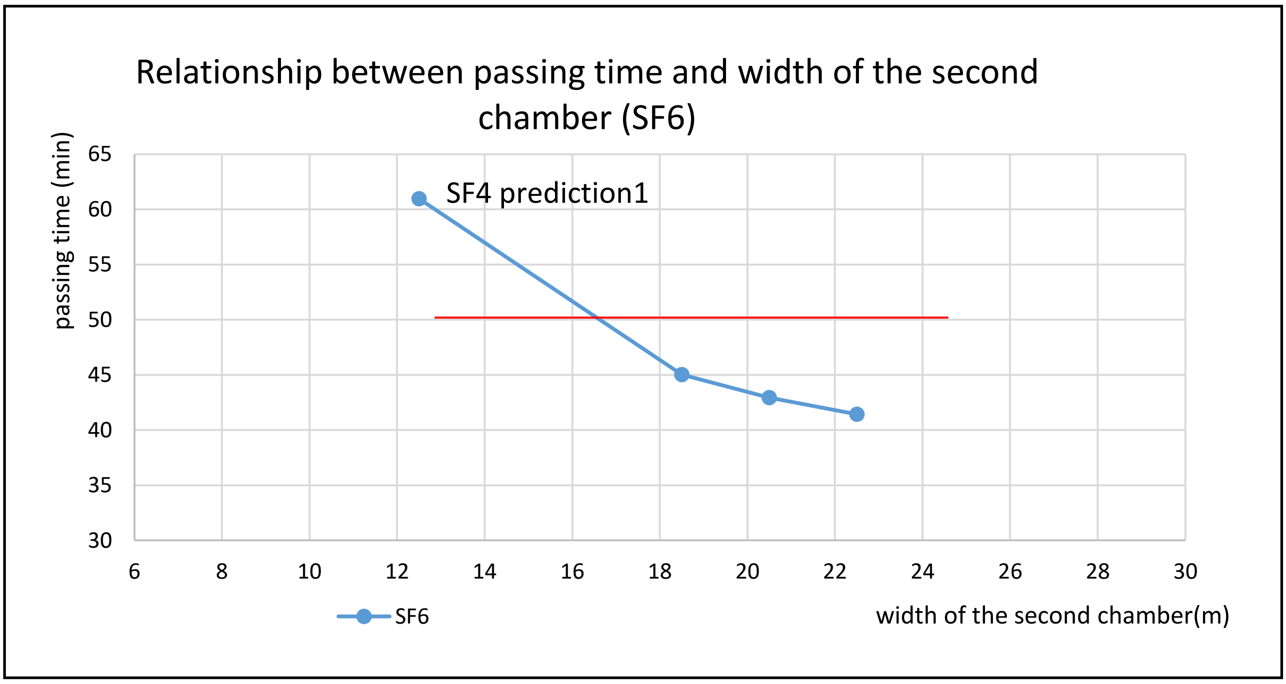


Figure 6. 9 Relationship between passing time and increasing width of the second chamber

The result shows that when the width of the second chamber is increased, the passing time becomes less. The rate of decline becomes smaller and smaller. Finally, when the width of the second chamber is more than around 17 meters, passing time can meet the requirement.

In 2050, in order to enlarge the chambers, the old chamber or the 2nd chamber can be changed but the change of two chambers at the same time is not discussed. Only the second chamber is changed. The relationships of passing time and length (width) of different chambers are shown as following figure 6.10. Scenario SF4 is taken as reference standard.

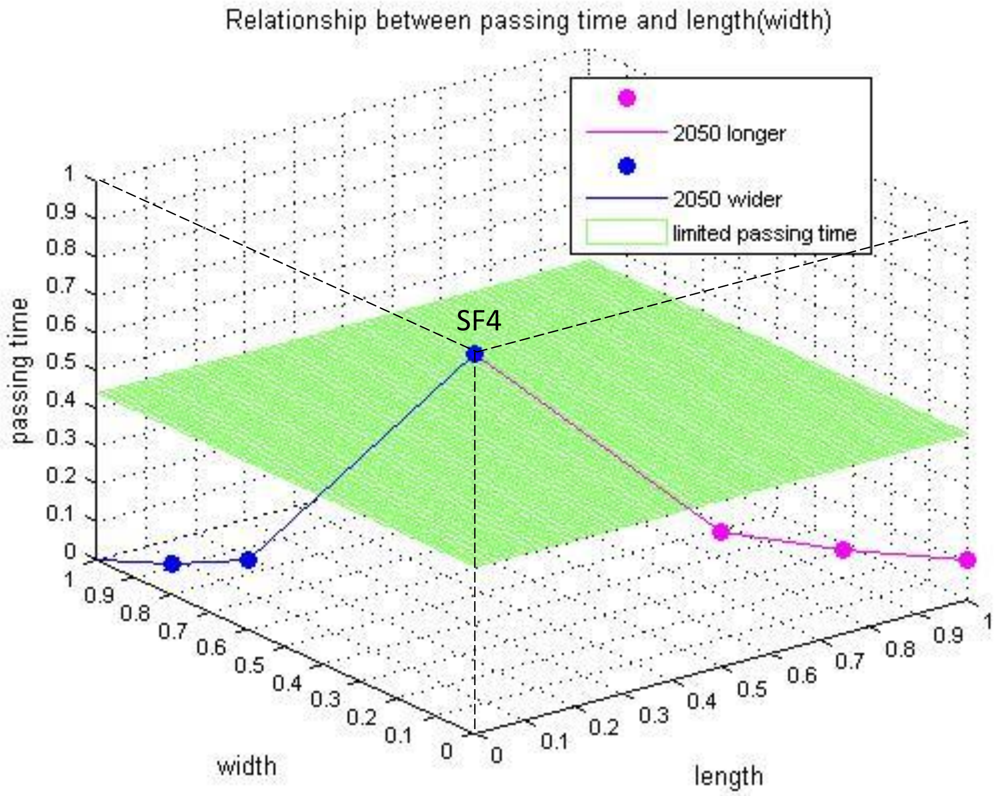


Figure 6. 10 Relationship between passing time and length (width) of the second chamber

Through the above graph, the comparison is shown between changes of length and width.

Overall, with the increase of length and width of the second chamber, the passing time can be reduced in 2050. The rate of decline becomes smaller and smaller. However, the decline rate when the width is enlarged (SF6), is larger than that of increasing the length of the chamber (SF5). In other words, enlarging the width of the second chamber is more efficient than enlarging the length of the chamber. This regulation is the same as the current scenarios.

6.2.7 Summary of future scenarios

In above sections, future scenarios are simulated, and the results are analysed. Based on the predicted data from different resources (prediction 1), Eefde lock with one chamber and two chambers (existing one plus designed one) will face the problem of passing time again in 2050. Though the problem is less serious than current scenarios, solving such problems in the future will improve the efficiency of locking. Furthermore, it is meaningful to study the enlargement of chambers in the future and also choose the optimum scenario for the future.

The regulation may be due to the horizontal area of chambers. Therefore, the relationship between the total area of chambers and passing time is going to be studied next. The situations are divided into two types, enlargement based on one chamber and enlargement of the second chamber.

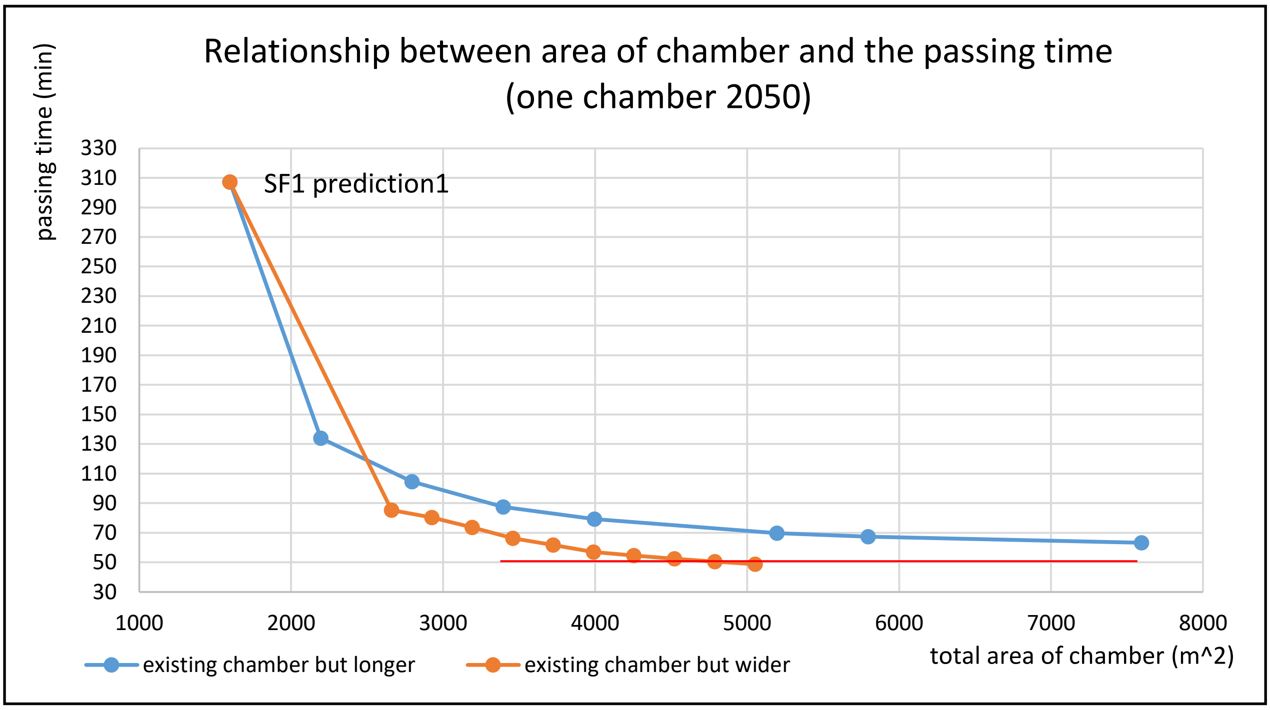


Figure 6. 11 Relationship between passing time and total area of chamber (one chamber 2050)

Above graph shows the situation of one chamber. With the same area, making the old chamber wider has smaller passing time, compared to making the chamber longer.

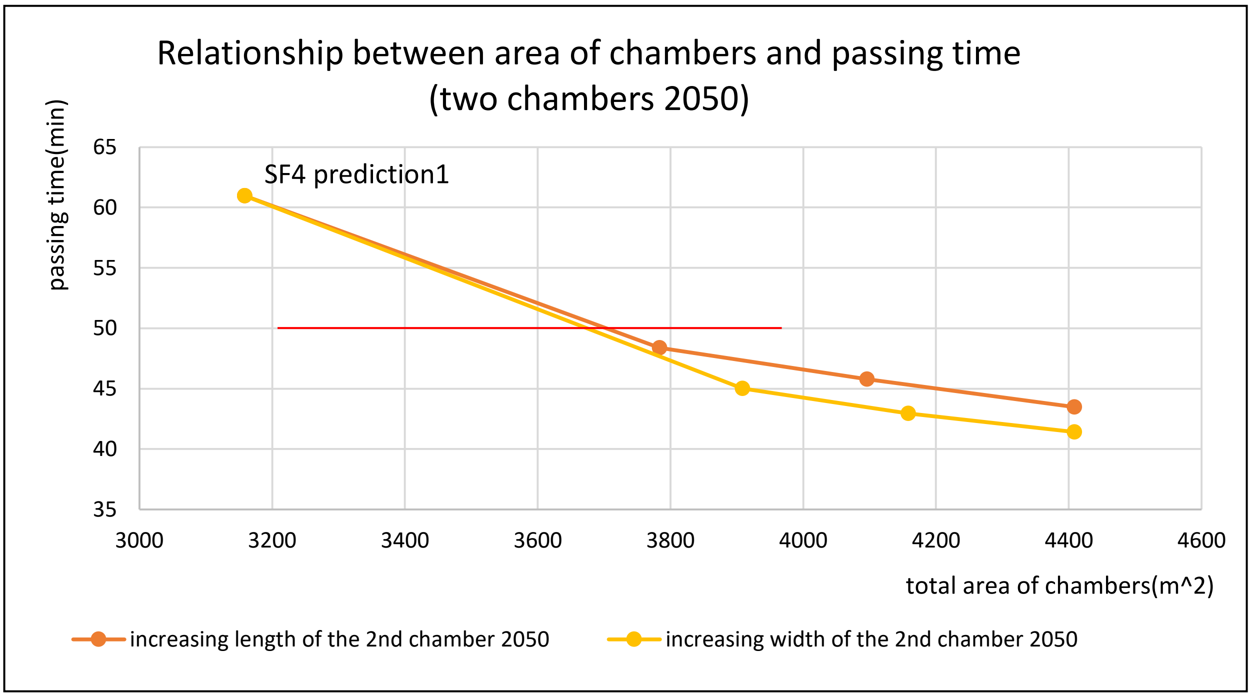


Figure 6. 12 Relationship between passing time and total area of chamber (two chambers)

From above graphs, the differences of the total area of chambers are not large by enlarging the length and the width of chamber. Thus, before the requirement of passing time is met, the effects of two ways are similar. If the passing time is going to be reduced further, the differences of two ways become obvious. At this moment, how to choose the optimum scenario should also depend on the costs and benefits which is going to be discussed later.

Comparing figure 6.11 with 6.12, when the second chamber is changed, the passing time has the effective reduction. If the measurements are taken to the existing Eefde lock, the reduction of passing time is slow and the much extra area of chamber is needed. Therefore, the change of the second chamber is more effective than the change of only one chamber.

6.3 Summary

The results of current scenarios and future scenarios are analyzed in Chapter 6. Following table 6.4 shows the results briefly. The methods of enlarging the length of chamber, enlarging the width of chamber, and building the new chamber can all reduce passing time. However, the effectiveness of scenarios is different. Enlarging the length in current scenarios seems to be the least effective method. In the current scenarios, building the extra new chamber is the most effective method. In the future scenarios, the enlargement of the existing chamber is not effective. The enlargement is done based on the second chamber. When the second chamber is wider or longer, the regulation is similar to the current scenarios that the enlargement of width is more effective than the enlargement of length. The scenarios will be compared further in view of costs and benefits.

Table 6. 4 Evaluation of scenarios

Current scenarios			
Dimensions / Scenarios	Length (m)	Width(m)	Effectiveness
Base scenario (S1)	133	12	0
Longer chamber (S2)	>308	12	+
Wider chamber (S3)	133	>20	++
New chamber (S4)	125	12.5	+++

Future scenarios			
Dimensions (existing or 2nd chamber) / Scenarios	Length (m)	Width(m)	Effectiveness
Base scenario (SF1)	133	12	0
Longer chamber (SF2)	-	12	0
Wider chamber (SF3)	133	>37	+
Two chambers (SF4)	125	12.5	+
Longer the 2nd chamber (SF5)	>175	12.5	+
Wider the 2nd chamber (SF6)	125	>17	++

After simulations, according to the first criterion explained in Section 1.4, the scenarios which can meet the requirement of passing time are listed in the following table 6.5. In the next chapter, the costs-benefits analysis will be given to these scenarios. In future scenarios, SF1 and SF2 cannot meet the requirement. SF3 which enlarges the width of the existing chamber would meet the requirement but the horizontal area becomes very large (figure 6.11). Furthermore, the responsible authority of the Eefde lock has planned to build the second chamber, so the study of the Eefde lock is more meaningful for two chambers. Last but not the least, the study of the lock with two chambers can also give the relationship between the dimensions of chamber and the costs-benefits.

Table 6. 5 Summary of scenarios which meet the requirement of passing time

Scenarios	Dimensions(m)	Area of chamber(s)(m^2)	Passing time (min)
Current scenarios			
Longer chamber (S2)	12*308	3696.0	47.74
Wider chamber 1 (S3a)	20*133	2660.0	48.28
Wider chamber 2 (S3b)	22*133	2926.0	45.45
Building the second chamber (S4)	12.5*125+133*12	3158.5	37.28
Future scenarios			
Longer 2nd chamber 1 (SF5a)	12.5*175	2187.5	48.39
Longer 2nd chamber 2 (SF5b)	12.5*200	2500.0	45.78
Longer 2nd chamber 3 (SF5c)	12.5*225	2812.5	43.48
Wider 2nd chamber 1 (SF6a)	18.5*125	2312.5	45.02
Wider 2nd chamber 2 (SF6b)	20.5*125	2562.5	42.95
Wider 2nd chamber 3 (SF6c)	22.5*125	2812.5	41.42

7 Analysis of costs and benefits

The criteria of the optimum scenario of the enlarged lock are the balance between passing time and costs-benefits (Section 1.4). In following sections, the cost of each scenario is estimated roughly. The benefit means the reduction of waiting cost. It will be calculated by two methods, rough calculation and calculation based on types of vessels. The final selection of optimum scenarios also takes into account of the passing time.

7.1 Estimation method and scope

In order to get the costs of enlargement project, it is however not necessary to collect data on a detailed scale. The general expenditure categories are used instead. In this paper, the cost of construction of lock is composed of two parts.

- Major investments for construction
- Operational and maintenance costs

In reality, there are many kinds of construction costs, such as demolition of quay walls. Except above costs, others are difficult to estimate because of the unknown information about lock's economy. Furthermore, other kinds of costs do not have a large impact on the comparison between different scenarios. Thus, only above two aspects of costs are taken into account.

Investment expenditure contains the expenditure for new infrastructure and expansion of infrastructure. Maintenance costs of locks are expenditures for maintaining the functionality of locks. The maintenance costs are generated by year. Usually, periodic inspection and preventive maintenance are needed in the first 10 to 15 years. But after this period and often earlier, more maintenance may be expected. (Toorn, 2010)

In this thesis, only the construction costs of enlarged area are taken into account, other than the total project of the lock. The demolition of lock walls and reconstruction of new gates are not taken into account. With regard to the maintenance and operational costs, fixed and variable costs are distinguished. 80% for fixed cost and 20% for variable costs. (ECORYS Transport and CE Delft, 2005)

In the case of future scenarios, an interest rate of 5% used in Cost-Benefit Analysis for EU-projects is advised. (ECORYS Transport and CE Delft, 2005)

According to results of the simulation (table 6.5), scenarios which meet the requirement of waiting time, should be taken into account to calculate the costs and benefits. In current situations, S2, S3 and S4 all have scenarios which meet the requirement of waiting time. In future scenarios, because SF2 and SF3 are not as effective as SF4, SF5 and SF6, only the Eefde lock with two chambers will be taken into account. Also, since the authority has already planned to build the second chamber, studying the situation of two chambers are more meaningful for the future.

7.2 Investment for construction

The enlargement of lock chamber contains many stages, such as demolition of the old chamber wall, the move of the gate, dredging, earthmoving, protection of foundation, etc. However, the costs of the complex stages cannot be estimated exactly. It is also not clear how the costs of these stages are included in the total price. Therefore, attention is paid to the relationship between the total costs and the area of chambers. Ad van der Toorn presented that the costs of navigation locks on the River Rhine, see figure 7.1. (Toorn, 2010)

	name	year	build.cost M. Fl	build.cost M. Euro	pres.cost M. Euro	area m * m	unit costs K.Euro/m.m	remark
1	Lith	1992	100	45	91	3600	25	second lock
2	Helmond	1992	26	12	24	1375	17	
3	Oranje	1990	130	59	129	4800	27	
4	Oester	1990	64	29	63	3173	20	
5	Vlaardingen	1986	20	9	23	650	36	also storm barrier
6	Schiedam	1978	25	11	43	720	60	also storm barrier
7	Terneuzen	1962	98	45	296	21160	14	2 chambers
				Total	**669**	**35478**	**19**	
8	Terneuzen	2015?		200 - 300	200 - 300	6 - 27000	11 tot 13	Not build yet! excl. dredging

In the case of a mean head of 4 meter, the unit costs are ~ 5000 Euro / cubic meter

Figure 7. 1 Cost estimation for navigation locks on Rhine (Toorn, 2010)

The average unit cost is 19000 Euro per square meter according to above figure. The average unit cost takes into account of all seven locks except unbuilt Terneuzen. However, in the thesis, not all seven locks will be used to find the relationship between the area of chambers and the unit costs. The reasons and selection are given in next Section 7.2.1. In this chapter, after getting the relationship between the area of locks and the unit costs, the unit costs of each scenario will be found on the tendency line since the area of chambers is known. Furthermore, using a tendency to find the unit costs for every scenario is more accurate than using average unit costs for all scenarios. The cost level is based on 2010.

7.2.1 Construction costs of current scenarios

In current scenarios, there are three methods of enlarging lock. They are increasing the length of the lock chamber, increasing the width of the lock chamber, and building a second chamber. The scenarios are selected which meet the requirement of waiting time. The dimensions of enlarged Eefde lock are known from Chapter 6.

The unit cost of enlarged area can be found based on the principle according to locks on the River Rhine (figure 7.1). The graph 7.2 is shown as follows. First four locks in figure 7.1 (Lith, Helmond, Oranje and Oester) are used to get the trend line. Vlaardingen and Schiedam are not used because their costs contain the storm barrier. Temeuzen is not considered as well because it is far away from the main trend. The relationship is assumed to be linear.

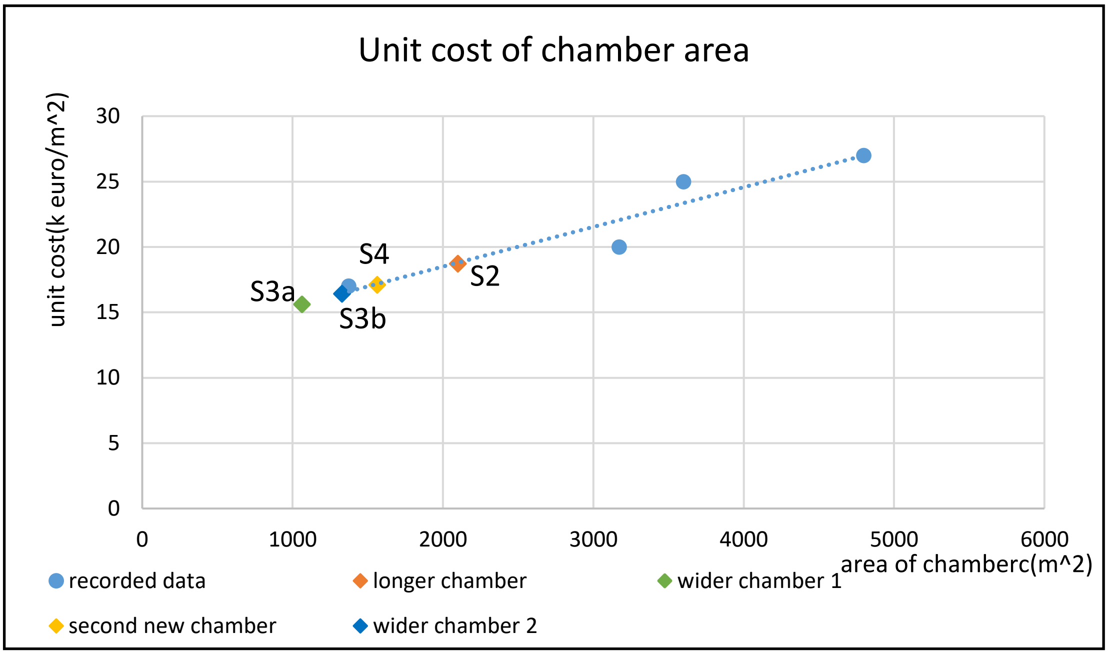


Figure 7. 2 Unit cost per chamber area

In figure 7.2, the formula of the trend line is as follows.

$$y = 0.003x + 12.43 \tag{7.1}$$

There are four types of current scenarios, S1, S2, S3 and S4 (Section 3.1). After simulation, the scenarios which meet the requirement of waiting time are selected. The scenarios are listed in the first column of following table 7.1. After calculating the enlarged area which is compared with the base scenario, the unit cost of enlarged area in every scenario can be calculated by above equation 7.1. At last, total costs of enlargement are calculated as follows. The costs of enlargement are considered as the costs of enlargement project.

$$(+)\text{Total costs of enlargement}=(+)\text{Enlarged area} \times (+)\text{ Unit cost} \tag{7.2}$$

From the following table 7.1, it can be found that enlarging the length takes the most cost. The increase of width takes the least cost. As mentioned in Section 1.1 background, the estimated investment is about 100 million which is much more than the costs of S4 shown in table 7.1 (26.8 million). The reason is that the costs here are only for the enlargement of chamber. There are many other engineering costs, such as energy cost and material cost. 100 million is for whole enlargement project.

Table 7. 1 Construction cost of current enlargement scenarios

Scenarios	Dimensions(m)	Area of whole chamber(s)(m^2)	Enlarged area(m^2)	Unit cost(k Euro/m^2)	Total costs of enlargement(M.Euro)
Base scenario (S1)	12*133	1596	-	-	-
Longer chamber (S2)	12*308	3696	2100	18.73	39.3
Wider chamber 1 (S3a)	20*133	2660	1064	15.62	16.6
Wider chamber 2 (S3b)	22*133	2926	1330	16.42	21.8
Building the second chamber (S4)	12.5*125+133*12	3158.5	1562.5	17.12	26.8

7.2.2 Construction costs of future scenarios

Future scenarios are based on the existing Eefde lock with one chamber first. Then, Eefde lock with two chambers is simulated as well. The measurements of reducing waiting time are to enlarge the dimensions of the new chamber. Since the second chamber is going to be built in 2017, suggestions are possible to be given to the construction of the second chamber. As known from Chapter 6, SF2 which enlarges the length of the chamber is not effective so that the scenarios SF2 are ignored. When it comes to the situation that the second chamber is changed, six scenarios are used in this section which can be seen later in table 7.2.

In current scenarios, the enlarged area is used to get the unit cost. In the case of future scenarios, when the dimensions of the second chamber is changed, the total area of the second chamber becomes the enlargement part which is used to find the unit cost as shown in figure 7.3.

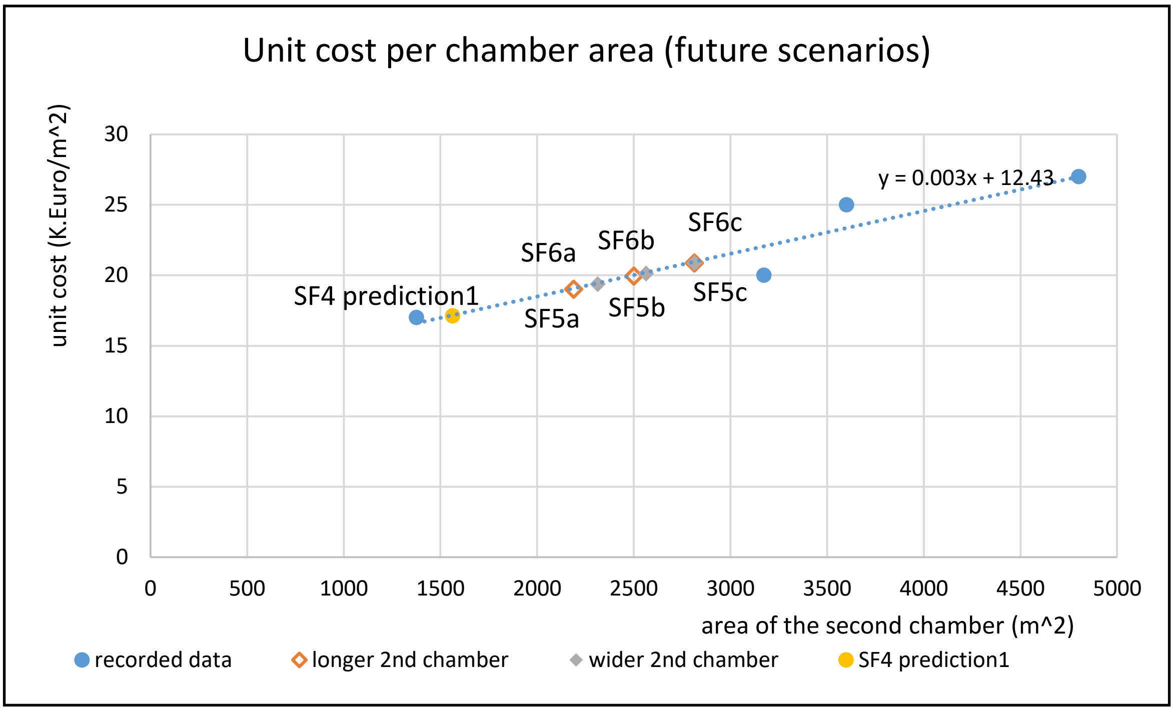


Figure 7. 3 Unit cost of enlarged area

Equation 7.2 can be also used in future scenarios. Results are shown in following table 7.2.

Table 7. 2 Construction costs of enlargement scenarios (future scenarios)

Scenarios	Dimensions of the second chamber (m)	Enlarged area (m^2)	Unit cost(k Euro/m^2)	Total costs of the enlarged area (M.Euro)
Eefde lock with two chambers (SF4)	12.5*125	1562.5	17.1	26.7
Longer 2nd chamber 1 (SF5a)	12.5*175	2187.5	19.0	41.6
Longer 2nd chamber 2 (SF5b)	12.5*200	2500	19.9	49.8
Longer 2nd chamber 3 (SF5c)	12.5*225	2812.5	20.9	58.7
Wider 2nd chamber 1 (SF6a)	18.5*125	2312.5	19.4	44.8
Wider 2nd chamber 2 (SF6b)	20.5*125	2562.5	20.1	51.6
Wider 2nd chamber 3 (SF6c)	22.5*125	2812.5	20.9	58.7

In future scenarios, when the length is longer, the construction costs increase. This principle also applies to the scenarios of increasing width.

7.3 Operational and maintenance costs

Operational and maintenance expenditures mean to keep the lock working in regular. It is assumed that both operational and maintenance costs have a lifetime over 1 year. In the thesis, annual operational and maintenance costs are calculated.

It is difficult to estimate operational costs of locks. According to Ad van der Toorn (2010), operational costs of the weir-lock complex on River Rhine is estimated in the order of 3 million per year. It contains costs for operation, administration and control of the weir gates and navigation locks. The thesis does not need to consider weir gates and the costs mentioned by Ad van der Toorn are for four complexes. Therefore, the operational cost of Eefde lock can be estimated roughly in the order of 1 million which is less than complexes.

The inspection and maintenance in the long run will take a rough 1% of the realization costs per year. Presenting this as a net-present-value makes a total amount in the order of (1+r)/r* Cc (Toorn, 2010). Because the rate is about 5%, the inspection and maintenance is 20% of the construction costs.

Therefore, based on the last section of construction investment, the operational and maintenance costs per year can be listed in the following table.

Table 7. 3 Annual operational and maintenance costs of current scenarios

Costs / Scenarios	Operational costs(M.Euro)	Maintenance costs(M.Euro)	Sum(M.Euro)
Increase length (S2)	1	7.86	8.86
Increase width 1 (S3a)	1	3.32	4.32
Increase width 2 (S3b)	1	4.36	5.36
Building the second chamber (S4)	1	5.36	6.36

Table 7. 4 Annual operational and maintenance costs of future scenarios

Costs / Scenarios	Operational costs(M.Euro)	Maintenance costs(M.Euro)	Sum(M.Euro)
Eefde lock with two chambers (SF4)	1	5.34	6.34
Long 2nd chamber 1(SF5a)	1	8.32	9.32
Long 2nd chamber 2 (SF5b)	1	9.96	10.96
Long 2nd chamber 3 (SF5c)	1	11.74	12.74
Wider 2nd chamber 1 (SF6a)	1	8.96	9.96
Wider 2nd chamber 2 (SF6b)	1	10.32	11.32
Wider 2nd chamber 3 (SF6C)	1	11.74	12.74

7.4 Benefits

The scenarios of enlargement reduce waiting time to some degree. The cost of extra capacity of lock should be balanced by the reduction of ship waiting cost. The reduction of waiting cost at locks is different from cost when vessels wait in harbours, because the engine of vessels works in different situations (Bolton, 1981).

Generally, there are two methods of calculating waiting cost. One is the rough calculation which multiplies the average costs with the total waiting time of vessels.

The second method takes into account of the types of vessels. Different vessels have their own waiting cost.

7.4.1 Rough calculation of waiting costs

The value of waiting time is defined by ECORYS and METTLE (2005) that a value of 78 Euro per vessel per hour for container shipments and 74 Euro for non-container shipments. According to the data sheet from RWS, there are 9.5% of vessels in April 2014 is container ships, and others are non-container shipments. Therefore, the average value considering the composition is 74.4 Euro per vessel per hour.

According to Section 2.3.2 locking process, the locking time of the Eefde lock is 20 minutes. According to simulation, the average passing time of one month is known. Thus, the waiting time can be calculated by deducting 20 minutes from total passing time. The number of vessels in April of 2014 is 1285. Finally, waiting cost at Eefde lock in April of 2014 can be calculated by following equation 7.3.

$$\text{Waiting costs (K.Euro)} = \text{Average waiting time (min)} \times 1285 \times 74.4 \text{ (Euro per vessel per hour)} \tag{7.3}$$

In the following table 7.5 and table 7.6, the reduction of waiting costs per month is also shown which is compared with base scenario. The results obtained by equation 7.3 is average values for one month. Annual waiting costs are also given in the following table.

Table 7. 5 Rough calculation of current scenarios

Current scenarios						
Scenarios	Passing time(min)	Average waiting time (min)	Waiting costs per month (K.Euro)	Reduction of waiting costs per month (K.Euro)	Waiting costs per year (M.Euro)	Reduction of waiting costs per year (M.Euro)
Base scenarios (S1)	96.64	76.64	122.12		1.47	
Longer chamber (S2)	47.74	27.74	44.20	77.92	0.53	0.94
Wider chamber 1 (S3a)	48.28	28.28	45.06	77.06	0.54	0.92
Wider chamber 2 (S3b)	45.45	25.45	40.55	81.57	0.49	0.98
Building the second chamber (S4)	37.28	17.28	27.53	94.58	0.33	1.13

Table 7. 6 Rough calculation of future scenarios

Future scenarios						
Scenarios	Passing time(min)	Average waiting time(min)	Waiting costs per month (K.Euro)	Reduction of waiting costs per month (K.Euro)	Waiting costs per year (M.Euro)	Reduction of waiting costs per year (M.Euro)
Two chambers (SF4)	60.97	40.97	65.28		0.78	
Longer 2nd chamber 1 (SF5a)	48.39	28.39	45.24	20.04	0.54	0.24
Longer 2nd chamber 2 (SF5b)	45.78	25.78	41.08	24.20	0.49	0.29
Longer 2nd chamber 3 (SF5C)	43.48	23.48	37.41	27.87	0.45	0.33
Wider 2nd chamber 1 (SF6a)	45.02	25.02	39.87	25.41	0.48	0.30
Wider 2nd chamber 2 (SF6b)	42.95	22.95	36.57	28.71	0.44	0.34
Wider 2nd chamber 3 (SF6C)	41.42	21.42	34.13	31.15	0.41	0.37

From above tables, it can be seen that in current scenarios, building the second chamber has the most reduction of waiting costs. Enlarging length and width of the chamber has a similar reduction.

In future scenarios, different enlargement scenarios have a similar reduction of waiting costs.

7.4.2 Waiting costs based on types of vessels

According to Bolton (1981), shipping costs are calculated according to the following equation.

$$\mathrm{C} = \mathrm{a} \times \mathrm{W} + \mathrm{b} \times \mathrm{T} \tag{7.4}$$

In equation, C=variable trip cost (Euro)

W=waiting time per trip (hr) (inclusive passing time)

T=sailing time per trip (hr)

a=cost of waiting time (Euro/hr)

b= cost of sailing time (Euro/hr)

Because the thesis focuses on the lock, the sailing cost is ignored, and the calculation equation can be simplified as follows.

$$\mathrm{C} = \mathrm{a} \times \mathrm{W} \tag{7.5}$$

The latest waiting costs of different vessels are provided by RWS as the following table (TUDelft, 2010). The rightest column gives the waiting costs per hour for different commercial vessels.

Table 7. 7 Overview of cost numbers of inland shipping (TU Delft, 2010)

	Klassering		Karakteristieken maatgevend schip					Vaarkosten per km		Wachtkosten per uur
	Klasse DVS	Klasse CEMT	gem lvm (ton)	max diepgang geladen	breedte	lengte	omschrijving	beladen	leeg	
	M1	I	350	2,5	5,05	38,5	Spits	€ 9,7	€ 6,7	€ 38
	M2	II	550	2,6	6,6	50-55	Kempenaar	€ 10,5	€ 7,6	€ 45
B	M3	II	750	2,6	6,6	55-70	Hagenaar	€ 12,2	€ 8,9	€ 54
U	M4	III	950	2,7	8,2	67	Dortmund-Eems	€ 14,1	€ 10,2	€ 64
L	M5	III	1150	2,7	8,2	80-85	Verlengde Dortmund-Eems	€ 16,7	€ 12,1	€ 76
K	M6	IV	1550	2,9	9,5	80-85	Rijn-Herne schip	€ 21,4	€ 16,0	€ 99
	M7	IV	1950	3	9,5	105	Verlengde Rijn-Herne schip	€ 26,0	€ 19,4	€ 121
	M8	Va	2500	3,5	11,4	95-110	Groot Rijnschip	€ 32,0	€ 24,0	€ 154
	M1	I	350	2,5	5,05	38,5	Spits	€ 6,8	€ 4,7	€ 38
	M2	II	550	2,6	6,6	50-55	Kempenaar	€ 7,6	€ 5,5	€ 48
C	M3	II	750	2,6	6,6	55-70	Hagenaar	€ 9,1	€ 6,7	€ 59
O	M4	III	950	2,7	8,2	67	Dortmund-Eems	€ 10,9	€ 7,9	€ 73
N	M5	III	1150	2,7	8,2	80-85	Verlengde Dortmund-Eems	€ 13,2	€ 9,6	€ 90
T	M6	IV	1550	2,9	9,5	80-85	Rijn-Herne schip	€ 17,4	€ 13,1	€ 121
	M7	IV	1950	3	9,5	105	Verlengde Rijn-Herne schip	€ 21,6	€ 16,4	€ 152
	M8	Va	2500	3,5	11,4	95-110	Groot Rijnschip	€ 27,3	€ 20,8	€ 198
	M1	I	350	2,5	5,05	38,5	Spits	€ 7,8	€ 5,5	€ 58
	M2	II	550	2,6	6,6	50-55	Kempenaar	€ 8,3	€ 6,1	€ 69
T	M3	II	750	2,6	6,6	55-70	Hagenaar	€ 10,2	€ 7,6	€ 82
A	M4	III	950	2,7	8,2	67	Dortmund-Eems	€ 12,3	€ 9,1	€ 95
N	M5	III	1150	2,7	8,2	80-85	Verlengde Dortmund-Eems	€ 14,6	€ 10,7	€ 109
K	M6	IV	1550	2,9	9,5	80-85	Rijn-Herne schip	€ 19,1	€ 14,5	€ 138
	M7	IV	1950	3	9,5	105	Verlengde Rijn-Herne schip	€ 26,9	€ 20,7	€ 192
	M8	Va	2500	3,5	11,4	95-110	Groot Rijnschip	€ 38,5	€ 29,8	€ 274

The classes of vessels are known in the data documents provided by RWS, but the proportion of three types (bulk, container and tank) is not clear. Thus, the average values of waiting cost of three types of vessels are calculated. The results are in table 7.8.

Table 7. 8 Waiting costs based on RWS class

RWS class	Waiting cost per ship per hour (Euro)
M1	45
M2	54
M3	65
M4	77
M5	92
M6	119
M7	155
M8	209

Because the waiting time of different vessels is not clear, only average passing time is known in the output of the simulation. Thus, the average waiting time is used but the waiting cost per hour is taken as above table. Then, the waiting cost is calculated by the following equation.

$$C_w = n \times a \times W_{avg}$$
$$\mathrm{coe} = \mathrm{n} \times \mathrm{a} \tag{7.6}$$

Where C_w=total waiting cost

n= amount of vessels

a=waiting cost per ship per hour (Euro) see table 7.8

W_{avg}=waiting time (min)

coe=waiting time coefficient (Euro)

The number of different vessels in April of 2014 is known from table D.1 in Appendix D. Except above types of vessels (M1 to M8), other types of vessels use the average value of 74.4 Euro per ship per hour. The coefficient coe can be calculated as follows.

Table 7. 9 The calculation of coefficient coe

RWS-Coding of ship type	RWS class	Number of vessels (n)	Waiting cost per ship per hour (a)	coe (Euro)
1,2,3,12,21	M0	3	74.4	223.2
	M1	41	45	1845
	M2	98	54	5972
	M3	124	65	8060
	M4	97	77	7469
	M5	170	92	15640
	M6	214	119	25466
	M7	102	155	15810
	M8	155	209	32395
	others	281	74.4	20906
	Total	1285	-	133106

Similar to table 7.5 and table 7.6, waiting costs are calculated. Based on the equation 7.6, the total costs are calculated. The results are shown in table 7.10 and table 7.11. For example:

Waiting costs of longer chamber (S2)=(27.74 /60×133106)/1000=61.54 K.Euro
Compared to base scenario, the reduction of waiting costs (S2) = 170.02-61.54=107.3 K.Euro
Annual reduction of waiting costs (S2) = 107.03×12 =1.29 M.Euro

Table 7. 10 Waiting costs of current scenarios

Current scenarios						
Scenarios	Passing time(min)	Waiting time(min)	Waiting costs per month (K.Euro)	Reduction of waiting costs per month(K.Euro)	Waiting costs per year (M.Euro)	Reduction of waiting costs per year (M.Euro)
Base scenarios (S1)	96.64	76.64	170.02		2.04	
Longer chamber (S2)	47.74	27.74	61.54	108.48	0.74	1.30
Wider chamber 1 (S3a)	48.28	28.28	62.72	107.30	0.75	1.29
Wider chamber 2 (S3b)	45.45	25.45	56.46	113.56	0.68	1.36
Building the second chamber (S4)	37.28	17.28	38.33	131.69	0.46	1.58

Table 7. 11 Waiting costs of future scenarios

Future scenarios						
Scenarios	Passing time(min)	Waiting time(min)	Waiting costs (K.Euro)	Reduction of waiting costs(K.Euro)	Waiting costs per year (M.Euro)	Reduction of waiting costs per year (M.Euro)
Base scenarios (SF4)	60.97	40.97	90.89		1.09	
Longer chamber 1 (SF5a)	48.39	28.39	62.98	27.83	0.76	0.33
Longer chamber 2 (SF5b)	45.78	25.78	57.19	33.62	0.69	0.40
Longer chamber 3 (SF5c)	43.48	23.48	52.09	38.72	0.63	0.46
Wider chamber 1 (SF6a)	45.02	25.02	55.51	35.30	0.67	0.42
Wider chamber 2 (SF6b)	42.95	22.95	50.91	39.90	0.61	0.48
Wider chamber 3 (SF6c)	41.42	21.42	47.52	43.29	0.57	0.52

By the method which takes into account of ship types, the calculation results are more than results of rough estimation in the last section 7.4.1 (table 7.5 and table 7.6). This is because that many types of vessels have unit waiting cost higher than average unit waiting cost (74.4 euro). Furthermore, it can be also explained by table 7.9. Main types of vessels, such as M5, M6, M7 and M8, have large numbers of vessels and high unit waiting cost at the same time. Since the total number of vessels and total coe are known, the average waiting costs per hour is calculated to be 103.6 euro which is larger than 74.4 euro. Thus, the waiting costs based on types of vessels are larger than the rough estimation.

In current scenarios, building the second chamber still has the most reduction costs since this scenario can reduce the most waiting time compared with other two scenarios. In future scenarios, reduction of waiting cost in the scenario of the wider chamber is more than making the chamber longer.

7.4.3 Summary of benefits

In above sections, two methods are taken to calculate the waiting costs of different scenarios. The rough calculation does not take into account of types of vessels. However, in reality, bigger ships may need longer time to pass through Eefde lock. The errors of calculation results exist.

When the calculation of waiting costs is based on different vessels, results become more accurate. However, because the types of vessels are not clear completely, errors are produced as well.

The value of waiting time will not have a large influence on the comparison between scenarios. Therefore, the reduction of waiting costs by the method based on types of vessels is used in next analysis.

7.5 Costs-benefits analysis

In Section 7.2, 7.3 and 7.4, the costs and benefits are estimated respectively. Costs and benefits are taken into consideration at the same time in this section. The net costs are calculated according to following equation 7.7. In the equation, value is put in without a sign. The results are shown in table 7.12 and table 7.13.

$$\text{Net benefits} = -\text{Construction costs} - \text{Operational and maintenance costs} + \text{Benefits} \quad (7.7)$$

Table 7. 12 Net costs of current scenarios

Current scenarios					
	Enlarged area (m^2)	Construction costs (M.Euro)	Operational and maintenance costs (M.Euro)	Benefit (M.Euro)	Net costs (M.Euro)
Longer chamber (S2)	2100	39.3	8.86	1.30	-46.86
Wider chamber 1 (S3a)	1064	16.6	4.32	1.29	-19.63
Wider chamber 2 (S3b)	1330	21.8	5.36	1.36	-25.80
Building the second chamber (S4)	1562.5	26.8	6.36	1.58	-31.58

Table 7. 13 Net costs of future scenarios

Future scenarios					
	Enlarged area (m^2)	Construction costs (M.Euro)	Operational and maintainance costs (M.Euro)	Benefit (M.Euro)	Net costs (M.Euro)
Longer chamber 1 (SF5a)	2187.5	41.6	9.32	0.33	-50.59
Longer chamber 2 (SF5b)	2500	49.8	10.96	0.40	-60.36
Longer chamber 3 (SF5c)	2812.5	58.7	12.74	0.46	-70.98
Wider chamber 1 (SF6a)	2312.5	44.8	9.96	0.42	-54.34
Wider chamber 2 (SF6b)	2562.5	51.6	11.32	0.48	-62.44
Wider chamber 3 (SF6c)	2812.5	58.7	12.74	0.33	-71.11

From above tables, the net costs of current scenarios are from 20 to 50 million. The net costs of future scenarios are a little more than current scenarios which are up to 70 million. When the length is longer or the width is wider, the net costs become more. Therefore, there is a possible relationship between the area of the enlarged chamber and net costs. Figure 7.4 shows the relationship between enlarged area and costs-benefits. The future scenarios in figure 7.4 only show five dots because net costs of SF5c and SF6c coincide.

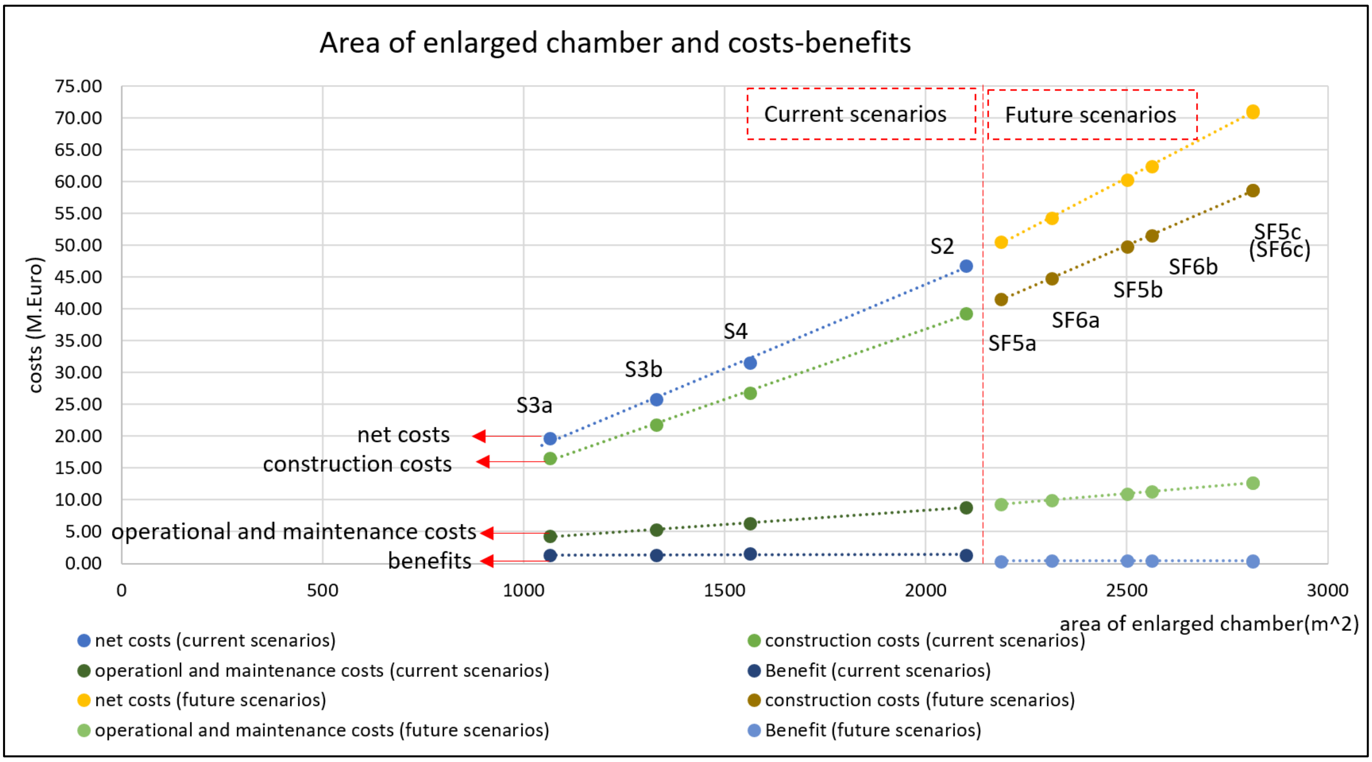


Figure 7. 4 Relationship between area of enlarged chamber and net costs

In both current scenarios and future scenarios, more area of the enlarged chamber means more net costs will be spent. In current scenarios, the lowest point is the scenario which enlarges 8 meters for the width of the chamber. With regards to the future scenarios, adding 50 meters on length has the least net costs. The costs-benefits and the enlarged area has a linear relationship. The change of net costs is quicker than other costs and benefits. In figure 7.4, it is found the benefits are a little. It is because that the benefits in the thesis are only the reduction of waiting time in view of vessels. There are many other benefits, such as the development of local economy which is not included in the thesis.

However, not only the net costs are taken into account of choosing the optimum scenario, but from ship holders' prospect of view, the passing time should be as little as possible. The graphs are made as follows (see figure 7.5 and figure 7.6).

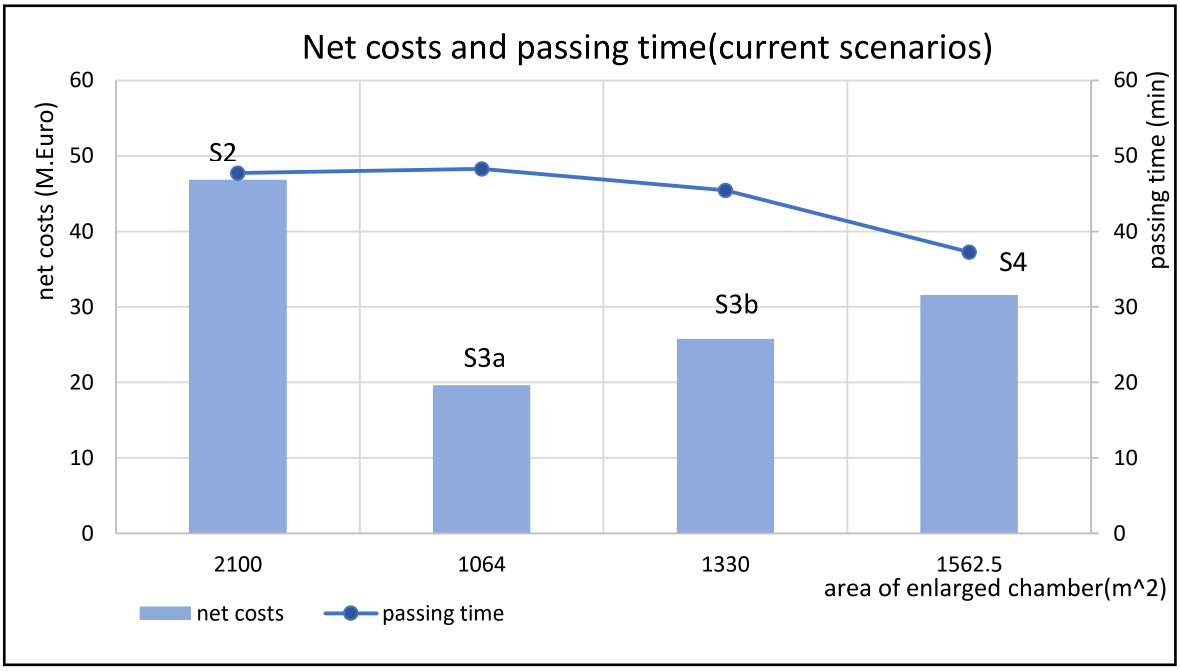


Figure 7. 5 Relationship between net costs and waiting costs in current scenarios

Compared with the base scenario S1, the net costs for unit reduced passing time is calculated as follows. It is assumed that the base scenario is not enlarged so it does not have net costs which is considered as 0 and the passing time is 96.64 minutes.

Table 7. 14 Net costs of unit reduced passing time (current scenarios)

Scenarios	Base scenario S1	S2	S3a	S3b	S4
Passing time(min)	96.64	47.74	48.28	45.45	37.28
Net costs(M.euro)	0	-46.86	-19.63	-25.80	-31.58
Net costs of per unit reduced passing time(M.euro)	-	-0.96	-0.41	-0.50	-0.53

In current scenarios, the waiting time decreases with the increase of net costs if ignoring S2. Scenario S2 has both high waiting time and net costs so this scenario is not efficient. By table 7.14, it is found that scenario S3a which makes chamber wider has the least net costs for unit reduced passing time. In other words, in order to reduce passing time, scenario S3a has the minimum unit cost. The dimensions in S3a are 133*20 m. S3b and S4 have the similar net costs for unit reduced passing time.

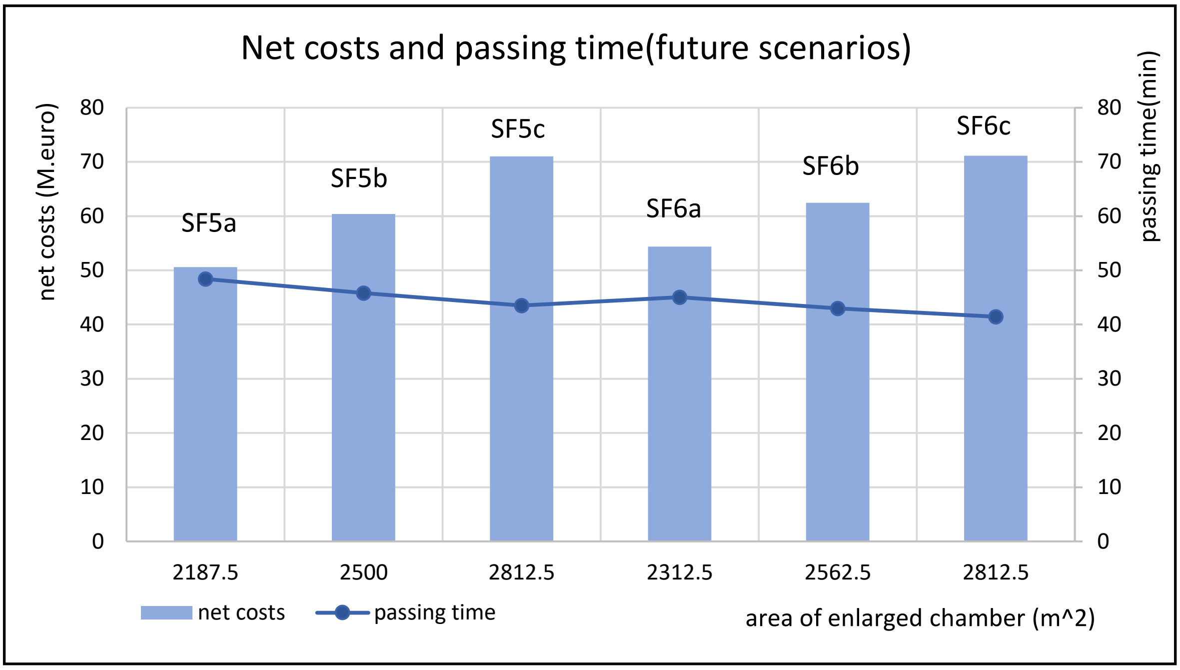


Figure 7. 6 Relationship between net costs and waiting costs in future scenarios

Following table calculates the net costs for per unit reduced waiting time. The work is similar to the current scenarios.

Table 7. 15 Net costs of unit reduced passing time (future scenarios)

Scenarios	SF4	SF5a	SF5b	SF5c	SF6a	SF6b	SF6c
Passing time(min)	60.97	48.39	45.78	43.48	45.02	42.95	41.42
Net costs(M.euro)	0	-50.59	-60.36	-70.98	-54.34	-62.44	-71.11
Net costs of per unit reduced passing time(M.euro)	-	-4.02	-3.97	-4.06	-3.41	-3.47	-3.64

In future scenarios, according to figure 7.6, there are two decreasing processes. The net costs increase with the decrease of waiting time for SF5 and SF6 respectively. By table 7.15, it is found that scenario SF6a which makes the second chamber wider has the least net costs for unit reduced passing time.

Therefore, scenario SF6a is the optimum scenario. The dimensions of the chamber in scenario SF6a is 18.5*125. It means the proposed width of chamber is larger than the plan of RWS which is 12.5 meters.

8 Generalized approach to optimum enlargement scenarios

In above chapters, the optimum scenarios of the Eefde lock are studied. Except providing recommendations to the authorities of the Eefde lock, the approach of determining the optimum scenarios can be generalized for others locks with insufficient capacity. Since the study of the Eefde lock is based on the month without holidays, the generalized approach is not applicable for the locks used for recreational vessels. This chapter is going to give an introduction to the generalized approach.

1. Study the problems of the target lock

The first step is to learn the problem of the target lock. The delay time of the lock should be known and the aim of enlarging the lock should be clear.

2. Determine criteria

Criteria are important indexes to determine the optimum scenarios. According to case of the Eefde lock, at least two criteria are made. One is used for making sure that the waiting time is less than 30 minutes. However, the passing time of locks is different since the locking time of different locks is different. Passing time should be calculated. Costs of enlargement should be as less as possible under precondition of the least waiting time. If the target lock has other requirements, extra criteria will be added.

3. Make scenarios (wider chamber or extra new chamber)

Scenarios have control variables of length, width and the number of chambers. However, based on the study of the Eefde lock. Making chamber wider is more effective than making chamber longer. And the optimum current and future scenario for the Eefde lock are to make the first or second chamber wider. Therefore, the scenarios of making chamber longer can be ignored.

When the width of chamber is enlarged, the intervals can be taken as two meters which is the same with the Eefde lock but also according to the study of Kooman and Bruijn.

The initial extra chamber can take into account of the minimum capacity lock. Detailed dimensions are in Appendix B.3.

4. Simulations of scenarios

The purpose of simulation is to get the passing time and capacity of the lock for each scenario. The input data contain two parts, the lock and vessels. Data should be as more as possible which make results more accurate.

In the thesis, SIVAK is used as simulation program. SIVAK is widely used in the Netherlands. If the target lock is located in other countries, an appropriate program needs to be selected.

5. Select scenarios based on the criterion of passing time

After simulations, not all scenarios can meet the requirement of passing time. Therefore, scenarios should be selected. Remaining scenarios will be put in the costs-benefits analysis.

6. Costs-benefits analysis for remaining scenarios

In this section, costs and benefits will be calculated respectively. Net costs are what is going to be compared with waiting time. Then, the net costs of per unit reduced passing time are calculated so how much it costs to reduce unit passing time is known. At last, the optimum scenarios are determined based on the net costs per unit reduced passing time.

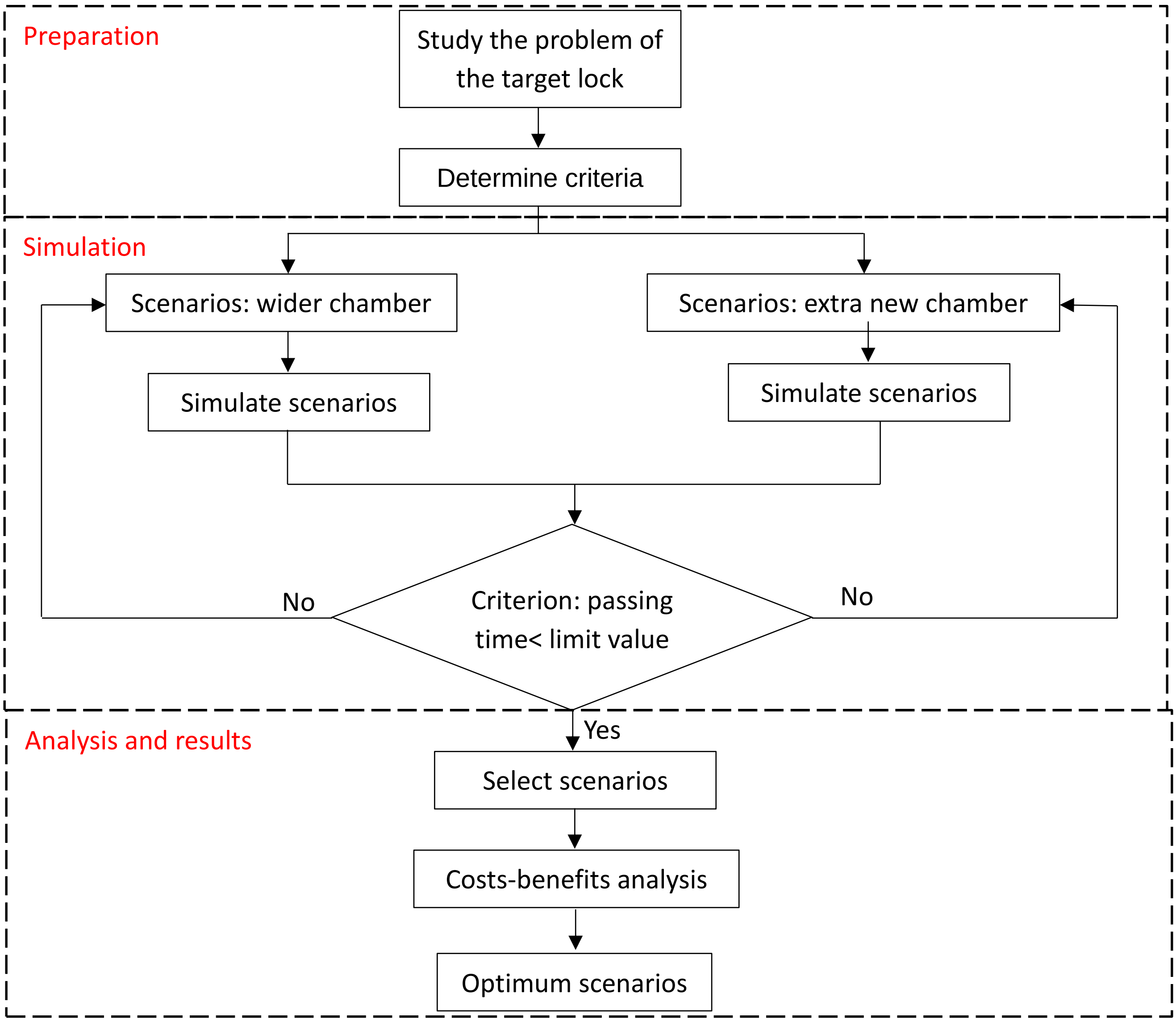


Figure 8. 1 Generalized approach for other locks

9 Conclusions and recommendations

9.1 Conclusions

The main purpose of the thesis is to determine the optimum enlargement layout of the Eefde lock. The outline of the thesis is in line with the research process.

- Studying literature and collecting information
- Making scenarios
- Simulations
- Validation of models
- Analysing the results of simulations
- Costs-benefits analysis

In the thesis, there are some limitations and assumptions. The study focuses on the Eefde lock itself. The costs of enlargement contain the construction, operational and maintenance costs. Other costs are not taken into account, such as demolition of quay walls and installation of new gates. Furthermore, the optimum scenarios are determined by the reduction of waiting time and costs-benefits. The environmental and social influences are not taken into account. In the future, the size and distribution of vessels may change. It is difficult estimating the change of vessels for future. It is assumed that the size and distribution of vessels in the future are the same with the current situation.

The scenarios are divided into current situations and future situations. For current situations, there are base scenario which is the present lock (S1), enlarging the length of existing chamber (S2), enlarging the width of the existing chamber (S3) and building one new chamber (S4). For future situations, there are base scenario (SF1), enlarging the length of existing chamber (SF2), enlarging the width of existing chamber (SF3), building the second chamber (SF4), enlarging the length (SF5) and width of the second chamber (SF6).

The indicators of scenarios are the length, the width and the number of chambers. In each simulation, only one indicator is changed.

SIVAK is used as the simulation model due to its own advantages and it is used by the Dutch authorities. In SIVAK, information about chamber and vessels is needed. The data and information have been collected and analyzed before simulations. In the analysis, the data of 2014 and 2015 are compared with each other. The number of vessels in 2015 is a little less than that in 2014. These two years have similar distribution of ship numbers in different months (figure 2.13 and figure 2.14). July is the busiest month which contains holidays. Without the consideration of holidays, April becomes the busiest month in 2014. By studying the relationship between the dimensions and the number of vessels, it is concluded that vessels in M5 and M6 class are main commercial types, and recreational vessels also have a large number.

After simulations, the scenarios are selected according to the requirement that the passing time should be smaller than 50 minutes and the waiting time should be smaller than 30 minutes. After selecting scenarios which meet the first criterion (passing time), these scenarios are used to calculate the costs and benefits. Then, considering the waiting time and net costs, net costs of per unit reduced passing time are calculated. At last, optimum scenarios are determined for the current and future situation respectively.

The number of vessels through the Eefde lock in April of 2012 and 2014 are used for current scenarios. The number of vessels of 2050 are predicted in the thesis. Data are provided by Rijkswaterstaat.

- **Prediction of commercial ships in 2050**

In the thesis, there are two methods of predicting the number of ships in 2050. One is the prediction by RWS. Another method is based on different sources. The ship number is predicted according to the tendency line based on the real data. As shown in figure 4.8, both methods show an increasing tendency of ship number. However, the prediction by Rijkswaterstaat is smaller than the prediction by other sources. The enlargement plan of RWS follows their own prediction. The prediction based on other sources leads to the insufficiency of RWS's plan for 2050.

- **Current situations**

Comparing 2012 and 2014, the average passing time of both directions (WE and EW) increases from 78.55 to 96.64 minutes. The passing time of two years cannot meet the requirement that it should be smaller than 50 minutes. The existing Eefde lock has long waiting time which cannot meet the requirement. It is in line with the plan of Rijkswaterstaat who plans to enlarge the Eefde lock.

When scenarios S2, S3 and S4 are taken, the passing time can be reduced but the rates of reduction are different. Based on figure 6.5, if the dimensions of the existing chamber are changed, enlarging the width of chamber is more effective than enlarging the length of chamber. Construction of the new chamber (S4) is the most effective method of reducing passing time, compared to other two scenarios.

By costs-benefits analysis, the existing chamber but wider has the least net costs (table 7.12). Although the scenario S4 reduces the passing time most effectively, the net costs of S4 are not the least. Therefore, the final optimum scenario will take into account of both waiting time and costs-benefits.

In the current situation, according to table 7.14, in view of unit reduced passing time, scenario S3a has the least net costs compared to base scenario. Therefore, the optimum scenario is to enlarge the current chamber to the dimensions of 133*20 m. According to Molenaar (2011), the vertical lift gate which is the type of the existing Eefde lock is applicable for single sided water retaining inland lock. The width of lock gate is between 10-24 m. Thus, the width of lock chamber in scenario S3a is achievable.

Figure 9. 1 Possible optimum dimensions for the current situation

- **Future situations**

In future scenarios, if the Eefde lock still has only one chamber, the passing time will reach to 102.79 minutes under the prediction by RWS who predicts that there will be little increase in the future. Prediction of vessels in 2050 is also given by other sources and is higher than the prediction by RWS. Therefore, no matter under which prediction, the existing Eefde lock will not be sufficient in 2050.

Then, the Eefde lock with the designed second chamber (12.5*125 m) is simulated in future scenarios. Under the prediction of RWS, the passing time is reduced to 37.52 minutes which meets the requirement. However, under the prediction of other sources, the planned second chamber will not be sufficient. The second chamber will need enlargement in 2050 as well. By simulations, the enlargement of the width of the second chamber is more effective than the enlargement of the length (figure 6.12), but the difference between enlarging the length (SF5) and enlarging the width (SF6) is not large.

By costs-benefits analysis, the longer or wider the second chamber is, the more the net costs are. In other words, the larger the area of the second chamber is, the more the costs are (figure 7.4).

It is expected that there will be an increase of vessels (prediction by other sources). Combining the reduction of waiting time and costs-benefits and calculating the net costs of per unit reduced passing time, the optimum scenario of future is scenario SF6a which makes the second chamber wider. The possible dimensions of the second chamber are 18.5*125 m. The graph is as follows.

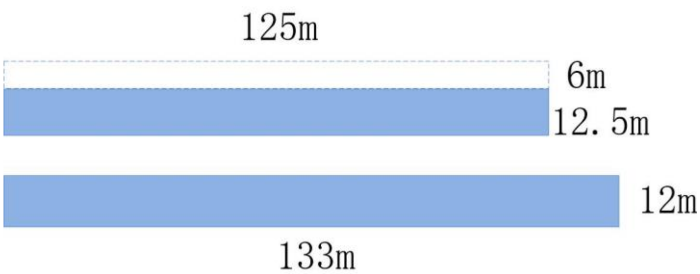


Figure 9. 2 Possible optimum dimensions for future situations

- **Other conclusions**

Before costs-benefits analysis, there is a principle about the reduction of passing time that the enlargement of width is more effective than the enlargement of the length when the modification is based on one chamber. Furthermore, building the extra chamber is the most effective method of reducing waiting time and the optimum horizontal area of the extra chamber depends on the costs-benefits analysis. In the case of the Eefde lock, the optimum scenarios for both current and future scenarios are making the chamber wider if the net costs are taken into account. Thus, making chamber wider becomes the first scenario which should be considered when other locks are enlarged.

9.2 Recommendations

According to the results of thesis, recommendations are given to locks having problems with insufficient capacity. Furthermore, this thesis takes the Eefde lock as case to simulate and subsequently, there are some recommendations to the responsible authority of the Eefde lock. For models, there is also some space to improve.

1. Recommendations to other locks having problems with insufficient capacity

The thesis focuses on the relationships between the dimensions of chamber, the costs and benefits. It is found that, enlarging the width of the chamber has a larger impact on the waiting time than changing the length of chamber. Therefore, when considering enlarging the locks, the extension of width should be considered first.

There are also rules between the net costs and the enlarged area. Enlarged area is horizontal area when the width or length is enlarged. Focusing on general area, it finds that the net costs increase in line with the increase of enlarged area. However, if combining net costs and waiting time, the net costs of unit reduced waiting time will explain further which scenario is optimum in view of both waiting time and net costs.

2. Recommendations to the Eefde lock

For current situation, the plan of enlargement for the Eefde lock is building one new chamber (12.5*125 m). However, if the current problem is going to be solved, the optimum scenario is to make the existing chamber wider and the final dimensions is 133*20 m. According to table 7.14, the net costs of unit reduced waiting time by RWS do not have a large difference from the optimum scenario. Furthermore, considering the assumption of the thesis, the current plan of RWS is reasonable as well. However, with regard to future, RWS's prediction is small. The plan of RWS is not enough to reduce the waiting time in the future under the high prediction. The optimum scenario for future is building the second chamber with the dimensions of 18.5*125 m.

If it is possible, it is better to make the second chamber wider than the current plan. However, the thesis does not take into account of the change of economy, such as the change of interest rate. Thus, whether building the second chamber with larger dimensions is economical, should be calculated and discussed in detailed with relevant experts. Except the costs of engineering, the potential costs, for example the investment of environmental protection should be taken into account as well.

3. Increasing the accuracy of the model

In the thesis, there are many assumptions due to the lack of information. For example, in the future, the dimensions and the composition of vessels will change. In further study, the insufficiency of information should be added completely in the model so that more accurate results can be obtained at last. Furthermore, the costs of some engineering are not clear, for example the costs of demolition of quay walls and the installation of new gates. More detailed costs and benefits should be considered in the future.

4. Improvement in further research

In the thesis, costs and benefits are estimated roughly. In reality, the investment of project is usually in several phases and the cash inflow should also be discounted to the present value. In further research, the economy analysis should be refined.

Moreover, the case of the Eefde lock has its own particularity. More cases should be studied in order to find more general principles for other locks.

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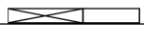
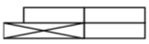
Appendix A Reference vessels

A.1 Classification of reference vessels

CEMT Class	Motor vessels							Pushed convoys (Barge				
	RWS Class	Characteristics of reference vessel**				Classification		RWS Class	Characteristics of reference pushed convoy**			
		Designation	Beam	Length	Draught (laden)	Cargo capacity	Beam and length		Combination	Beam	Length	Draught (laden)
			m	m	m	t	m			m	m	m
0	M0	Other				1-250	B<= 5.00 of L<= 38.00					
I	M1	Péniche	5.05	38.5	2.5	251-400	B= 5.01-5.10 and L>=38.01	BO1		5.2	55	1.9
II	M2	Kempenaar	6.6	50-55	2.6	401-650	B=5.11-6.70 and L>=38.01	BO2		6.6	60-70	2.6
III	M3	Hagenaar	7.2	55-70	2.6	651-800	B=6.71-7.30 and L>=38.01	BO3		7.5	80	2.6
	M4	Dortmund Eems (L < = 74 m)	8.2	67-73	2.7	801-1050	B=7.31-8.30 and L=38.01-74.00	BO4		8.2	85	2.7
	M5	Ext. Dortmund Eems (L > 74 m)	8.2	80-85	2.7	1051-1250	B=7.31-8.30 and L>=74.01					
IVa	M6	Rhine-Herne Vessel (L <= 86 m)	9.5	80-85	2.9	1251-1750	B=8.31-9.60 and L=38.01-86.00	BI	Europa I pushed convoy	9.5	85-105	3.0
	M7	Ext. Rhine-Herne (L > 86 m)	9.5	105	3.0	1751-2050	B=8.31-9.60 and L>=86.01					
IVb												
Va	M8	Large Rhine Vessel (L <=111 m)	11.4	110	3.5	2051-3300	B= 9.61-11.50 and L=38.01- 111.00	BII-1	Europa II pushed convoy	11.4	95-110	3.5
	M9	Extended Large Rhine Vessel (L >111 m)	11.4	135	3.5	3301-4000	B= 9.61-11.50 and L>= 111.01	BIIa-1	Europa IIa pushed convoy	11.4	92-110	4.0
								BIIL-1	Europa II long	11.4	125-135	4.0
Vb								BII-2l	2-barge pushed convoy long	11.4	170-190	3.5-4.0
VIa	M10	**Ref. vessel 13.5 * 110 m**	**13.50**	**110**	**4.0**	**4001-4300**	**B=11.51-14.30 and L=38.01- 111.00**	BII-2b	2-barge pushed convoy wide	22.8	95-145	3.5-4.0
	M11	**Ref. vessel 14.2 * 135 m**	**14.20**	**135**	**4.0**	**4301-5600**	**B=11.51-14.30 and L>= 111.01**					
	M12	Rhinemax Vessel	17.0	135	4.0	>= 5601	B>= 14.31 and L>= 38.01					
VIb								BII-4	4-barge pushed convoy (incl. 3-barge long)	22.8	185-195	3.5-4.0
VIc								BII-6l	6-barge pushed convoy long (incl 5-barge long)	22.8	270	3.5-4.0
VIIa								BII-6b	6-barge pushed convoy wide (incl. 5-barge wide)	34.2	195	3.5-4.0

…s)		Coupled units (Convoys)							Headroom *
Classification		RWS Class	Characteristics of reference coupled unit**				Classification		
Cargo capacity	Beam and length		Combination	Beam	Length	Draught (laden)	Cargo capacity	Beam and length	incl. 30 cm spare headroom
t	m			m	m	m	t	m	m
0-400	B<=5.20 and L= all	C1l	2 péniches long	5.05	77-80	2.5	<= 900	B<= 5.1 and L=all	5.25*
		C1b	2 péniches wide 	10.1	38.5	2.5	<= 900	B=9.61-12.60 and L<= 80.00	5.25*
401-600	B=5.21-6.70 and L=all								6.1
601-800	B=6.71-7.60 and L=all								6.4
801-1250	B=7.61-8.40 and L=all								6.6
									6.4
1251-1800	B=8.41-9.60 and L=all								7.0*
									7.0*
		C2l	Class IV + Europa I long 	9.5	170-185	3.0	901-3350	B=5.11-9.60 and L=all	7.0*
1801-2450	B=9.61-15.10 and L<=111.00								9.1*
2451-3200	B=9.61-15.10 and L<=111.00								9.1*
3201-3950	B=9.61-15.10 and L=111.01-146.00								9.1*
3951-7050	B=9.61-15.10 and L>=146.01	C3l	Class Va + Europa II long 	11.4	170-190	3.5-4.0	3351-7250	B=9.61-12.60 and L>=80.01	9.1*
3951-7050	B=15.11-24.00 and L<=146.00	C2b	Class IV + Europa I wide 	19.0	85-105	3.0	901-3350	B=12.61-19.10 and L<=136.00	7.0* only for class IV coupled unit
		C3b	Class Va +Europa II wide 	22.8	95-110	3.5-4.0	3351-7250	B>19.10 and L<=136	9.1*
7051-12000 (7051-9000)	B=15.11-24.00 and L=146.01-200	C4	Class Va + 3 Europa II 	22.8	185	3.5-4.0	>=7251	B>12.60 and L>=136.01	9.1*
12001-18000 (12001-15000)	B=15.11-24.00 and L>=200.01								9.1*
12001-18000 (12001-15000)	B>=24.01 and L=all								9.1*

* In classes I, IV, V and higher the headroom has been adjusted for 2, 3 and 4 layers of containers respectively (headroom on canals relative to reference high water level = 1% exceedance/year)

** The characteristics of the reference vessels have a margin of error of ± 1 meter in the length, and ± 10 cm in the beam.

NB:
1: A reference vessel is a vessel whose dimensions determine the dimensions of the waterway and the engineering structures on or in it.
2: New waterways and enlarged waterways are based on the largest reference vessel within a CEMT class.
3: Classes M3, M4, M6, M8, M10 and M11 may be used only for the renovation of existing waterways, locks and bridges.
4: The smallest dimensions of a reference vessel represent the lower threshold for categorizing a waterway in a particular standardized class.

A.2 Introduction of cargo-carrying commercial vessels

Motor cargo vessels

Motor cargo vessels are ships that powered by diesel. They can carry different types of cargos, such as containers and bulks.

Figure A.1 The motor cargo vessel with containers (BMT Surveys, n.d.)

The characteristics of reference vessels for Dutch waterways are listed in following table (RWS, 2011). In reality, some vessels are larger than the represent vessels. Thus, the design and construction should also consider the real situations.

In the table A.1, the reference draught is based on the average maximum draught for the waterway. Some vessels navigate with smaller draught because they are not fully laden. In most situations, vessels navigate in a laden situation to their destination and return in the empty situation. Table A.1 can be used when the design takes into account of the upper limit of vessels. Different from table A.1, table A.2 shows data of class characteristics which consider all vessels, not only the reference vessels. As stated in Waterway guidelines 2011 (RWS, 2011), the height above the waterline is defined as the height that is not exceeded by 90% of empty vessels in a certain class.

Table A. 1 Characteristics of reference motor cargo vessels (RWS, 2011)

CEMT class	beam(m)	Length (m)	draught (m)		height above waterline (m)	cargo capacity (ton)	engine capacity (kW)	bow propeller (kW)
			laden	empty				
I	5.05	38.5	2.5	1.2	4.25	365	175	100
II	6.6	50 - 55	2.6	1.4	5.25	535 - 615	240 - 300	130
III	8.2	67 - 85	2.7	1.5	5.35	910 - 1250	490 - 640	160 - 210
IV	9.5	80 -105	3.0	1.6	5.55	1370 -2040	750 - 1070	250
Va	11.4	110 -	3.5	1.8	6.40	2900 -3735	1375 -1750	435 - 705
VIa	17.0	135	4.0	2.0	8.75	6000	2400	1135

Table A. 2 Class characteristics of motor cargo vessels (RWS, 2011)

CEMT-class	height above waterline 90%		average cargo capacity (tonnes)	average engine capacity (kW)
	empty	laden		
I	4.65	3.35	365	175
II	5.8	4.6	540	250
III	6.3	5.1	935	435
IV	6.7	5.3	1505	690
Va	7.1	5.4	2980	1425
VIa	10.0	8.0	5125	2015

Above tables do not apply to container vessels but the container vessels are presented now separately. A standard container is 8 feet 6 inches, or 8½ feet, high (= 2.60 m) and 8 feet wide (= 2.44 m) (RWS, 2011). Some container vessels can hold more than three layers of containers while other vessels can carry one or two layers considering the requirement of safety. The capacity of some types of vessel expressed in TEU (twenty-foot equivalent units, equal to 6.06 m) is shown in following table A.3.

Table A. 3 Container capacity of several types of vessel (RWS, 2011)

vessel class or type	container capacity (TEU) beam x height x length
II/III	2 x 2 x 7 = 28
Neokemp	2 x 3 x 8 = 48
IVa	3 x 3 x 10 = 90
Va	4 x 4 x 13 = 208
Va extended	4 x 4 x 17 = 272
VIa	6 x 4 x 17 = 398
E I – push barge	3 x 3 x 9 = 81
E II – push barge	4 x 4 x 10 = 160

Pushed convoys

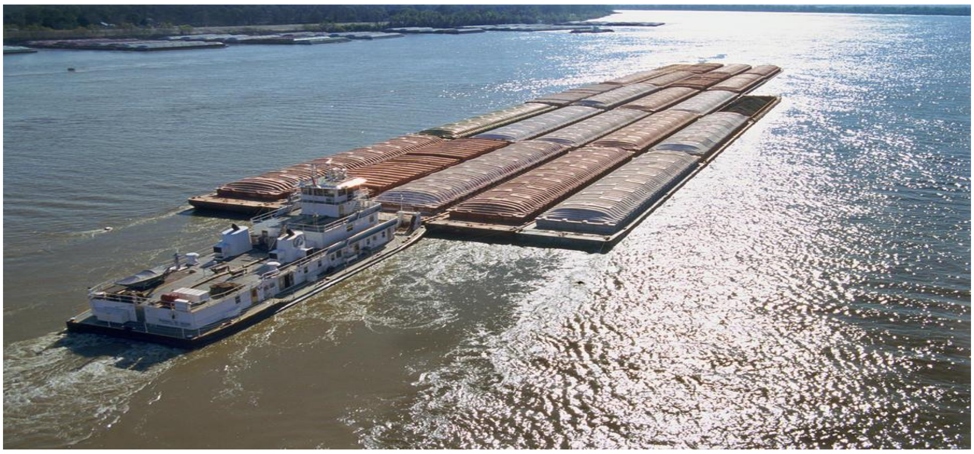


Figure A.2 Pushed barges and tugs ("M.O.B., Tugboats, and Reality", n.d.)

The push barges and tugs together form pushed convoys. Based on the beams, length and draught of vessels, barges are classified into four types. These four types can be found in table A.4. What is more, the combination of push tugs and pushed barges can be different. Thus, the general pushed convoys have several classifications which is shown in table A.5.

Table A. 4 Characteristics of reference push barges (RWS, 2011)

CEMT-class	type of push barge	beam (m)	length (m)	draught when laden (m)	cargo capacity
IV	I	9.5	70.0	3.0	1450
Va	II	11.4	76.5	3.5	2450
Va	IIa	11.4	76.5	4.0	2780
Va	I verleng	11.4	90.0	4.0	3220

Table A. 5 Characteristics of reference pushed convoys (RWS, 2011)

CEM T	type of pushed convoy	beam (m)	length (m)	draught when laden	cargo capacity
I	1 barge in front	5.2	55	1.9	≤ 400
II	1 barge in front	6.6	60 – 70	2.6	401-600
III	1 barge in front	8.2	85	2.7	601-1250
IV	1 barge in front Europa	9.5	85 – 105	3.0	1251-1800
Va	1 barge in front Europa	11.4	95 – 135	3.5 - 4.0	1801-3950
Vb	2 Europa II barges long	11.4	170 – 190	3.5 - 4.0	3951-7050
VIa	2 Europa II barges wide	22.8	95 – 145	3.5 - 4.0	3951-7050
VIb	4 Europa II barges	22.8	185 – 195	3.5 - 4.0	7051-12000
VIc	6 Europa II barges long	22.8	270	3.5 - 4.0	12001-18000
VIIa	6 Europa II barges wide	34.2	195	3. 5 - 4.0	12001-18000

Coupled units

A couples unit means that a vessel with another vessel or barged attached alongside which is defined by the inland waterways police regulations (BPR). Details of characteristics of reference coupled units are offered in Waterway guidelines 2011 (RWS, 2011) as well. Table B.6 gives the data of reference coupled units.

Table A. 6 Characteristics of reference coupled units (RWS, 2011)

CEMT-class	type of coupled unit	bea m	lengt h (m)	draught when laden	cargo capacity
I	2 péniches, long	5.05	80	2.5	≤ 900
I	2 péniches, wide	10.1	38.5	2.5	≤ 900
IVb	1 Europa I	9.5	170 – 185	3.0	901 - 3350
Vb	1 Europa II	11.4	170 – 190	3.5 - 4.0	3351 - 7250
VIa	1 Europa II	22.8	95 – 110	3.5 - 4.0	3351- 7250
VIb	3 Europa II barges	22.8	185	3.5 - 4.0	≥ 7250

Besides vessels with cargos, some vessels navigate without cargos but they work as passenger ships, fishing vessels, large cargo transporters etc. The dimension of vessels could influence the infrastructures within waterways.

Figure A. 3 One passenger ship (Keuvelaar, 2011)

A.3 Introduction of inland recreational vessels

The recreational vessels in Dutch have large diversification of dimensions. They are classified into three types (RWS, 2000).

Table A. 7 Recreational navigation classes

Category	class	height (m)	draught (m)	width (m)	length (m)
Sailing boats	1	8.50	1.25	3.00	9.00
	2	12.00	1.50	3.50	10.00
	3	12.00	1.75	3.75	11.00
	4	>>12.00	1.90	4.00	12.00
Motorboats	1	--	0.90	3.50	10.00
	2	2.75	1.10	3.75	12.00
	3	2.75	1.40	4.00	14.00
	4	3.40	1.50	4.25	15.00
Traditional boats	bv1	>>12.00	1.20	5.50	25.00
	bv2	>>12.00	1.40	6.50	30.00

Appendix B Inland ship locks

Inland shipping is one of the important transport modalities. It has the obvious economic advantage in many types of commodities, particularly bulk commodities like grains, coal, and ore (Marriage, Marsh, Albert, and Davies, 2013). There are different conjunctions during inland shipping, such as bridges and locks.

Locks are fixed structures which are used to raise or lower boats. Most locks are used in canals and rivers but they can be used to transport massive ships between seas as well (UXL Encyclopedia of Science, 2002). They link two parts of a canal with different water levels and make it possible for vessels to pass through. In China, the class of locks is defined according to the maximal dead weight tonnage through locks (Ministry of Transport of the People's Republic of China, 2001). However, in the Netherlands, there is no clear classification of locks but waterways are clarified.

In the Netherlands, guidelines for the dimensions of inland waterways and locks are based on the standard ship types of some decades ago. The standard ships are largest vessels that waterways can accommodate. The increase of dimensions of ships makes it necessary to replace some locks in the Netherlands in the next 10 to 20 years.

Approximately, one-third of goods transport is through inland water shipping in the Netherlands. International goods are transported to Germany, France and other countries by rivers or canals. There are around 5000 modern and innovative ships. The Netherlands has the biggest inland shipping fleet of Europe (Atlas, 2010). According to Eurosta (2016), the Netherlands has 359,898 thousand tonnes of goods transported by inland waterways in 2015. These total goods were transported by different vessels, such as motor cargo vessels, self-propelled tankers etc. It is reported that about 193,603 thousand tonnes goods are transported by motor cargo vessels which account for the most percentage, compared with other vessels. Figure B.1 describes the share of goods by type of inland vessels in 2013. Figure B.2 shows the share by type of inland vessels in the Netherlands in 2015 (Eurosta, 2016).

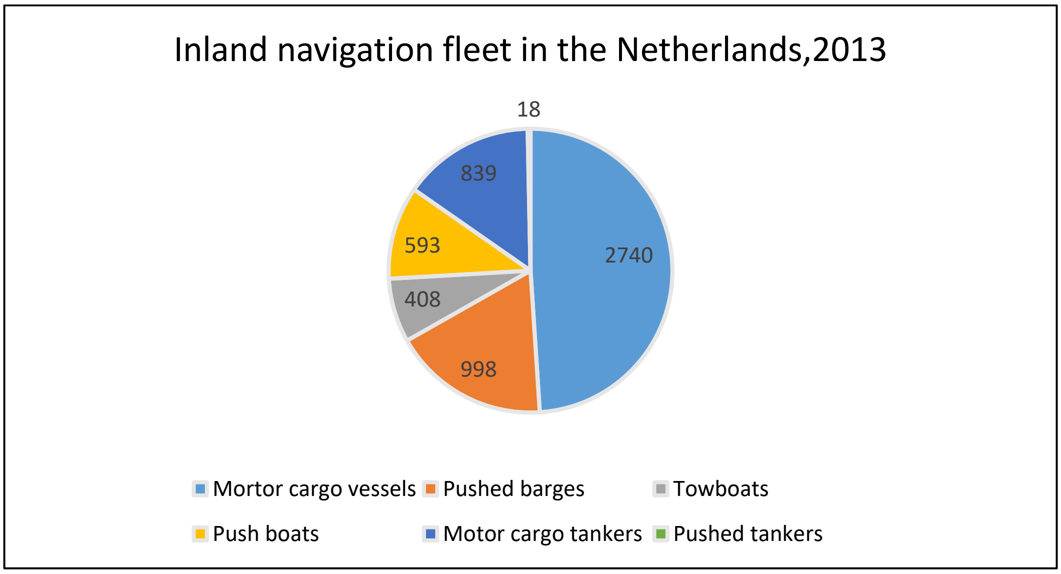


Figure B. 1 Share by type of vessels in total transport in 2013 (in tonne) (source: Eurosta, 2016)

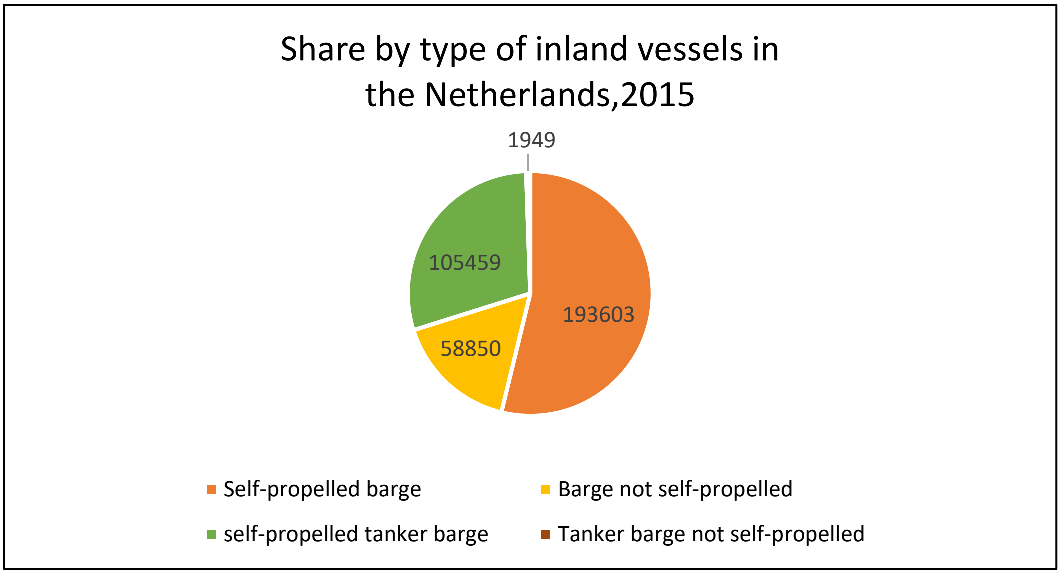


Figure B. 2 Share by type of vessels in total transport in 2015 (in tonne) (source: Eurosta, 2016)

Statistics Netherlands (CBS) has collected data about the tendency of inland navigation and summarized them in figure B.3. From the following figure, we can find that the transport performance keeps increasing, whereas capacity has a little decrease since 2011. We can expect that the demand for inland water transport will continue increasing in the next several years.

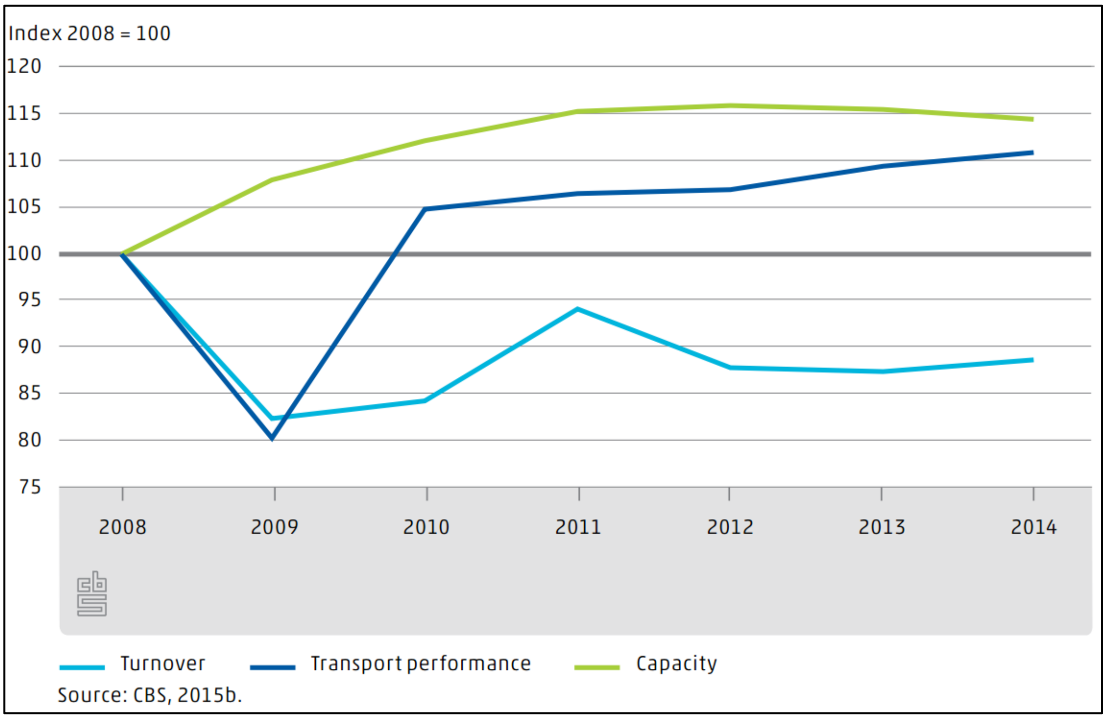


Figure B. 3 Turnover, performance and capacity of inland navigation in the Netherlands

(Statistics Netherlands, 2015)

Especially, the containers are the main type of goods. The number of containers is increasing generally, and the percentage of containers in total goods increased as well.

B.1 Dimensions of locks

Ship lock consists of several parts, such as lock heads and chambers which are shown in figure B.4. Basically, most locks have rectangular chambers, two fixed sides and two lock gates at two ends. In order to lift ships, there are also lifting systems and facilities for emptying or filling water in chambers. Except chambers, the holding basin is important for the operation of locks because ships wait in line there. Usually, holding basin consists of run-out zone, waiting area, line-up area and funnel.

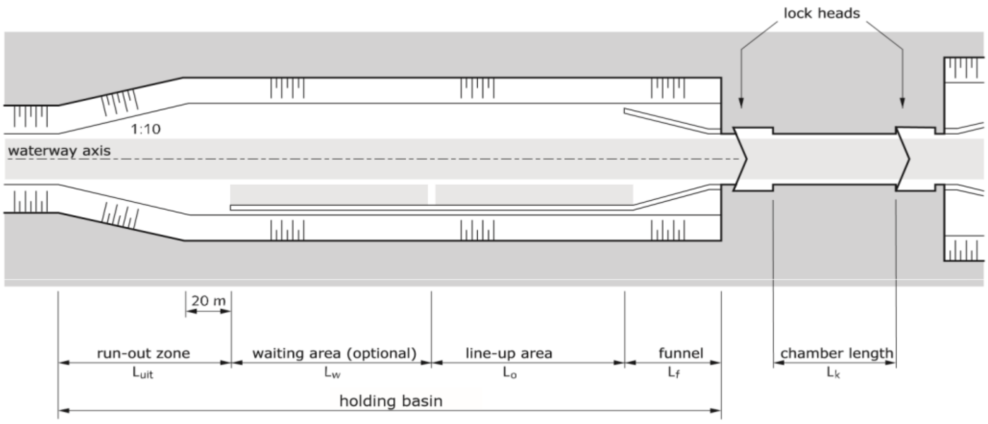


Figure B. 4 Components of a typical ship lock area (RWS, 2011)

Lock chambers are main parts of construction so it is important to determine the size of chambers. From an economical perspective, the reasonable design of lock chamber can reduce the cost of construction and the cost of waiting time but it should also have enough capacity for the increasing ships. The reasonable design is obtained by balancing the cost, benefit and the capacity of locks. The dimensions of ship locks includes width, length and depth. According to Waterway guidelines 2011 (RWS, 2011), the length of lock chambers depends on the length of vessels. The minimum usable length of the chamber between the stop lines is 1.1 times the length of the reference vessel (RWS, 2011). The width of chambers should also take into account of the width of fenders at both sides of vessels.

The dimensions of ship locks depends on the reference vessels and the method of mixed locking. Vice versa, the dimensions of ship locks determines which types of fleet share can navigate in waterways. Especially in the case of European countries, some rivers and canals link several countries, such as Meuse. Meuse rises in France and flows through Belgium and the Netherlands. Finally, it reaches to the North Sea. When vessels navigate in Meuse, they need to pass through several locks. Any locks which lack enough of space or have much delay may cause a traffic jam of waterways.

B.2 Lock capacity

The definition of the lock capacity is as follows in Capacities of Inland Waterways. (Groenveld, Verheij and Stolker, 2006)

"The capacity of a lock is the maximum quantity of traffic, expressed in number of ships, dead-weight capacity or otherwise, that can be locked through under the prevalent conditions per time unit if the

lock operators work continuously."(P.22)

$$\mathrm{Cs} = \left(2 * \frac{n_{max}}{T_c}\right) \text{ [ships/time unit]}$$

$$\mathrm{C}_T = \mathrm{C}_s \cdot T_s \text{[tonnes carrying capacity/time unit]}$$

n_{max} is the average number of ships over a large number of maximum capacity locking operations. T_c is the corresponding average cycle time. $\mathrm{C}_s$is the average carrying capacity of the ships. $T_s$is the average carrying capacity per ship.

Many types of research have already been done around the world to estimate the capacity of locks. Todor BAČKALIĆ and Maša BUKUROV (2011) analyse the real situation to determine the capacity of locks. In many cases, mathematic approaches are used to study the capacity of locks. In China, Liao (2012) developed an analytical model for a waterway lock based on the relationship between the area and tonnage (RAT) of inland freight vessels and the percent of the available chamber (PAC). Three Gorges ship lock in China is taken as a typical example to study the capacity of the ship lock. The study of three Gorges ship lock was also done by Liu and Mou (2015) through analysis methods.

The approaches to enlarge the capacity of locks have been studied and are applied in many real cases. In the Netherlands, an implementation study for a new sea lock in the existing sea lock complex at Ijmuiden was executed by the Directorate-General (DG) and Public Works Noord Holland from 2010 to 2012 (INEA, 2013). The Volkerak Locks are the busiest and most intricate lock complex in Europe (Government of the Netherlands, 2016). They are going to be enlarged as well in order to handle the vessels more smoothly. Other examples are the locks on the Erie Canal in New York, the United States. Many locks have been doubled during last decades. A number of lock chambers were also widened or lengthened due to the increase of traffic. In China, many old ship locks cannot meet the increasing capacity of inland waterways as well so that a number of locks are planned to be enlarged. In the example of Hai-an ship lock in China, several scenarios of enlargement of ship locks were compared with each other. The choice of scenarios depends on the overall consideration of economic, construction technology and the environment.

B.3 Minimum capacity lock

According to Waterway guideline 2011 (RWS, 2011), the minimum capacity lock is a lock that can take a single reference vessel at a time. When the volume of traffic is larger, the simulation model like SIVAK should be used. A minimum capacity lock is seldom sufficient on a waterway of class V or higher, and further investigation will generally be needed

waterway class	chamber length L_k	chamber width B_k	sill depth*
I	43	6.0	2.8 - 3.1
II	60	7.5	3.1 - 3.2
III	80 - 95	9.0	3.1 - 3.3
IV	95 - 115	10.5	3.5 - 3.7
Va	125 - 150	12.5	4.2
Vb	210	12.5	4.7

* sill depth = maximum draught of reference vessel + keel clearance; an extra increment may need to be introduced for translation waves

Figure B. 5 Minimum capacity locks

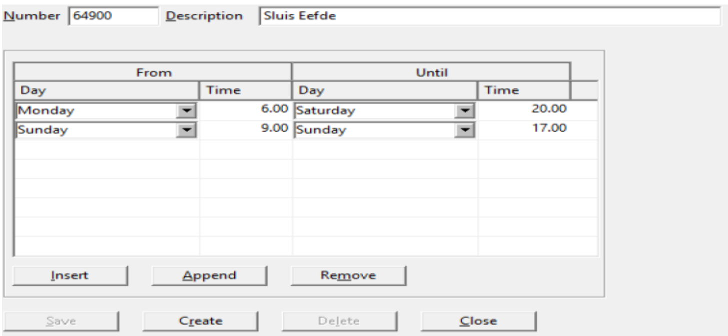
Appendix C Twente canal and Eefde lock

Twente canal is a major waterway in the Dutch provinces of Gelderland and Overijssel. It is a major transportation artery to and from Twente. It enables large barges and tugs to reach the harbors of Hengelo, Enschede and Almelo. It plays an important role in the transport of sand, gravel, salt, cattle food and containers. The location of Twente canal is shown in figure C.1.

Figure C. 1 The location of the Twente canal (Worldatlas, 2017)

The total Twente canal can be separated into several stretches. The Eefde – Delden canal stretch is 33km long, the secondary waterway between Delden and Almelo is 15km long and the Delden – Hengelo, Hengelo – Enschede canal stretches have lengths of 9km and 5km respectively. Total canal length is 65km (POT, 2013). Twente canal was widened and deepened between 2004 and 2007. After that, the classification of the Twente canal was changed from a CEMT class IV waterway to a CEMT class Va waterway. CEMT class Va waterway means that a large Rhine ship can travel along the canal. The maximum width of the Rhine ship is 11.5m and the maximum length is 110m.

There are some locks along the canal. The dimensions of locks should meet the requirement of upgraded Twente canal. Eefde lock is one of the locks along Twente canal. The working time of the Eefde lock is given by RWS as following figure C.2.



Number 64900 Description Sluis Eefde

From		Until	
Day	Time	Day	Time
Monday	6.00	Saturday	20.00
Sunday	9.00	Sunday	17.00

Insert Append Remove

Save Create Delete Close

Figure C. 2 Operation schedule

Appendix D Vessels through Eefde lock

Following tables are made based on the data from RWS. The first table shows the information of vessels through the Eefde lock in April 2014 The second table describes the vessels through Eefde lock in July 2015.

Table D. 1 Vessels of April 2014

RWS-Coding of ship type	RWS class	Number of vessels	Length	Average	Dev	Width	Average	Dev
1,2,3,12,21	M0	3	16-26	22.67	7.51	322-523	456	116.05
	M1	41	39-49	41.34	4.19	504-509	507.78	0.99
	M2	98	40-63	54.63	5.5	595-670	651.58	21.61
	M3	124	54-77	63.19	6.6	682-729	718.07	9.07
	M4	97	55-74	67.79	4.77	731-827	797.10	32.66
	M5	170	75-86	80.06	2.79	776-827	819.82	5.27
	M6	214	70-86	82.98	3.04	850-960	933.41	25.43
	M7	102	90-110	103.91	3.94	900-954	942.48	17.84
	M8	155	80-110	107.52	6.83	963-1141	1100.73	53.04
	B01	3	35-48	41.33	6.51	474-500	491.3	15.01
	B02	2	48	48	0	660	660	0
	B04	2	83	83	0	820	820	0
	BI	2	99	99	0	948	948	0
Others (RWS-Coding)	40	3	17	17	0	490	490	0
	43	3	16-17	16.67	0.58	450-458	455.33	4.62
	44	6	21-49	36.33	12.69	520-710	628.33	87.45
	45	5	18-21	19	1.22	450-525	490	37.91
	49	3	60-86	75.33	13.61	660-953	811	146.71
	80	223	15	-	-	-	-	-
	82	16	-	-	-	-	-	-
	85	8	30	-	-	500	-	-
	89	5	-	-	-	-	-	-
	Total	1285	-	-	-	-	-	-

Table D. 2 Vessels of July 2015

	Number of vessels	Length(m)	Average	Dev	Width (cm)	Average	Dev
M1	42	39-50	42.38	4.84	505-509	507.6	1.17
M2	83	39-66	55.66	5.65	511-670	653.8	27.18
M3	127	54-77	63.7	6.96	703-730	719.32	7.97
M4	81	58-74	69.21	4.11	736-826	800.15	30.49
M5	143	75-86	80.07	3.07	810-830	821.11	2.72
M6	269	67-86	82.98	3.58	859-960	933.26	25.66
M7	118	95-110	104.53	2.97	900-954	938.27	21.2
M8	166	85-110	108.35	5.19	965-1145	1103.41	53.41
B01	2	29-36	32.5	4.95	400-500	450	70.71
B04	4	83	83	0	820	820	0
BI	2	83	83	0	850-870	860	14.14
Others	463	15-50/-	21.3		348-660	469.58	73.86
Total	1500						

Appendix E SIVAK program

INPUT IN SIVAK

ARRIVAL PATTERN

In the part of arrival patterns, the intensity per hour of the week is described. Small commercial vessels, large commercial vessels and recreational vessels are included.

Number

Just a random number is chosen here

Description

Eefde Sluis IVS2012 wk13-16 kleine beroepsvaart WO

OPERATIONAL SCHEDULE

Number

64900 is used here.

Description

Just name, Sluis Eefde, is used.

Day and time

Operation time of the lock is set here. From Monday to Saturday, work period is from 6.0 am to 20.0 pm. On Sunday, time is shorter, from 9.0 am to 17.0 pm.

CHAMBER

Number

Give in a number to see it in the chambers list.
Just a random number is chosen here.

Description

Give a description of the chamber. Sluis Eefde kolk is used.

Length

Give the length of the chamber. The length inputted is the 133 meters length (RWS).

Width

Give the width of the chamber. The width is 12 meters.

Waterplane length

The waterplane length is used for calculation of water losses. It is not necessary so for now, it is still 133 meters which is the usable chamber length.

Lock head width

The width of the lock head used for the influence of the lock sizes on the speed of in and outgoing vessels. The width of the lock head is now the same as the chamber width 12 meters. It can be changed based on different scenarios.

Operation schedule

Time schedule used in Block can be used or '0 no' which means that the lock will work 7 days a week 24 hours a day. Actually, Eefde lock has its own operation schedule as set in above section. *64900-Sluis Eefde* is selected then.

Optimization

Optimization is used to set whether, and if so to what extent prefer new plan. There are two choices, Partial and Full. The following assumptions apply:

- This can only be applied in the case of mixed locking;
- The safety distances are applied;
- There is sufficient room for maneuver to allow changes between the order of sailing in and order of arriving
- Partial optimization

With help of the rules used for a not optimized lock, the first plan is made. All vessels which are in this first plan are implemented in the final locking plan. After this, by changing the order of sailing in, an optimal surface yield with additional not yet planned but in sight vessels will be obtained.
Note: using this option did not give any differences in results.

- Full optimization

With all candidates in sight obtain an optimal surface yield.

In both cases the longest waiting ship will be put in the planning
It is theoretically possible to make an optimal mathematical chamber filling with vessels. However in reality this is not feasible. That's why in SIVAK there are two strategies.

- Vertakken en begrenzen (Branch and Bound)
  In a systematic way, the sailing in is determined. As soon as it is clear that additional ship doesn't give a better solution, the group of planned vessels will be expanded with other vessels.
- Heuristiek (Heuristic)
  The implemented heuristic aims to fill up the free width of the chamber from the deepest part onwards.

For small numbers of ships, both methods work well, although it looks that the first gives better solutions but it takes longer to calculate.

Guide Jetty length

The trap length is the length you have to take into account for the in and outgoing vessels to maneuver. For side 1, the length is 100m. For side 2, the length is 120m.

Entrance depth

The free navigable depth is relative to the reference level. If the threshold condition is a negative number, it means it is below the level. Assume the IJssel is at 0 level, side 2 should be 6.5 m above level.

Time to open doors

Time used to open the doors for the vessels to come in. For both side 1 and side 2, the time is about 2 minutes.

Time to close doors

Time used to close doors of the chamber. For side 1, time is 2 minutes. For side 2, time is 3 minutes.

Leveling base time

Time to level the chamber.

Leveling factor

The factor multiplied with the change in the water table. Therefore the leveling base time will change with this factor on the water table. RWS gives 2.1 for 1 to 2, and 1.3 for 2 to 1

Squeeze

There is a squeeze option where the ships partially interfere their space. Squeeze will slow down the passing time.

Ship classes allowable

Here is a list of all ship classes. User must select which classes are appropriate. This will be determined based on information of appendix D.

Ship classes guaranteed service

There are no priorities given in the reality model. Prioritized ships slow the process down and there is no exact quantity of prioritized ships

SHIP CLASS

In this part, each ship belongs to one and only one class of vessel. Each ship class has a number and a description. The characteristics of different ship class include

- Capacity(dwt)
- Width(m)
- Length(m)
- Draught loaded(m)
- Draught unloaded(m)
- Air draught(m)
- Minimum and maximum velocity loaded and unloaded

SHIP TYPE

Each ship is considered to have a type, such as tanker, bulk carrier, container ship etc. The settings for this part are left as they were as there is no insight in the certificates and safety measures.

LOCKING REGIME

The operation of a lock can be subjected to a protective regime. Under a protective regime, the lock is operated by a special strategy. This includes the range of locking ships and the size of the pool (s).

Minimum chamber utilization open side/closed side

Minimum percentage of the covered space by the vessels of the total available space in the chamber are different at open side and closed side. Closed side is safer for vessels to maneuver, and vessels can be closer to the door. 60% is taken for open side. 80% is for closed side.

Maximum resulting waiting time

A locking won't be delayed further if the waiting time of the longest waiting ship exceeds the maximum waiting time. When there are more ships waiting, the chamber will be filled with ships to make the passing time as less as possible. 50 minutes is used here.

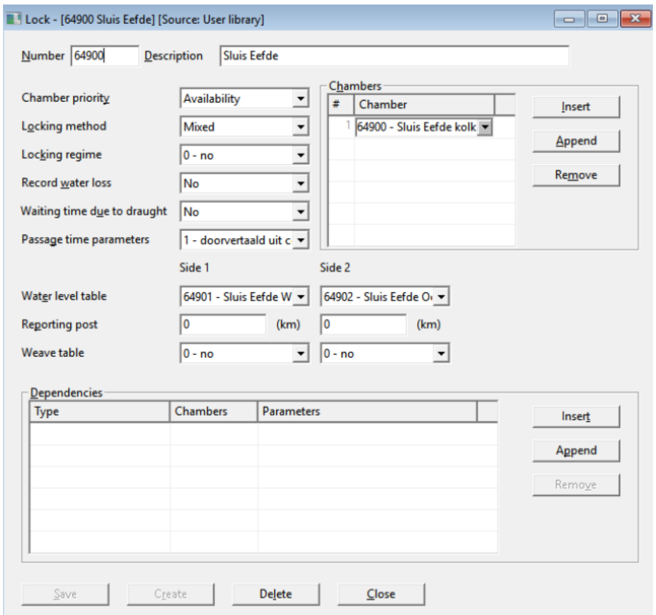
Waiting time pleasure craft

Factor of the maximum resulting waiting time, which determines the waiting time of a pleasure craft in the chamber. 0.5 is taken as factor.

Schedule for periodical locking

A schedule can be chosen for the periodical locking. This function is not used.

LOCK



This part is mainly used for the lock with more than one chamber.

Chamber priority

Chamber priority indicates the priority when choosing a chamber. The choice may be determined on the basis of surface, availability, or filling of the lock. Availability is selected.

Locking method

There are two locking methods.

- Separated

By separated locking, the ships are placed in the chamber in homogeneous groups (with respect to the category).

- Mixed

In this case, safety distances of the placement of the ships has been taken into account, but the ships are not grouped according to category.
Both cases will be considered during simulation.

FLEET

This part is used to choose the fleet share, which is different for each situation. Condensing factor can make the amount of incoming vessels varied. The extent is the amount of weeks you want to run the model for.

FLEET SHARE

A fleet section explains the features of a fixed collection vessels.

•% Cert

The percentage of ships sailing with a certificate.

• 1% cone

The percentage of ships sailing with one cone.

- ***2% cones***

The percentage of ships sailing with two cones.

- ***# / week***

The number of ships of this group per week.

- ***% Reserv***

The percentage of ships have the possibility to reserve. Reserve means that the ship is announced at the start or alter its route at all works on that route.

WATER LEVEL TABLE

A height of water table describes the water level, with respect to an assumed to be known zero-level, as a function of the time. In the simulation, appropriate values at any time can be obtained by linear interpolation. The height of water table is hereby cyclically applied to the specified cycle length. The cycle length is 24(hh.mm).

Appendix F Model setup process

(1) Step 1: Put data into blocks

Data are input in different scenarios as described in chapter 4.2.

(2) Step 2: Build the network

The network of the model consists of nodes, waterway sections and the lock. As shown in figure F.1, the local area of Eefde lock is studied. Totally, there are six nodes, four sections and one lock. Between the node 3 and node 4, the distance is considered to be the length between two lock gates. The waterway sections 2-3 and 4-5 are close to lock and where vessels wait for locking. Fleets are generated at point 1 and point 6.

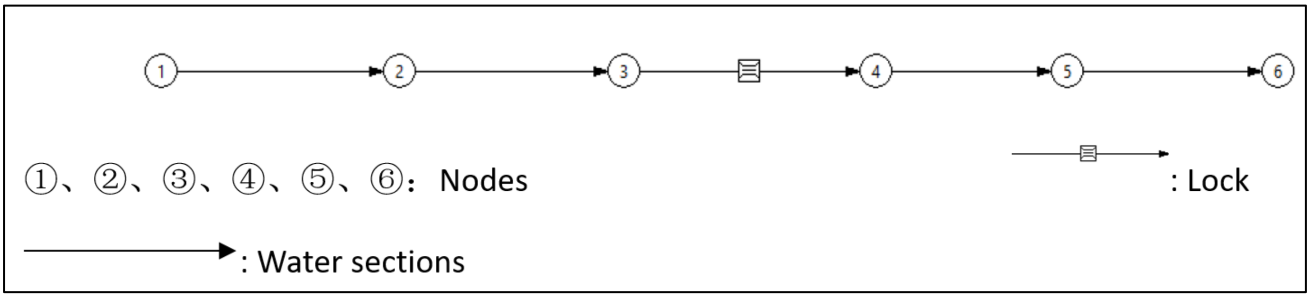


Figure F. 1 The network of Eefde lock

For each section, blocks of water section should be selected by right mouse click.

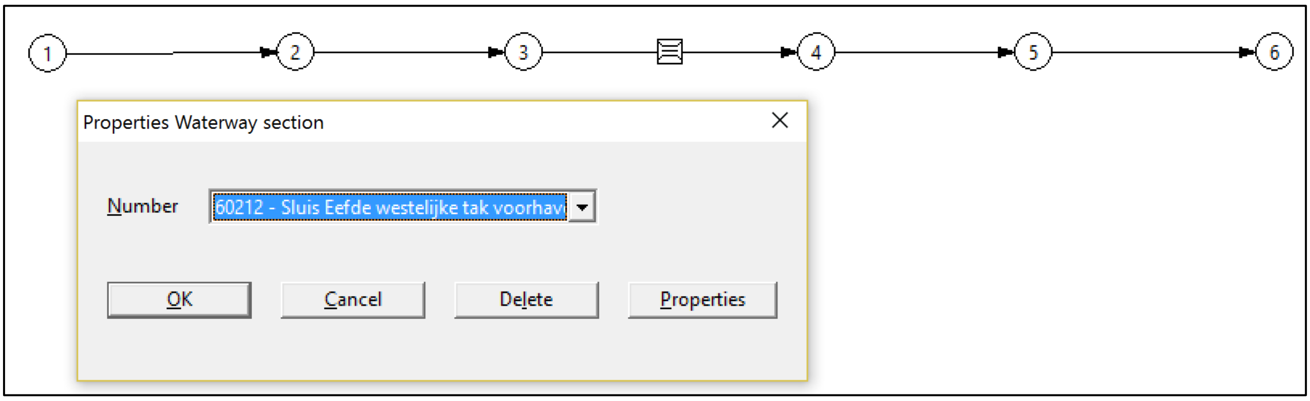


Figure F. 2 Select waterway sections

When the lock is built in the network, different lock blocks are chosen according to different scenarios, as shown in following figure F.3.

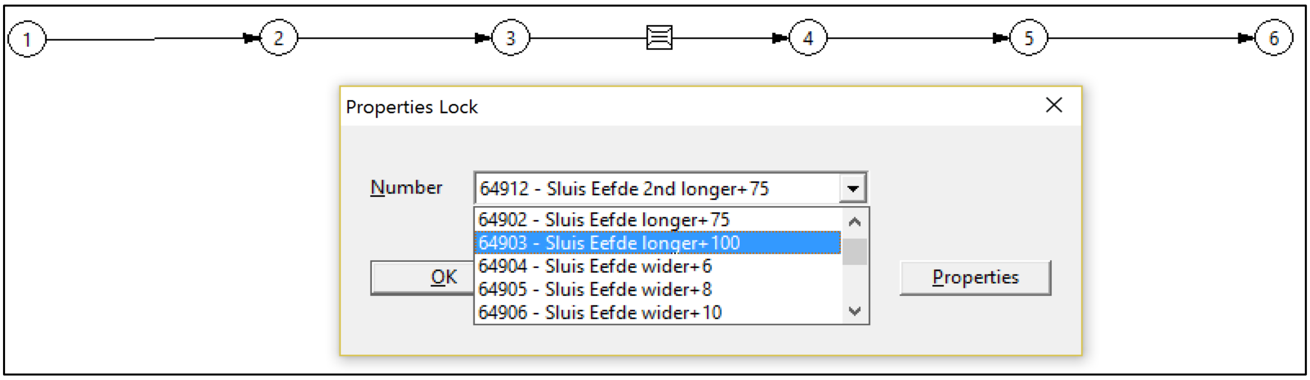


Figure F. 3 Select the lock

(3) Step 3: Set the Route network

The arrows shown above in the network do not stand for the direction of navigation. The routes of two directions are defined by determining the source and destination. Nodes are clicked in order of 1 to 6 and 6 to 1. Two routes are determined at last.

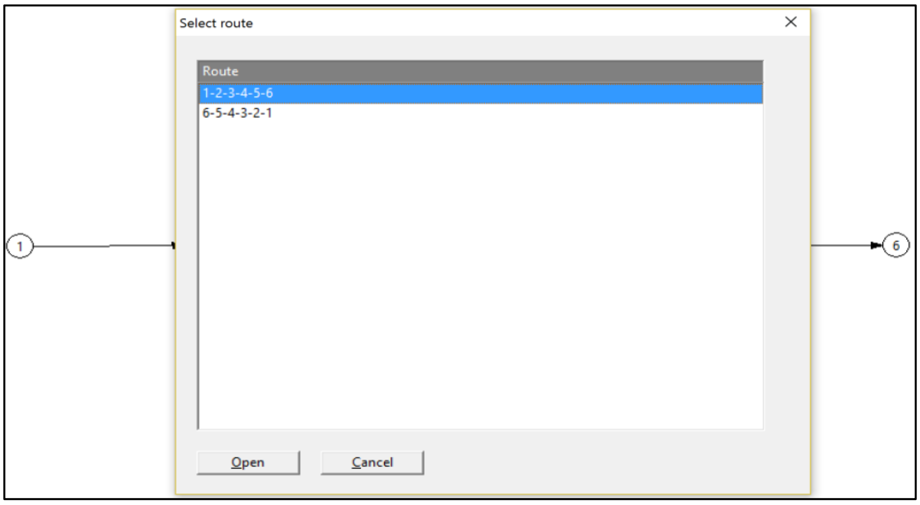


Figure F. 4 Determine routes

Then, after opening the routes, by button 'Properties', the fleet is selected (figure F.5). There are two types of fleet. One is for current scenarios, and the other fleet is for future situations.

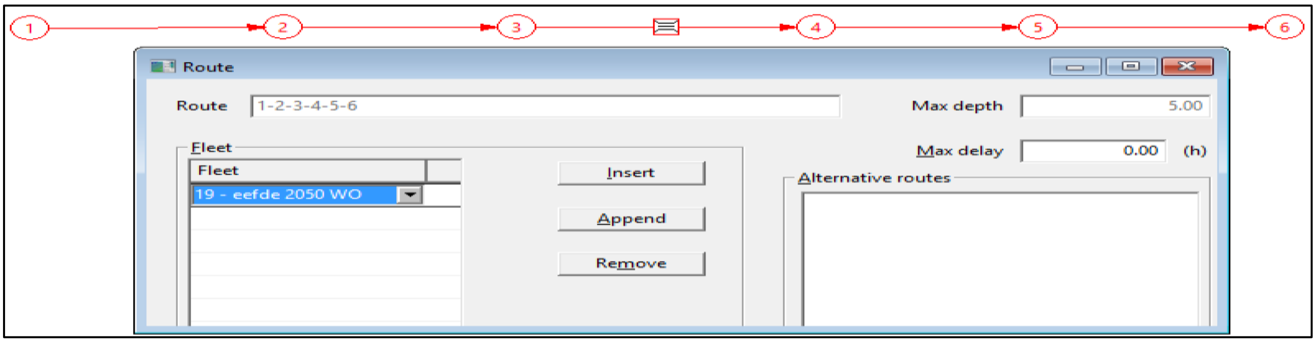


Figure F. 5 Determine fleet

(4) Step 4: Run the model

Based on different scenarios, the diagrams are displayed as follows.

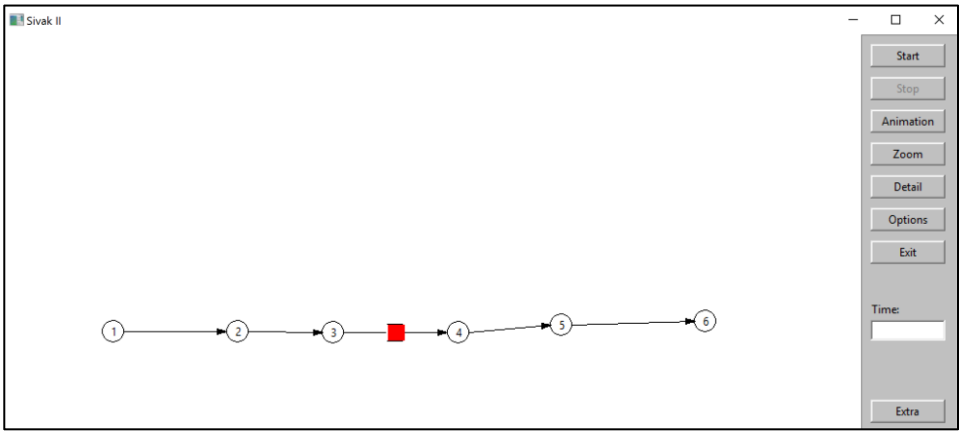
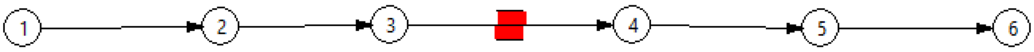


Figure F. 6 Run the model

The number of the lock chamber and the locking process can be observed directly in the above page.

(a) Simulation animation (one chamber)



(b) Simulation animation (two chambers)

Figure F. 7 Simulation animations