MASTER

Decision model for the renewal of navigation lock components

the decision making process : renovation, replacement or standardization within existing navigation locks in the Netherlands

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About the author:
L. (Luca) Middelburg - 1028028
Construction Management & Engineering
Eindhoven University of Technology
March, 2019

Graduation committee
Prof.dr.ir.B. (Bauke) de Vries (b.d.vries@tue.nl)
Dr. Ing. P.J.H.J. (Peter) van der Waerden (p.j.h.j.v.d.waerden@tue.nl)
Dr. E.J. (Erik-Jan) Houwing (E.J.houwing@tudelft.nl)
M. (Martijn) van den Elzen (martijn.vd.elzen@movares.nl)

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Summary

The Dutch waterway network has about 6,000 kilometers of rivers and canals, which makes it the most dense in Europe. Many canals serve as drainage as well for navigation. The commercial part of these waterways has a total length of 2,200 kilometers and accounts for approximately 40% of the international freight transfers and 20 % of the domestic freight transfers. This part of the network is state-owned and operated by Rijkswaterstaat. The smaller waterways are managed by provincial and water authorities in the Netherlands.

Authorities responsible for the planning and management of inland waterway infrastructure are faced with the issue of renewing their networks. In Western countries, major parts of the waterway network, such as navigation locks, bridges, and weirs, are ageing and need to be replaced to ensure waterway performance.

In the 1930's many navigation locks were built in the Netherlands. Rijkswaterstaat manages 137 of these navigations locks. Rijkswaterstaat started a program called MultiWaterWerk, in order to renovate or replace 52 navigation locks in the Netherlands in the next two decades. 37 of these navigation locks have reached their technical lifespan and 15 navigation locks do not meet the requirements anymore.

The main reason for the start of the MultiWaterWerk program is that the asset managers of the navigation locks came across multiple solutions for the same problem. Most of the navigation locks were considered as a unique project. This resulted in a diversity of solutions. This diversity of solutions had a negative effect on availability and management of the navigation locks.

The goal of MultiWaterWerk is to obtain a better reliability and availability, lower life cycle costs and a more predictable estimation of the construction cost and time. To reach this goal, a new possibility is added to the current possibilities; renovation and regular replacement. This new possibility is called standardization. Standardization is a form of replacement, however in case of standardization it will be replaced by a standardized part.

At this moment, it is still unknown how the added value of standardization can be proven. Currently decision makers base their decision, whether to renovate or replace a lock component, on one specific lock and do not take multiple locks into account. This is because they are unware of the possible positive effects of standardization. Furthermore, currently there is no strategy in deciding whether to renovate, replace or to apply a standard component.

The goal of this thesis is to develop a decision model which helps the asset manager to choose between the possibilities renovation, replacement or standardization of navigation lock components for the MultiWaterWerk program. Furthermore, the added value of standardization of a cluster with respect to replacement will be investigated.

To reach this goal, the following steps are taken: the first step was to make a literature study which consists of general information about navigation locks and how decisions are made about the renewal of infrastructure in the Netherlands. The second step is to develop a conceptual model which determines which aspects are needed for the model and how to

translate these aspects into costs. The third step discusses the three most commonly used management strategies. Here comes to light how current decisions are made about the renovation or replacement of a component. Step four are interviews with advisors and asset managers which provide information how they currently decide whether a navigation lock component gets renovated or replaced and their idea about standardization. Step five is the optimization of the conceptual model by implementing the received information, which results in the refined model. Step six is to illustrate this model by means of a case study. The case study consists of the component mitre gates, because gates have a high standardization suitability.

The final model makes use of a multi-criteria analysis which provides the opportunity to make an decision between the three possibilities. With the final model the decisionmaker can decide which aspects are most important. This can be done by putting weights to the aspects costs, performance and sustainability. In this way it gives the decisionmaker the opportunity to focus on a specific aspect.

Possibilities / Aspects	**Weight**	**Renovation**	**Replacement**	**Standardization (1)**	**Standardization (xx)**
Costs (€)	x	A	B	C	S_1
Performance (€)	y	D	E	F	S_2
Sustainability (€)	z	G	H	I	S_3
Total (€)		xA+yD+zG	xB+yE+zH	xC+yF+zI	$xS_1+yS_2+zS_3$

Table 1: Final decision model

The final decision model provides an overview of the total costs of all the aspects and shows the optimum solution for the renewal of the component. The additional column standardization (xx) shows what the minimum number of navigation locks is to make a more feasible solution than replacement and renovation. Furthermore, it shows what the average costs are per aspect and the total average costs, in case the minimum number of standardized navigation locks is known.

Finally, in order to demonstrate the functioning of the model, the model has been applied on the component mitre gates with the help of the case study Sluis Schijndel,. The model shows that renovation is the most feasible solution for this case study. In general it can be said that the aspect costs has the biggest influence on the decision making between the renovation, replacement or standardization of the component mitre gates. This is due that fact the operating and maintenance costs and construction costs are considerably high compared to the performance and sustainability costs.

Samenvatting

Het Nederlandse waterwegennet heeft ongeveer 6.000 kilometer aan rivieren en kanalen, waardoor het relatief de drukste in Europa is. Veel kanalen dienen zowel als voor afwatering als voor navigatie. Het commerciële gedeelte van de waterwegen heeft een totale lengte van 2.200 kilometer en is goed voor ongeveer 40% van de internationale vrachtbeweging en 20% van binnenlandse vrachtbewegingen. Dit deel van het netwerk is eigen van de staat en wordt beheerd door Rijkswaterstaat. De kleinere waterwegen worden beheerd door verschillende provinciale of waterschappen in Nederland. Waterschappen die verantwoordelijk zijn voor de planning en beheer van de binnenvaart, worden geconfronteerd met de veroudering van het netwerk. In westerse landen verouderen belangrijke delen van het waterwegennet zoals, navigatiesluizen, bruggen en stuwen. Deze dienen vervangen te worden om de prestaties te waarborgen.

In de jaren 30' werden veel sluizen in Nederland gebouwd. Rijkswaterstaat heeft 137 sluizen in beheer. Rijkswaterstaat startte het programma MultiWaterWerk (MWW) voor de vervanging of renovatie van 52 van deze sluizen in de komende 2 decennia. 37 van deze sluizen hebben hun technische levensduur bereikt en 15 voldoen niet meer aan de eisen. De belangrijkste reden voor de start van dit programma is dat de beheerders van de sluizen met verschillende oplossingen kwamen voor hetzelfde probleem. Dit komt omdat de meeste sluizen als uniek worden beschouwd en waardoor er telkens een unieke oplossing kwam. Deze diversiteit van oplossingen had een negatief effect op de beschikbaarheid en het beheer van de sluizen.

Het doel van MultiWaterWerk is om de prestaties te verhogen, de kosten te verlagen en een betere voorspelling te kunnen geven wat betreft de bouwduur en bouwkosten. Om dit doel te bereiken wordt een nieuwe mogelijkheid toegevoegd aan de huidige mogelijkheden; renovatie en vervangingen. Deze nieuwe mogelijkheid wordt standaardisatie genoemd. Standaardisatie is een vorm van vervangingen, maar in geval van standaardisatie vindt deze vervanging plaats door een standaard.

Het doel van dit onderzoek is om een beslissingsmodel te ontwikkelen dat de beheerders van de sluizen helpt met het kiezen tussen de mogelijkheden; renovatie, vervanging of standaardisatie van een sluis component. Dit onderzoek zal ook ingaan op de toegevoegde waarde van standaardisatie van een cluster in tegenstelling tot vervanging.

Om dit doel te bereiken zijn de volgende stappen genomen: de eerste stap was om een literatuurstudie te maken. Deze literatuurstudie bestaat uit algemene informatie over sluizen en hoe de beslissingen worden gemaakt wat betreft de vernieuwing van de infrastructuur in Nederland. De tweede stap is het ontwikkelen van een conceptueel model, welke bepaald welke aspecten in het beslismodel nodig zijn en hoe deze vertaald kunnen worden naar kosten. De derde stap bespreekt de drie meest gebruikte beheers strategieën van Rijkswaterstaat. Hier komt aan het licht hoe beslissingen worden genomen over de renovatie of vervanging van een component. In de vierde stap zijn de interviews met de experts weergeven. Hierin komt naar voren op basis van welke aspecten de experts een keuze maken voor de renovatie of vervanging van een component. Daarnaast is naar hun mening gevraagd wat betreft het idee van standaardisatie. Stap vijf is de optimalisatie van het conceptueel

model. Het conceptueel model is geoptimaliseerd door de informatie van de voorgaande stappen samen te voegen en te bekritiseren, wat leidt tot het definitieve beslismodel. Stap zes is om dit definitieve beslismodel te testen aan de hand van een casus. De casus gaat over het component stalen punt deuren, omdat gebleken is dat dit component veel belovend is wat betreft standaardisatie.

Het beslismodel bestaat uit een Multi criteria-analyse die de mogelijkheid biedt om een beslissing te nemen tussen de drie mogelijkheden. Met het beslismodel kan de beheerder beslissen welke aspecten hij het belangrijkst vindt. Dit kan gedaan worden door gewichten aan de aspecten kosten, prestaties en duurzaamheid te geven. Via deze manier heeft de beheerder de mogelijkheid om zich op een specifiek aspect te concentreren.

Opties / Aspecten	**Gewicht**	**Renovatie**	**Vervanging**	**Standaardisatie (1)**	**Standaardisatie (xx)**
Kosten (€)	x	A	B	C	S_1
Prestaties (€)	y	D	E	F	S_2
Duurzaamheid (€)	z	G	H	I	S_3
Totaal (€)		xA+yD+zG	xB+yE+zH	xC+yF+zI	$xS_1+yS_2+zS_3$

Table 2: Definitief beslismodel

Het beslismodel biedt een overzicht van de totale kosten van alle aspecten en toont de optimale oplossing voor de vernieuwing van het component. De extra kolom standaardisatie (xx) laat zien bij hoeveel sluizen er standaardisatie dient plaats te vinden om de voordeligste optie te zijn ten opzichte van renovatie en vervanging. Daarnaast laat deze kolom zien wat de gemiddelde kosten zijn per aspect en wat de gemiddelde totale kosten zijn, indien het aantal sluizen wat gestandaardiseerd moet worden bekend is.

Ten slotte is het definitief beslismodel toegepast op een het component stalen puntdeuren en met behulp van de casus Sluis Schijndel, om de werking van het definitieve beslismodel te demonstreren. Het model laat zien dat renovatie de meest haalbare oplossing is voor deze casus. Dit komt omdat in dit geval het aspect kosten de grootste invloed heeft op de beslissing tussen renovatie, vervanging of standaardisatie van het component stalen puntdeuren. Dit heeft voornamelijk te maken met het feit dat de bouwkosten en onderhoudskosten van dit component aanzienlijk hoger zijn dan de prestatie- en duurzaamheidskosten.

Abstract

In Western countries, major parts of the waterway network, such as navigation locks, bridges, and weirs, are ageing and need to be replaced to ensure waterway performance. In the 1930's many navigation locks were built in the Netherlands. Rijkswaterstaat manages 137 of these navigations locks. Rijkswaterstaat started a program called MultiWaterWerk (MWW), in order to renovate or replace 52 navigation locks in the Netherlands in the next two decades.

The goal of MultiWaterWerk is to obtain a better reliability and availability, lower life cycle costs and a more predictable estimation of the construction cost and time. To reach this goal, a new possibility is added to the current possibilities; renovation and regular replacement. This new possibility is called standardization. Standardization is a form of replacement, however in case of standardization it will be replaced by a standard.

The goal of this thesis is to develop a final decision model which helps the asset manager to choose between the possibilities renovation, replacement or standardization of navigation lock components for the MultiWaterWerk program. Furthermore, the added value of standardization of a cluster with respect to replacement will be investigated.

In order to define what the relevant aspects are for the decision making process of the infrastructure and how the current these decisions are made. Information is gathered and discussed about the decision making process of the Dutch Ministry of Infrastructure and the management strategies of Rijkswaterstaat. In addition to that, interviews with experts are conducted.

The final decision model provides an overview of the total costs of all the aspects and shows the optimum solution for when to renovate, replace or standardize a component. Furthermore, the final model shows the minimum number of navigation locks that needs to be standardized, in order to make it a more feasible solution than replacement and renovation.

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1. Introduction

1.1 Background

The Dutch waterway network has about 6,000 kilometers of rivers and canals, which makes it the most dense in Europe. Many canals serve as drainage as well as for navigation. The commercial part of these waterways has a total length of 2,200 kilometers and accounts for approximately 40% of the international freight movements and 20 % of the domestic freight transfers. This part of the network is state-owned and operated by Rijkswaterstaat. The smaller waterways are managed by different provincial or water authorities in the Netherlands (Rijkswaterstaat, 2018).

The main linkages in these networks are established and networks can therefore be considered more or less complete (OECD, 2007). Infrastructure planners in western countries are confronted with new challenges related to mature infrastructure network waterways. The infrastructure evolved gradually into highly advanced infrastructure networks that serve essential needs for societies. At the same time, western countries are in need to keep these networks competitive (G20, 2014).

Water authorities responsible for the planning and management of inland waterway infrastructure are faced with the issue of renewing their networks. In Western countries, major parts of the waterway network, such as navigation locks, bridges, and weirs, are ageing and need to be replaced to ensure waterway performance (Gil, 2009); (ACL, 2017); (IMF, 2014); (OECD, 2014).

In the 1930's many navigation locks were built in the Netherlands. Rijkswaterstaat manages 137 navigations locks. Rijkswaterstaat started a program called MultiWaterWerk (MWW). The program consists of the renovation or replacement of 52 navigation locks in the Netherlands in the next two decades. 37 of these navigation locks have reached their technical lifespan and 15 navigation locks do not meet the requirements anymore (Rijkswaterstaat, 2015).

The main reason for the start of this program is that the asset managers of the navigation locks came across multiple solutions for the same problem. Most of the navigation locks were considered as a unique project. This resulted in a diversity of systems. This diversity of systems/solutions had a negative effect on availability and management of the navigation locks (MultiWaterWerk, 2015). For the renovation and replacement of components, it is possible to use the current configurations or to use an overall standard.

The goal of MultiWaterWerk is to obtain a better reliability and availability, lower life cycle costs and a more predictable estimation of the construction cost and time (Rijkswaterstaat, 2015).

To reach this goal, a new possibility is added to the current possibilities; renovation and regular replacement. This new possibility is called standardization. Standardization is a form of replacement, however in case of standardization it will be replaced by a standard.

MultiWaterWerk is working on innovative solutions for lock components which are re-usable. An example of standardized components are; lock gates or the control system. To find the optimal solution, collaboration with the market is required (Rijkswaterstaat, 2015).

Currently it is hard to validate what the advantages of standardization is compared to the current possibilities, because a lot of data is still missing about the effects on the costs, the

performance and the sustainability. As a result of these missing data it is hard to decide whether to apply standardized components or go for the current possibilities.
Renovation and replacement are expenses which increase the lifespan of a component. These expenses are made besides the regular maintenance and are needed because the end of the lifespan is reached (Rijkswaterstaat, 2010).
The existing infrastructure can be renewed by means of renovation, regular replacement or standardization. To make a decision between these three possibilities three aspects are being considered: costs, performance and sustainability.
Furthermore, Rijkswaterstaat aims to work 100% circular in the year 2030 (Rijkswaterstaat, 2018), indicating that sustainability has high priority on the agenda at Rijkswaterstaat. Furthermore, research has shown that standardization of certain components leads to higher performance (Slijk, 2013).
Rijkswaterstaat is using several management strategies for the renovation and replacement process of the navigation locks. The current management strategy are based on three aspects; costs, performance and sustainability.

1.2 Problem definition / objective of the thesis

Currently, there is a very large variety in the design of navigation locks within the Netherlands. This variety complicates their management and maintenance leading to a sub-optimal availability, reliability and life cycle costs (Rijkswaterstaat, 2015).
Previous research showed that the standardization of lock gates has a great potential in optimizing the locks in terms of availability, reliability and life cycle costs (Slijk, 2013). However, it is still unknown how the added value of standardization can be proven. Currently decision makers base their decision, whether to renovate or replace a lock component, on a specific lock and do not take multiple locks into account. This is because they are unware of the possible positive effects of standardization. Furthermore, currently there is no strategy in deciding whether to renovate, replace or to apply a standard component.
The goal of this thesis is to develop a decision model which helps the asset manager to choose between the possibilities renovation, replacement or standardization of navigation lock components for the MultiWaterWerk program. Furthermore, the added value of standardization of a cluster with respect to replacement will be investigated. To achieve this goal, a model will be created. This model will help to determine what the most appropriate possibility will be in terms of cost.

1.3 Research question(s)

To reach the objectives of the thesis, the following main and sub-questions need to be answered.

Main research question:
How does a decision model looks like which can help the asset manager to choose between renovation, replacement or standardization of navigation lock components for the MultiWaterWerk program?

Now the sub-questions are highlighted and discussed.

Sub-question 1: Which aspects need to be taken into consideration for the development of the model?
By means of the literature study and interviews the aspects will be determined.
Sub-Question 2: How is currently decided to renovate, replace or standardize a component?
By means of a literature study and interviews the aspects will be determined.

Sub-Question 3: Which effects does standardization have on the performance, costs and sustainability in contrary to regular replacement in general?
By means of a literature study and a case study this question is validated. This question focusses on the outcome of the research, considering the implementation of certain components of the standardized navigation locks.

Sub-Question 4: Which effects does standardization have on the performance, costs and sustainability on the component lock gates?
By means of a case study this question is validated. This question focusses on the outcome of the research, considering the implementation of certain components of the standardized navigation locks.

1.4 Research design

This research will be carried out in 8 different steps. The first step, the literature study, consists of general information about navigation locks. The second step is to develop a conceptual model which determines which aspects are needed for the model. The third step discusses the three most commonly used management strategies. Here comes to light how current decisions are made about the renovation or replacement of a component. Step four are interviews with advisors and asset managers which provide information how they currently decide whether a navigation lock component gets renovated or replaced and their idea about standardization. Step five is the optimization of the conceptual model by implementing the received information, which results in the refined model. Step six is to test this model by means of a case study. The case study consists of the component mitre gates. This study results in a decision model which determines if a certain component needs to be renovated, replaced or standardized. Ultimately a conclusion with recommendations will be presented.

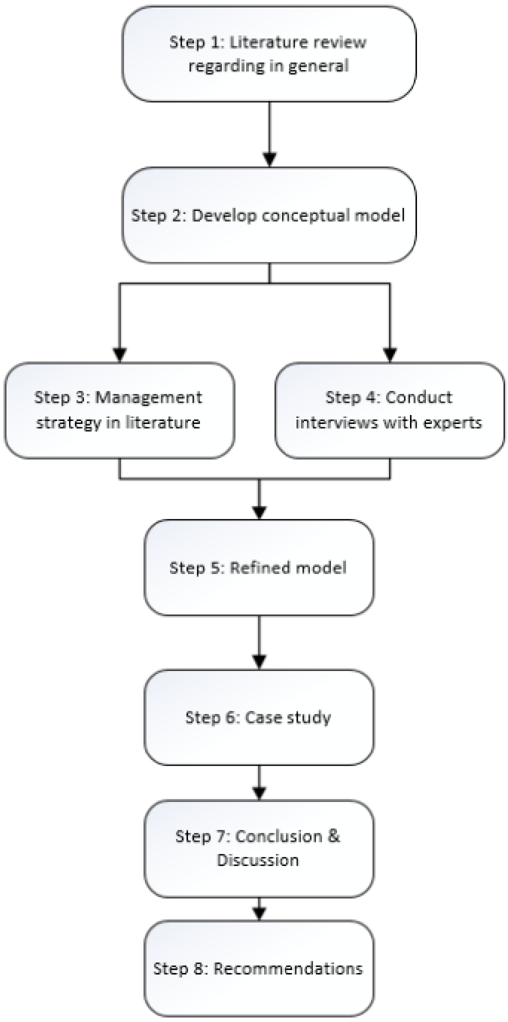


Figure 1: Steps research design.

Scope of the research

The goal of this thesis is to develop a decision model which helps the asset manager to choose between the possibilities renovation, replacement or standardization of navigation lock components for the MultiWaterWerk program. Furthermore, the added value of standardization of a cluster with respect to replacement will be investigated. To achieve this goal, a model will be created. This model will help to determine what the most appropriate possibility will be in terms of cost.

Previous research about standardization has shown that by standardization of steel mitre gates, the construction costs can be lowered (Levinson, 2018).

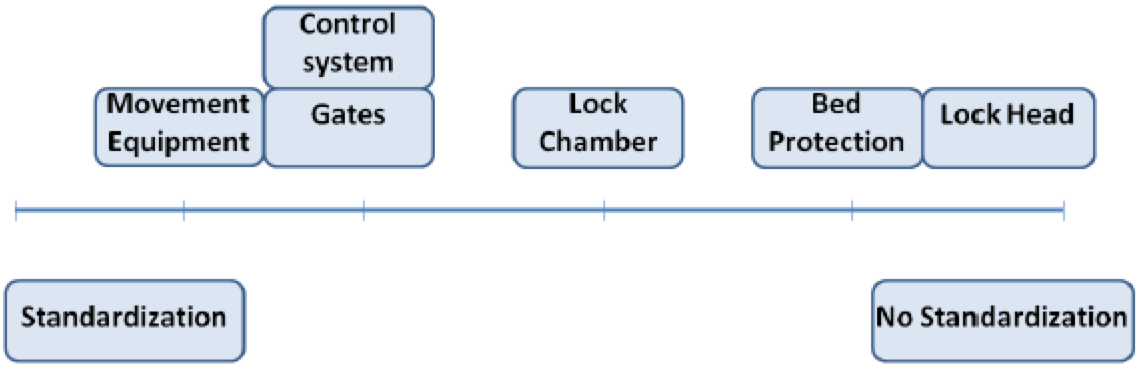


Figure 2: Standardization suitability (Slijk, 2013)

The case study of this research is specified to the gates of a navigation lock. Figure 2 shows the standardization suitability scale (Slijk, 2013). It shows that the gates of the navigation lock score rather high on the standardization suitability scale. This indicates that the gates of the navigation lock are suitable for standardization.

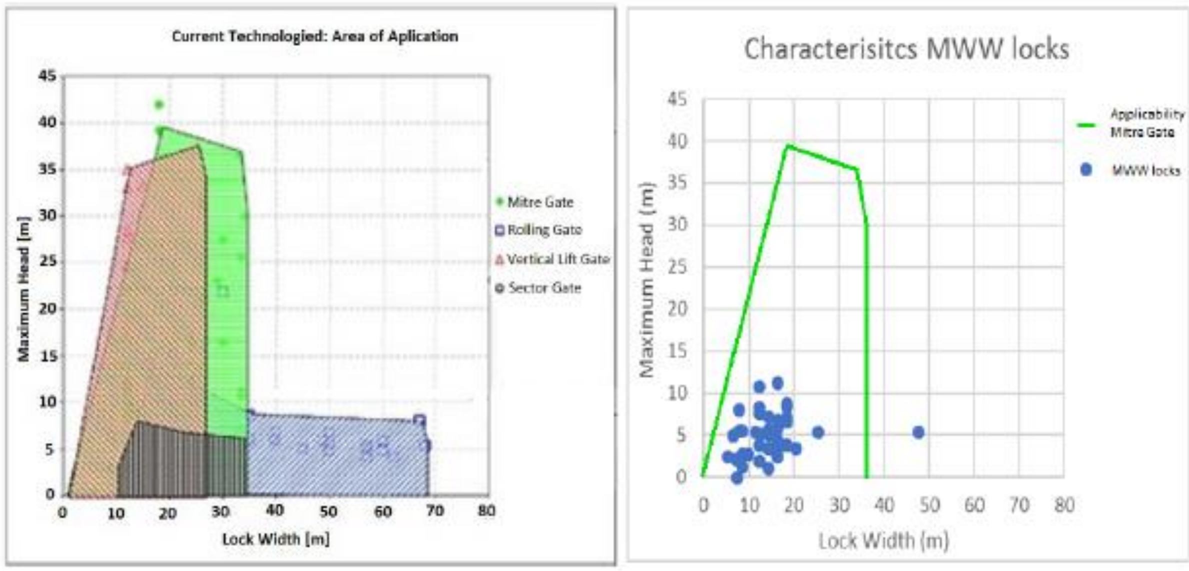


Figure 3: Left: Area of Application of Gate Types; Right: Positioning of MWW locks (Doeksen, 2012)

Four major lock types are in use: vertical lift, sector, rolling and mitre gates (Figure 3). Prior research about the best fit type of gate for the MultiWaterWerk program showed that almost all MultiWaterWerk locks are withing by the applicability domain of mitre gates (Doeksen, 2012). Accordingly, standardization is most applicable for the MultiWaterWerk program in case mitre gates are applied. Therefore, the case study will be specified on mitre gates.

1.5 The practical and scientific relevance

This research contributes to the scientific knowledge by comparing the different used decision making strategies and expressing all possibilities in costs. Furthermore, the approach how to implement standard components in the current decision making process will be known. The currently used management strategies will be discussed and evaluated. Thereafter, the best-fit management strategy for the MultiWaterWerk program will be verified by using a case study.

Ultimately, a decision model will be created which determine what the most appropriate possibility will be in terms of cost.

Furthermore, this research will reveal opportunities and limitations of using the created model in the civil engineer segment.

1.6 Reading guide

This research is structured in eight chapters and each chapter represents multiple subjects.

The first chapter will discuss the research problem and its context, the importance of the problem, goals and limitations of the research performed.

The second chapter describes the aspects which Rijkswaterstaat takes into account for the decision making between renovation or fully renewal of a certain component.

The third chapter elaborates how these aspects can be expressed and ultimately combined in a new proposed model to determine the renovation, replacement or standardization of a lock component.

The fourth chapter discusses the three most commonly used management strategies. It presents how current decisions are made about the renewal of a component.

The fifth chapter discusses the interviews which have been conducted with experts involved in the current decision making process. These interviews indicate how currently decisions are made regarding the renewal of navigation lock components and how the experts think about the new concept of standardization.

The sixth chapter discusses all the key aspects and the final decision model will be created.

The seventh chapter discusses a case study about steel mitre gates. This study will be used to validate the refined model. The last chapter a conclusion and discussion is drawn, and recommendations are lined up for possible future research.

2. Infrastructure in the Netherlands

The previous chapter showed that there is a need for a new model which can decide whether a lock component needs to be renovated, replaced or standardized. To make this decision it is initially important to understand how navigation locks work in general and why there is a need for this model. Therefore, this chapter first will provide background information about need for water-retaining structures, followed by the general definition of navigation locks, then navigation locks in the Netherlands, and finally aspects that are important with respect to the renewal of infrastructure. These aspects can be seen as the design determining aspects for the model. This chapter aims to discuss the most common design determining aspects and filter out the most significant ones in the context of the research. This chapter first reviews the general definition of navigation locks, then navigation locks in the Netherlands, and finally aspects that are important for Rijkswaterstaat in respect to navigation locks, in particular renovation, replacement and standardization.

2.1 Background

'Approximately half of the Netherlands lies below sea level and is protected against flood by primary dikes and other water-retaining structures' (Vrijling, 2001). There are three types of water-retaining structures and these are subdivided into dams, navigation locks and weirs.
A dam is an elevation of some type of material that separates two water surfaces. An example for a dam in the Netherlands is the Afsluitdijk. Navigation locks are a separation between two water levels, with gates. The main function of navigation locks is to bring ships from one water level to another. Weirs are water-technical constructions which regulate the water level in the river.
Although flooding is a typical high-consequence but low-probability event, it can be compared with other technological matters in society. Since the 80's the development and application of reliability theory makes it possible to assess flooding risks, by taking multiple failure mechanisms of a structure into account. Water authorities in Western countries are increasingly confronted with waterway renewal. Ageing waterway infrastructures put the reliability of the existing network under pressure (Willems, Anticipating water infrastructure renewal: A framing perspective on organizational learning in public agencies, 2018). Thus, there is a clear need of renewal, via renovation, replacement or standardization.

2.2 Navigation locks in general

Vrijburcht (2000) defines a navigation lock as follows: ''a navigation lock is constructed for the shipping industry. The functional requirements are primarily for the shipping industry; bringing ships from one water to another.'' Ships need to pass the navigation lock safely without endangering and damaging people, the environment, and considering the quality of life in the immediate vicinity (Vrijburcht, 2000).

Figure 4 represents an example of a ship that is passing a navigation lock. This is a navigation lock which has 2 sets of mitre gates. 1 set consists of 2 gates. The gates are pointing in the direction where the water-level is the highest.

When the water-level is equal on the side of the ship and the desired exiting direction, the gates will be opened and the ship can pass.

Some navigation locks are part of a flood defense system. Particularly in the Netherlands some navigation locks are situated in dykes, which form a barrier for the lower parts of the country and protects these parts against flooding. Moreover, some navigation locks are situated in a channel and control the water levels between the two sides.

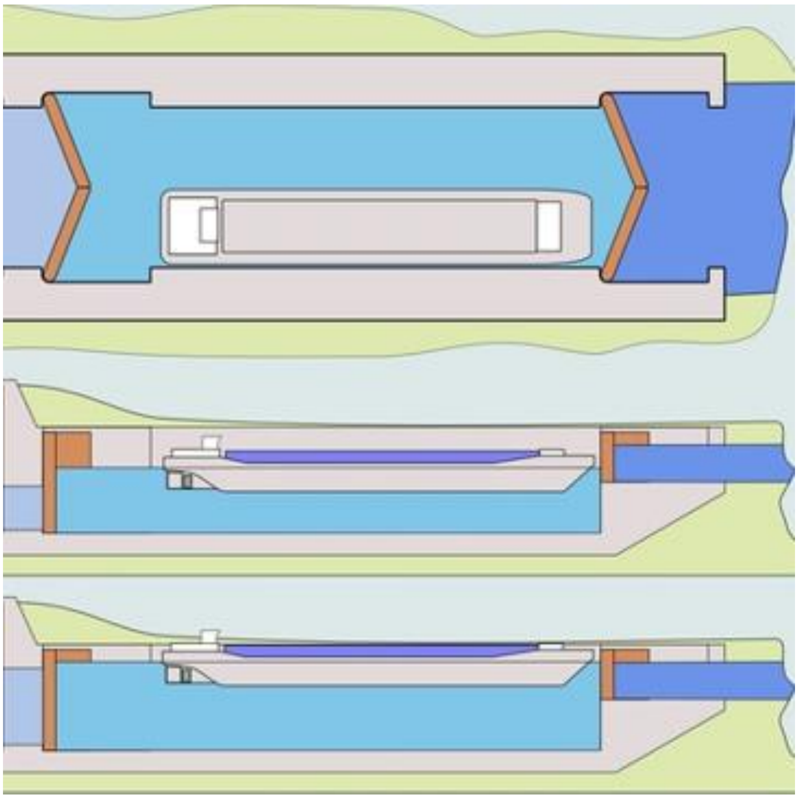


Figure 4: Navigation lock (Klein, 2013)

Another aspect of navigation locks relates to their role in water management. A distinction can be made between a passive role, limiting water losses and salt penetration as a result of the protective process, and an active role, in which a certain flow of water must be allowed to enter or to leave (Vrijburcht, 2000).

This indicates that navigation locks not only have the function to let ships pass, they also have the function to retain water from one side to another.

2.3 Navigation locks in The Netherlands

The current Dutch national inland waterway system consists of approximately 2,200 kilometers of canals and rivers (RWS, Beheer- en Ontwikkelplan voor de Rijkswaterem 2010-2015, 2009). Three main waterways can be considered within the Netherlands: the connection between the harbor of Amsterdam and Germany, the connection between the harbor of Rotterdam and Germany and the North-South connection (Filarski, 2014). The natural conditions determined the location and state of the waterways to a large extent. Originally, waterways were constructed and maintained by regional authorities. At the end of the 18th century, and concurrently with the Netherlands becoming a unitary state, the national water authority Rijkswaterstaat was founded, which became a powerful actor in Dutch water management. From the late 1800s until now, many hydraulic works have been built to increase the capacity. Figure 5 provides an overview of the total amount of navigation locks built (1890-2008) (Willems, 2015).

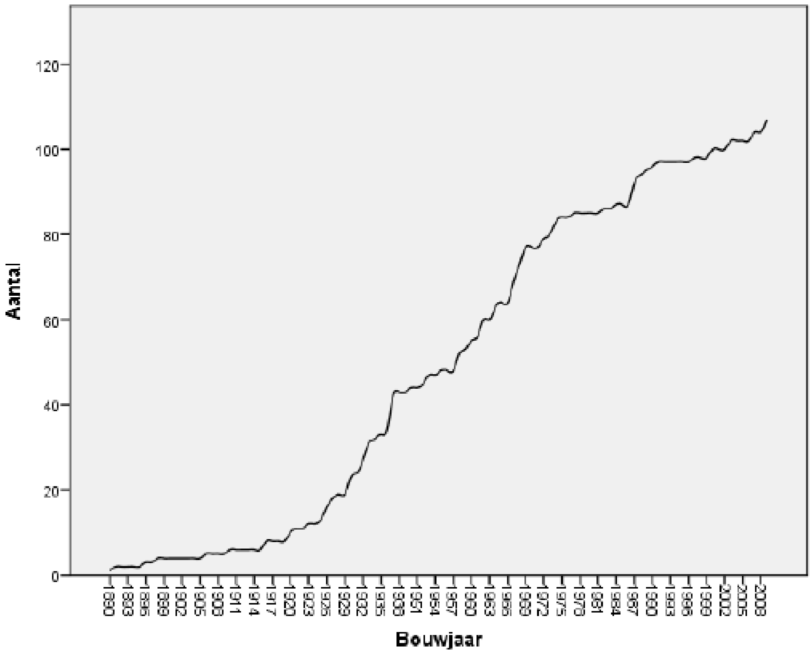


Figure 5: Total amount of navigation locks built since 1890 (DISK, 2014)

As figure 5 shows; in the 1930's there was a rapid increase in the total amount of navigation locks. The expected technical life-span of a navigation lock is about 100 years. This indicates that many of the navigation locks need to be renovated or replaced in the upcoming years. Appendix I shows a table which provides information about all the locks in the MWW program. Among this information the estimated end of the technical life span of the locks is given.

2.4 Relevant Aspects

This paragraph discusses the relevant aspects which the government considers as important aspects for the infrastructure in the Netherlands. This is needed for the construction of the model.

Recently, the Dutch minister of Infrastructure Cora van Nieuwenhuizen wrote a letter to the House of Representatives which stated that the current infrastructure in the Netherlands needs to be renewed, so that safety can be guaranteed and the infrastructure and becomes more sustainable. Moreover, currently the budget of Rijkswaterstaat is 150 million euro a year until the year 2020. However, from the 2020 and forwards it will be 350 million euro a year (Nieuwenhuizen, 2018). Rijkswaterstaat is an governmental organization in the Netherlands which controls 137 navigation locks in the Netherlands and can therefore be considered as an expert in management of navigation locks.

This massive increase of available money indicates the real necessity to rejuvenate and renew of the existing infrastructure. Furthermore, due to the increase of traffic, also on the water, new techniques need to be applied to prevent future failures (Nieuwenhuizen, 2018).

This letter discusses that there will be more budget available to accomplish for rejuvenating, renewing and making the existing infrastructure more sustainable. Rijkswaterstaat has the aim to work 100% circular in the year 2030 and is therefore an important aspect. The investments in the existing infrastructure is needed to guarantee the performance. Failure and malfunction of the infrastructure could leads to social nuisance and economic damage.
The literature above indicates that three aspects are considered during the decision making for the renewal of the existing infrastructure. These three aspects are costs, performance and sustainability.
The higher the investment costs, the higher the performance the more sustainable a component can be. Thus, the amount of money invested in a component will reflect on the performance and the sustainability of the component.

Now that the considered aspects of renewal of the infrastructure are defined, these aspects can be implemented in the decision making process for the renewal of navigation locks, since navigation locks are a part of the defined infrastructure.

2.5 Clarification of found aspects

For the decision making process a conceptual model needs to be created where these three aspects are considered. The conceptual model, which will be shown in the next chapter, will show what the costs are for each possibility with respect to each aspect. These three aspects can be divided into different forms by means of the life cycle phases of a navigation lock. By dividing these aspects into different forms, an overview can be created which shows the output of the different aspects in more detail. This output can be used in the conceptual model to decide which possibility is the most beneficial.

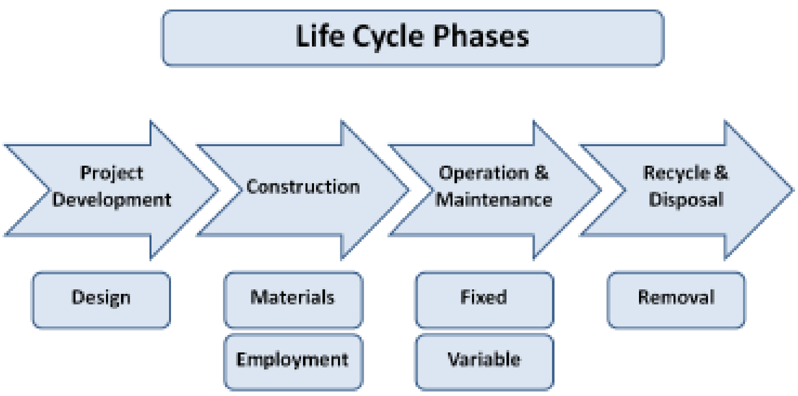


Figure 6: Life cycle phases of a project (Slijk, 2013).

Figure 6 shows that the life cycle of a product can be divided into four different phases. The first phase will be the product development phase, the second will be the construction phase, the third will be the operation & maintenance phase, and the last phase will be the recycle & disposal phase. All these phases will be explained in relation to the found aspects.

2.5.1 Costs

All the costs are related to the different phases of the life cycle of the construction, see figure 6. These phases can be related to product development costs, construction costs, operating and maintenance costs, recycling costs of the construction and the economic costs.
The production development costs are the costs which are related to the design of the component. The construction costs are the costs related to the realization of the component, like the used materials and engineering hours. The operating and maintenance costs are related to the fixed and variable costs which helps to let the component function. The recycling & disposal costs of the construction are costs related to removal and the recycling costs of the component.
To go further into detail about the recycling & disposal costs. Recycling first needs to be expressed in terms of the non-recycling percentage of the component. This is the part that creates costs, assuming that the recyclable part can be fully re-used and therefore creates zero costs. If the non-recycle percentage is known for the component, this percentage can be multiplied with the total tons in weight, to calculate the tons which are non-recyclable. Whenever the total non-recyclable tons are known, disposal costs can be calculated, by means of Appendix III. Appendix III shows the price per ton for each material. This will be mentioned as factor in Appendix III in the formula.

The results in the following formula: (1)
*Non-recycling percentage * tons in weight of non-recyclable part = tons non-recyclable.*

*Tons non-recyclable * factor in Appendix lll = recycle costs.*

2.5.2 Performance

The performance is related to all phases of the life cycle. For example, at the product development phase, the designer has to think about how the lock can be maintained during the lifespan, this relates to the operation & maintenance phase. The performance requirements are related to the stakeholders. The stakeholders of the navigation lock could be the asset manager, contractor or the shipping industry.
Performance can be translated into the reliability (R) and availability (A) of the navigation lock. The reliability and the availability can be determined by means of a fault tree analysis. Both reliability as availability are expressed in percentage. The fault tree analysis makes it possible to graphically model all potential failure mechanisms of the navigation lock per function. The fault tree analysis will be discussed in more detail in section 4.1.
Navigation locks must be very reliable, as part of the flood defense and a passage for vessels (Vrijburcht, 2000). Furthermore, the main function of navigation locks is to bring ships from one water to another (Vrijburcht, 2000). In case a ship wants to pass the navigation lock but the gate (for example) is not working, the whole navigation lock becomes unavailable. For this reason, the availability of certain components of the lock is important.
The navigation lock needs to perform as it is designed. Whenever the performance requirements are not met, this can lead to high economic costs. Whenever a navigation lock functions less frequently than it should, this will affect the shipping industry. The shipping industry experiences hinderance and can therefore loses valuable time.

2.5.3 Sustainability

Sustainability has to be considered during all phases. For instance, the percentage of the recycled component of the navigation lock can be high or low and this has to be taken into account during the product development phase.

Rijkswaterstaat wants to be 100% circular in the year 2030 (Rijkswaterstaat, 2018). This means that recycling is a high priority for Rijkswaterstaat. The circular economy revolves around the smart use of raw materials, products and goods, so that they can be reused infinitely: a closed cycle. For buildings, for example, 'circular' means that materials are reused, but also that the building can be used flexibly (MVO, 2018).

Navigation locks are primarily made of concrete (Vrijburcht, 2000). This means that all navigation locks built after 2030 need to be made out of recycled concrete. Furthermore, the remains of the navigation locks that are built before 2030 need to be recycled. Research has shown that the remaining lifespan (of wood, concrete as steel) exerts minimal influence on the recycling percentage of the component (CE, 2016). All of these materials can be related to an emission factor (kg CO2eq per unit).

2.6 Clarification possibilities

Now that the life cycle phases and their relation with the aspects are describes, the first step of the conceptual model can be created. However, first the definitions of the possibilities will be defined. Thereafter, the possible positive effects of standardization will be compared to renovation and regular replacement.

2.6.1 Renovation

Renovation is defined in the dictionary as: ‘to restore to good condition; make new or as if new again; repair’ (Dictionary.com, 2019). In this case the old component gets restored in such a state that it satisfies the current standards. Life time extended maintenance is a part of renovation because life time extended maintenance is a form of reparation.

2.6.2 Replacement

Replacement is defined in the dictionary as: ‘to provide a substitute or equivalent in the place of’ (Dictionary.com, 2019). In this case the old component gets replaced by a similar new product.

2.6.3 Standardization

The Ministry of Infrastructure encourages the use of smart innovations (Nieuwenhuizen, 2018). A smart innovation solution could be the implementation of standardization of certain components of the navigation lock. To decide whether standardization is a good option multiple aspects needs to be evaluated. This section describes what standardization is and uses the aspects found earlier in this research to assess standardization.

Standardization is defined in the dictionary as: ‘to bring to or make an established standard size, weight, quality, strength, or the like: to standardize manufactured parts. (Dictionary.com, 2018)

Previous research has shown that multiple components of a navigation lock are suitable for standardization, see figure 2. Previous research has found that standardization of navigation locks leads to many effects, see table 1 (Slijk, 2013). Four phases are described: Product development, construction, Operation & maintenance, and Recycling & Disposal.

	First order effect	Second order effect	Higher order effect
Product Development	- Higher costs for the development - Fewer parts for the manufacturing - Collaboration between Private and Public parties - Less market competition - Higher predictability of costs	- Lower costs for the development - Different or new player in the market - Less flexibility in design	- Change of contracts - Use of recycling material from earlier build locks
Construction	- Less market competition - More routine - Over dimensioning - Reduce of failure	- Reduction in costs due to the learning curve	- Combining the different elements on site - Use of recycling material from earlier build locks
Operation & Maintenance	- Higher predictability - Higher availability - Fewer spare parts - Exchange with other river locks	- Interrelations between river locks - Maintenance program is designed on Corridor level - Overall asset management	- One control system for the HVWN - Interrelated maintenance program
Recycling & Disposal			- Exchange with other river locks - Predictable rest value

Table 3: The effects of standardization based on different Life cycle phases (Slijk, 2013)

All the described life cycle phases in table 3 effects can be reflected to the aspects: costs, performance and sustainability of the navigation lock. The relation of these aspects with standardization are described in the next section.

The first order effect described in table 3 shows what the direct effects of the standardization process is and the intended use of the standard. For example: higher predictability of costs and availability.

The second order effect are is due the changes in human behavior as a result of the introduction of a new standard. These effects comes over time due to earlier made decisions and constructions. For example: reduction in costs due to the learning curve.

The higher order effects are about the standardization of river lock elements are thought from different perspectives. To take an example: standardized element can be recycled (Slijk, 2013).

2.7 Conclusion

The goal of this chapter was to identify the most common design determining aspects for the model. By defining which aspects the Ministry of Infrastructure is focusing on, the aspects of the model can be determined. The conceptual model will be based on three aspects; costs, performance and sustainability. To divided the three aspects into smaller forms, the life cycle is used. The life cycle divided the aspects in four different phases, which provides the opportunity to create more detailed overview. Furthermore, to compare the possibilities it is useful to translate all the aspects into costs. By doing this the conceptual model can be created. Furthermore, prior research showed that standardization can lead to the intended effect but also to lead to second order and higher order effects.

3. Provisional Model

The previous chapter identified the aspects which Rijkswaterstaat takes into account for the decision making between renovation or fully renewal of a certain component. Furthermore, it shows that the aspects can be related to the phases of the life cycle. By translating the everything into costs it will provide a clear overview between the three possibilities. The goal is to create a new proposed model to determine the renovation, replacement or standardization costs of a lock component. This chapter elaborates how these aspects can be expressed in a table and thereafter be translated into costs. The first section will describe the aspects and how these aspects are translated to costs. The second section will describe the conceptual model. At the end a conclusion will be drawn.

3.1 Aspects of the model

The literature indicates that costs, performance and sustainability are the most relevant aspects for the infrastructure and form the foundation of the decision making process to renovate, replace or standardize a certain component of a navigation lock.

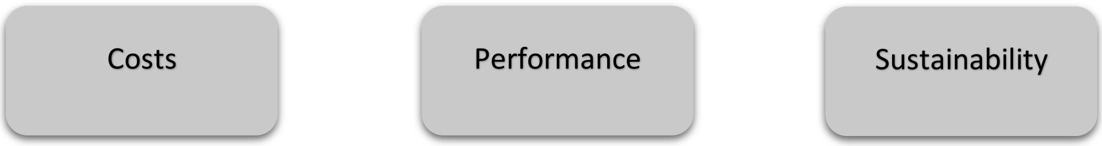


Figure 7: Relevant aspects

Figure 7 represents the aspects on which can be decided what needs to be taken into account for deciding among renovation, replacement or standardization of a certain component. Each of these aspects are explained further in the sections; 3.1.1, 3.1.2, and 3.1.3.

3.1.1 Costs

Chapter 2 described the life cycle phases and how these are related to the costs. The production development, construction, and operating and maintenance costs are known by the asset manager and can directly can be implemented. However, recycling costs can not directly be translated into costs, therefore following formula (1) is created.

This can be translated into the following table:

	Renovation	Replacement	Standardization
Production development costs	€A_1	€B_1	€C_1
Construction costs	€A_2	€B_2	€C_2
Operating and maintenance costs	€A_3	€B_3	€C_3
Recycling costs	€A_4	€B_4	€C_4
Total costs	€$A_{1,2,3,4}$	€$B_{1,2,3,4}$	€$C_{1,2,3,4}$

Table 4: Costs aspect

Table 4 shows what the costs are for the aspect costs. After implementing the costs for each life cycle phase at each possibility, the total costs for each possibility is known. The output of the total costs for each possibility will later be used in the conceptual model to decide whether to renovate, replace or to standardize a certain component of a navigation lock.

3.1.2 Performance

The performance for each possibility needs to be known in order to calculate the non-performance. Performance is divided into the terms reliability and availability, which are expressed in percentages.

The reliability and availability for each component will be translated into the following table:

	Renovation	Replacement	Standardization
Reliability	$\%D_1$	$\%E_1$	$\%F_1$
Availability	$\%D_2$	$\%E_2$	$\%F_2$
Non-performance (non-reliability)	$\%D_3$	$\%E_3$	$\%F_3$
Non-performance (non-availability)	$\%D_4$	$\%E_4$	$\%F_4$
Total	$\%D_1+\%D_3$ & $\%D_2+\%D_4$	$\%E_1+\%E_3$ & $\%E_2+\%E_4$	$\%F_1+\%F_3$ & $\%F_2+\%F_4$

Table 5: Performance aspect

Table 5 shows the performance aspect in its different forms and how it relates to the possibilities. To compare the three possibilities, performance ultimately needs to be expressed in costs. By doing this, an overview will be provided which shows all differences between the possibilities.

Because reliability and availability are expressed in percentages, these cannot directly be compared to costs and therefore needs to be translated to costs. To do this, the document NIS (Netwerk Informatie Systeem) of Rijkswaterstaat can be used. Rijkswaterstaat is saving information about the main road network, main waterway network and main water systems in NIS. NIS provides information about each of these network in terms of quantity, quality and the performance & usage of the network (Rijkswaterstaat, 2019).

If certain costs can be charged per main waterway network for the non-performance of the lock, the performance requirements can be translated into costs. This will be done by converting the non-availability and non-reliability percentages to hours and then multiplying them by the hourly rate that is calculated if a lock does not function.

To go into further detail: one year has 8.760 hours. In case the lock works perfectly the non-performance of the lock is 0%. However, for each hour that the lock is not performing this results in 1/8760 = 0,0114%. The other way around, 1% is 87,60 hours.

The penalty costs that will be charged for each lost hour are depended on (Kruijf, 2018):

- the quantity of ships passing the lock;
- the damage done in the logistics.

This leads to the following formula (2):

costs for non-performance = lost hours x penalty costs.

This can be translated into the following table:

	Renovation	Replacement	Standardization
Reliability	€D_1	€E_1	€F_1
Availability	€D_2	€E_2	€F_2
Non-performance (non-reliability)	€D_3	€E_3	€F_3
Non-performance (non-availability)	€D_4	€E_4	€F_4
Total	€D_1+€D_3 & €D_2+€D_4	€E_1+€E_3 & €E_2+€E_4	€F_1+€F_3 & €F_2+€F_4

Table 6: Performance aspect translated into costs

Table 6 shows the performance aspect, translated to costs, in its different forms and how it relates to the possibilities. After implementing the reliability, availability and non-performance costs, the total costs for each possibility is known. The output of the total costs for each possibility will later be used in the conceptual model to decide whether to renovate, replace or to standardize a certain component of a navigation lock.

Furthermore, when standardization is used as a means to improve the performance, in terms of reliability and predictability, it can be assumed that the positive effects of development and implementation of a standard can be advantageous for the economy. Moreover, standardization is advantageous for the ease of the asset management by the operation and maintenance (Slijk, 2013).

3.1.3 Sustainability

The sustainability of each possibility needs to be calculated before making a decision about the renovation, replacement or standardization of a certain component. To this end, sustainability is divided into the terms CO_2 emissions and recycle percentage.
As explained in chapter 2, Rijkswaterstaat wants to be 100% circular in the year 2030 (Rijkswaterstaat, 2018). This includes that all navigation lock built after 2030 need to be made of recycled material. Moreover, a research has shown that the remaining lifespan of wood, concrete and steel exerts minimal influence on the recycling percentage of the component (CE, 2016).
Navigation lock components are generally made out of wood, concrete and steel. All of these materials can be related to an emission factor (kg CO_2eq per unit). The total amount of used materials (in kg) needs to be calculated and translated into kg CO_2 per possibility. Appendix II provides an overview of the different kinds of materials and their emission factors.

This results in the following formula (3):

*Material * emission factor (kg CO_2eq per unit) = kg CO_2 emission.*

*kg CO_2 emission * 1.000 = CO_2 emission (ton)*

This can be translated into the following table:

	Renovation	Replacement	Standardization
CO2 emission EQ (tons)	(tons)G_1	(tons)H_1	(tons)I_1
Non-Recycle percentage	%G_2	%H_2	%I_2
	$G_{1,2}$	$H_{1,2}$	$I_{1,2}$

Table 7: Sustainability aspect

Table 7 shows the sustainability aspect in its different forms and how it relates to the possibilities. To compare the three possibilities, sustainability ultimately needs to be expressed in costs. By doing this, an overview will be provided which shows differences among the possibilities.
The CO_2 emissions are expressed in terms of kg CO_2 this cannot directly be compared to costs and therefore needs to be translated to costs. To do this, the calculated kg CO_2 per possibility needs to be multiplied by CO_2-price in euro's. The price in euro's per ton CO_2 which are used in The Netherlands are registered at the Dutch Central Bureau of Statistics. Currently, the price is 7.3 euro per ton CO_2 (CBS, 2019).

This results in the following formula (4):

*CO_2 emission (Tons) * price per ton = CO_2 emission price.*

The non-recycling process is expressed as a percentage, this cannot directly be compared to costs and therefore needs to be translated to costs. If the non-recycle percentage is known for the component, this percentage can be multiplied with the total tons in weight, to calculate the tons which are non-recyclable. Whenever the total non-recyclable tons is known. The dump costs per ton for each material can be found at appendix III. Thus formula (1) needs to be used.

All these prices together results in the can translated into the following table:

	Renovation	Replacement	Standardization
CO2 emission EQ (€)	€G_1	€H_1	€I_1
Recycle costs (€)	€G_2	€H_2	€I_2
Total costs (€)	€$G_{1,2}$	€$H_{1,2}$	€$I_{1,2}$

Table 8: Sustainability aspect translated to costs

Table 8 shows the sustainability aspect, translated in costs, in its different forms and how it relates to the possibilities. After implementing the CO_2 emission costs and recycle costs for each possibility, the total costs for each possibility is known. The output of the total costs for each possibility will later be used in the conceptual model to decide whether to renovate, replace or to standardize a certain component of a navigation lock.

3.2 Conceptual model

The conceptual model makes use of a multi-criteria analysis which provides the opportunity to make an decision between the three possibilities.
Multi−criteria analysis (MCA) is a model that supports comparison of e.g. different policy options on the basis of a set of criteria. They are very effectively in supporting the assessment of and decision making on complex sustainability issues because they can integrate a diversity of criteria in a multidimensional guise and they can be adapted to a large variety of contexts. The procedures and results obtained from MCA can be improved with the interaction of stakeholders (Herwijnen, 2005).

In order to calculated what the most beneficial possibility is, a new proposed model has been made:

Possibilities / Aspects	**Weight**	**Renovation**	**Replacement**	**Standardization**
Costs (€)	x	$A_{1,2,3,4}$	$B_{1,2,3,4}$	$C_{1,2,3,4}$
Performance (€)	y	$D_{1,2,3}$	$E_{1,2,3}$	$F_{1,2,3}$
Sustainability (€)	z	$G_{1,2}$	$H_{1,2}$	$I_{1,2}$
Total (€)		xA+yD+zG	xB+yE+zH	xC+yF+zI

Table 9: Proposed model

Table 9 shows the proposed model. To provide a clear overview all aspects are expressed in costs in the proposed model. Furthermore, the decision maker has the option to put weight to certain aspects. The weights are positive numbers. In this way it gives the decision maker the opportunity to focus on a specific aspect. It is assumed that the weights are evenly distributed over the three aspects. This includes that each aspect has the same influence on the results as the other aspects.
The multi-criteria analysis makes it possible to take all three aspects into consideration and thereby allows identification of the best possibility. However, it makes it also possible to put weights on certain aspects and hereby focus on those. The decision maker could decide to put a higher number for performance compared to the other aspect for example. A reason for this could be that the navigation lock is part of an important transport route and the non-performance will result in a high economic damage. This will result in the optimal possibility.

3.3 Conclusion & Discussion

The goal of this chapter was to create a new proposed model to determine the renovation, replacement or standardization costs of a lock component. By expressing all the different aspects in the costs, e.g. euros, a clear overview will be provided which shows what the cheapest solution is. In addition to that, the MCA provides the opportunity to add weights to the aspects which can have an influence on the outcome, this will identify the optimum solution.
This proposed model can be used to decide what the most beneficial option is for an individual lock component. However, as stated in chapter 2.6.3, the advantages of standardization will be best reflected whenever it is applied at multiple locations. To develop a model which shows what these advantages are and how these can be applied in the model, first further research need to be done about how currently the decisions are made for the renewal of

navigation lock components. Therefore, the three most commonly used management strategies by Rijkswaterstaat are discussed and multiple experts are interviewed about their decision making process.

4. Management strategies of Rijkswaterstaat

The previous chapter brought clarity about how the most beneficial option for an individual lock component can be decided. This chapter discusses the three most commonly used management strategies. It presents how current decisions are made about the renewal of a component. The goal is to get a better understanding of the current decision making process, in order to create a new model which takes the essentials of the current decision making into account. The first section discusses RAMS (Reliability, Availability, Maintainability, Safety), the second section will discuss ProBO (Risk-Based Management and maintenance), the third section discusses OBR (Object Beheer Regime). After that a discussion and a conclusion will be drawn.

To give an overview of the three management strategies, the strategies are constructed into four sub-sections:

1. What is the strategy?
2. When to apply the strategy?
3. What are the aspects of the strategy?
4. How are the decisions made in the strategy?

4.1 RAMS

The guideline of RAMS is set up with the goal to apply RAMS for the infrastructure. The guideline RAMS can be used in the whole life cycle for the entire infrastructure system.

4.1.1. What is RAMS

Based on four attributes RAMS describes the primary performance of the system. This performance level is determined in terms of Reliability (R), Availability (A), Maintainability (M), and Safety (S). The goal of RAMS is to map the process in these terms. How the process is mapped is explained in section 4.1.3.

4.1.2 When to apply RAMS

To maintain an optimum performance during the life time of a component, the RAMS method can used in the construction, the management and maintenance phases. Figure 8 shows the correlation between the RAMS aspects.

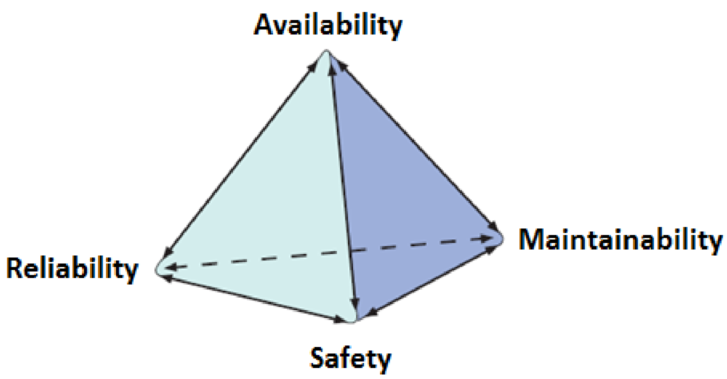


Figure 8: correlation between RAMS aspects (Bakker. et al., 2010)

4.1.3 What are the aspects of RAMS

The RAMS aspects (Reliability, Availability, Maintainability, Safety) are inter-correlated with each other. This means that; the availability has an influence on the safety, the maintainability has an influence on the reliability and so on.

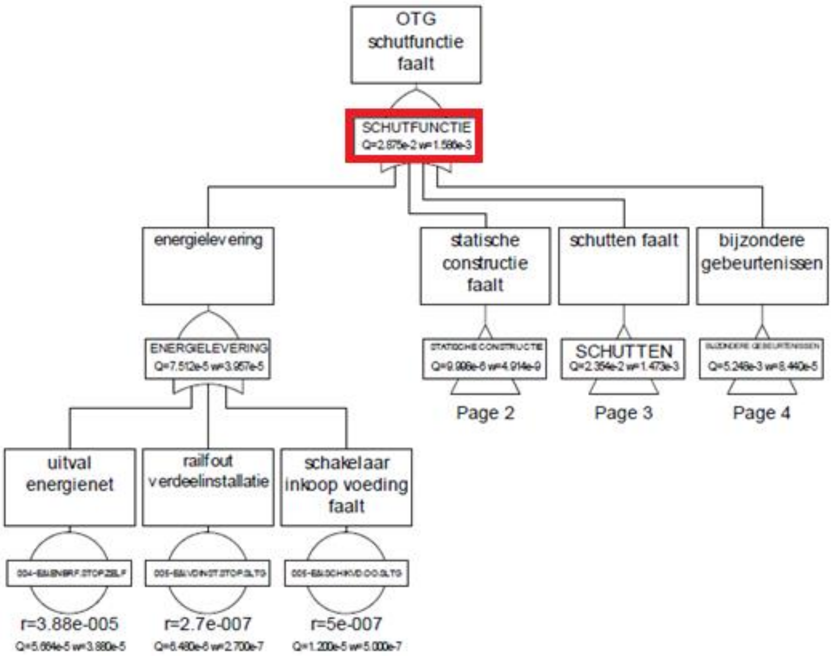


Figure 9: Fault tree (Schepers, 2013)

The first two aspects of RAMS; Reliability (R) and Availability (A) are determined by means of a fault tree analysis. Figure 9 shows an example fault tree analysis of a navigation lock. This fault tree analysis makes it possible to graphically model all potential failure mechanisms, in terms of reliability and availability of the navigation lock, per function.
The availability, represented in hours per year, of a function depends on the number and the duration of the failures. The failure frequency is important to the reliability.

A fault tree shows all the components which have an influence on the functioning of the lock. The non-reliability (W) and the non-availability (Q), circled in red, are linked to each component to determine the current performance. The Mean Time To Repair (MTTR) of the component is an important factor in determining the performance. The MTTR shows what the repair time of a certain component is. So, whenever a component is faster repaired, the availability of this component will be higher compared to a low repair time. All the non-availability and non-reliability can be derived of the following sources:

- Results of constructive analyses;
- Results of inspections;
- Component specific error data;
- RAM-data;
- Expert judgements.

The third aspects of RAMS: Maintainability (M) is determined by to what extent the system is maintainable. This includes that the system can be maintained within the desired time and available budget. Whenever this time increases, the availability decreases. For this reason, the functioning of the system / component is therefore dependent on the reliability as well as the maintainability. Maintainability can be divided into corrective and preventive maintainability.
The realization of maintainability depends on several factors, namely the availability of the required knowledge and skills, available budget, the spare materials, available data and documentation, and availability of the component to carry out the maintenance (Rijkswaterstaat, 2013).
The fourth aspect of RAMS is Safety (S). Safety (S) is defined as: 'being free of unacceptable risks in terms of injury to people.' These people can be users, servers or maintenance personnel. (Bakker. et al., 2010).

4.1.4. How are the decisions made

The consideration between renovation or replacement is a choice that is made by asset managers and policymakers. Their decision is based on the performance, costs and sustainability. However, the decision is primarily based on the performance of the component.

4.2 ProBO

Risk-based management and maintenance (ProBO: Probablistisch beheer- en onderhoud) is a guideline set up by Rijkswaterstaat. ProBO is a risk-based management and maintenance method to organize the entire management and maintenance process, for Rijkswaterstaat owned infrastructure in a practical way (Rijkswaterstaat, 2011). An important aspect of the ProBO working method is that the performance requirements are demonstrated in terms of reliability and availability for the navigation locks.

4.2.1. What is ProBO

Risk-based Management and Maintenance (ProBO) is an element of asset management and focuses in particular on giving insight of the level of performance of the component and the risks that can affect the performance level.
Key concepts within risk-based management and maintenance are:

- Management and maintenance are based on the risks that affect the performance level of a component;
- Continuous managing of the performance level by applying the PDCA-cycle (Plan, Do, Check, Act).
- Focused on technology, organization, and contracts.

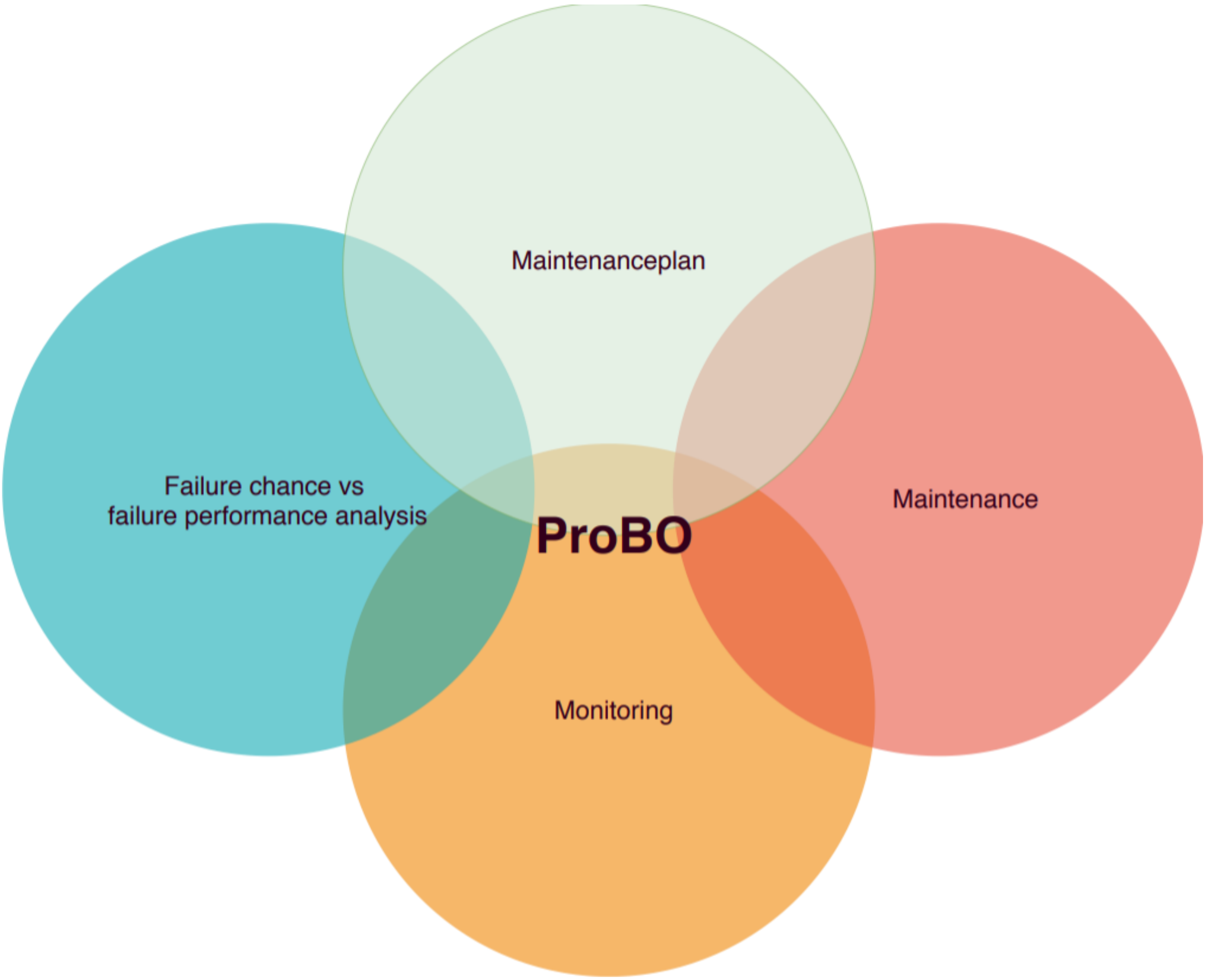


Figure 10: Risk-based management and maintenance (Rijkswaterstaat, 2011)

Figure 10 represents the risk-based management and maintenance cycle. After the realization phase, the component must be managed for the useful life to be maintained throughout the life of the service component. Within Rijkswaterstaat performance management in the management and maintenance phase is characterized as risk-based management and maintenance.

Whenever the asset manager fully implements the ProBO method this will result in the following (Van Maaren, Handreiking prestatiegestuurde risicoanalyses, 2018):
- Staying in control over the component; which means no surprises about maintenance and safety risks;
- Obey to the laws and the regulations;
- Achieve economic benefits concerning market integration by clustering management and maintenance work, exchangeability of Rijkswaterstaat staff on critical organizational positions, and more available data through more efficient and effective policy;
- To have one uniform communication model with the contractor or the user to make their performance transparent for (distance-) management;
- Optimization of the costs and the profits of maintenance;
- Unambiguously record all tasks, roles and responsibilities.

4.2.2. When to apply ProBO

ProBO will be applied after the realization of the component. After the realization phase, the component needs to be management and maintained for the whole technical lifespan. Within Rijkswaterstaat performance management in the management and maintenance phase is characterized as risk-based management and maintenance.

The goal is to obtain 100% transparency between the disciplines: traffic- and water management, project management, environmental management, maintenance management and information management. By accomplishing this goal, the most efficient strategy can be applied in terms of costs, performance and sustainability. However, in practice this is hard to accomplish because the theory is not always the same as reality. Each different project has a different contract and therefore their own lifecycle analysis and risks (Lamain, 2011).

Asset management links the operational management and maintenance to the tactical and strategic objectives of the organization. Operational and tactical analyses are conducted each year, where a 10-years vision is created. These analyses involve determining which measures and at what costs performance requirements for the respective area part can be achieved. These analyses use performance optimization models such as reliability-centered maintenance and result in tactical maintenance planning in water management (Lamain, 2011).

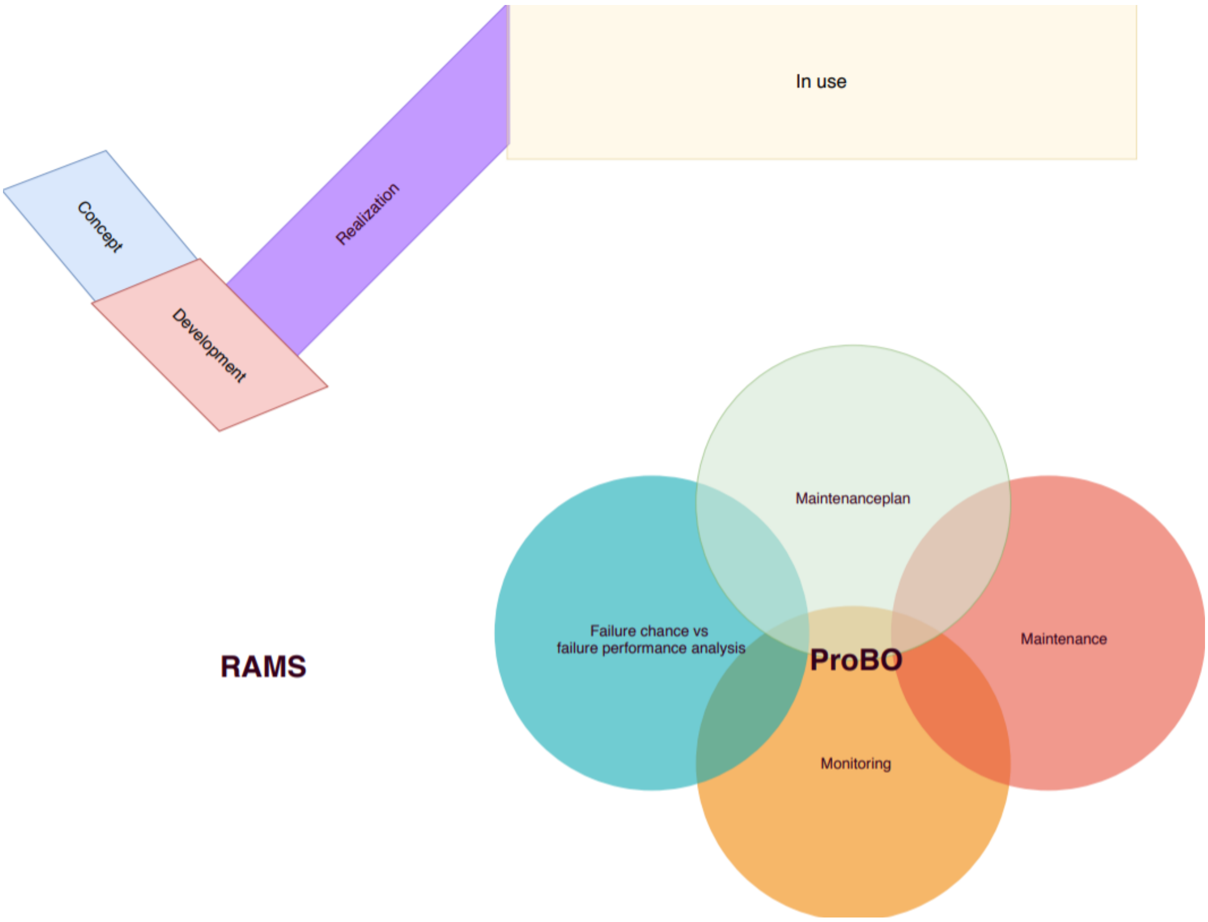


Figure 11:Relationship RAMS and ProBO (Rijkswaterstaat, 2011)

Figure 11 shows schematically the relationship between a System Engineering and RAMS with ProBO (risk-based management and maintenance). The left side shows the construction phase, where System Engineering and RAMS guidelines in consultation with asset manager are leading. A good analysis of the performance needs and an appropriate translation to the performance requirements are of major importance. Based on the set requirements the design phase can start and at set times the design must be verified against the set performance requirements (Van Maaren, Handreiking prestatiegestuurde risicoanalyses, 2018).

4.2.3. What are the aspects of ProBO

As said earlier; ProBO focusses on giving insight of the level of performance of the component and the risks that can affect the performance level. ProBO considers the aspects: performance, risks and costs (Van Maaren, Handreiking prestatiegestuurde risicoanalyses, 2018). Whenever the risks and the maintenance-costs are clear, the optimum between the level of performance of the component and the costs to maintain the level of performance can be found.

4.2.4. How are the decisions made

The consideration between renovation or replacement is a choice that is made by asset managers and policymakers. Their decision is based on the performance, costs and sustainability. However, the decision is primarily based on the performance, with respect to risk, of the component.

4.3 OBR

The OBR (ObjectBeheerRegime) refers to the wet infrastructure which are managed by Rijkswaterstaat. The locks which are a part of the OBR can be divided into different categories, namely; functionality, technical aspects and the management and maintenance.

4.3.1. What is OBR

The specification of the measures for management and maintenance takes place in the so-called object management regimes (OBR). The OBR highlights per object how the management and maintenance is conducted and for what reason. The main focus is on the management and maintenance of the network (Boomaerts, 2017).

4.3.2. When to apply OBR

The OBR can be applied during the on the management and maintenance phase. The OBR describes the management and maintenance from the perspective that the situation is qualitatively in order (Rijkswaterstaat, 2010).

4.3.3. What are the aspects of OBR

The goal is to guarantee the performance requirements at the lowest life cycle costs as possible. In addition to that, all new materials need to be 100% sustainable to meet the sustainability goal in 2030 (Rijkswaterstaat, 2010).

HVWN

	Schutsluis		
	Vast [k€]	Variabel [k€]	Totaal [k€]
DIJG	901	3.009	3.910
DLB*	3.078	10.851	13.928
DNB*	2.476	6.967	9.443
DNH	1.049	3.519	4.568
DNN	0	0	0
DON	1.427	5.035	6.462
DUT	2.383	6.938	9.321
DZH	1.241	4.608	5.849
DZL	2.472	6.593	9.065
RWS	15.027	47.519	62.547

Table 10: overview yearly maintenance costs of locks RWS (Rijkswaterstaat, 2010)

All the OBR's together indicate which package of management and maintenance measures are required to ensure that the infrastructures management by Rijkswaterstaat is maintained in the long term and functions properly (Boomaerts, 2017). Furthermore, the OBR describes the maintenance costs per year, as can been seen in table 10. Table 10 shows what the yearly maintenance costs are for locks in the Netherlands in the year 2010. The left column shows the different regions in the Netherlands. The 'vast' column shows the constant maintenance costs, the column 'variabel' shows the variable maintenance costs and the column 'totaal' shows the total costs for each region in the year 2010. At the bottom the total maintenance costs for Rijkswaterstaat for locks is shown.
The OBR handles the aspect performance in the following way: the asset manager of the navigation lock agrees upon an availability percentage and a maximum leveling time. Furthermore, the function of the waterway has an influence on the availability percentage, this depends on the operating time of the lock. The availability percentage of navigation locks in the main waterways is about 98-99%. The 1-2% non-availability is due to errors, planned maintenance and collisions (Rijkswaterstaat, 2010). Thus, as can explained the OBR aspects are: costs, performance and sustainability.

4.3.4. How are the decisions made

The OBR has information about the replacement and renovation process of the navigation locks which are reaching the end of their lifespan. The consideration between replacement and renovation is a choice that is made in conformity between the asset manager and policymakers. The decision will be primarily based on life cycle costs to keep the required performance.

4.4 Discussion

This section highlights the most important facts of the three most commonly used management strategies of Rijkswaterstaat.

- All three discussed management strategies consider all aspects of the conceptual model in their management strategy. However, the three management strategies have a different approach;

  - RAMS determines the reliability (R) and availability (A) of the component functions. Furthermore it provides insight in the maintainability (M) and the safety of the component (Bakker. et al., 2010). The focus of RAMS lies primarily on the performance;
  - Risk-based Management and Maintenance (ProBO) is an element of asset management and focuses in particular on giving insight on the level of performance of the component and the risks that can affect the performance level (Van Maaren, Handreiking prestatiegestuurde risicoanalyses, 2018).
  - The OBR (objectbeheerregimes) provides a general overview of the management and maintenance costs of all the different navigation locks in the Netherlands (Boomaerts, 2017). The OBR is primarily focusing on the costs aspect, in particular on life cycle costs;
- All management strategies make use of a fault tree analysis for determining the performance in terms of reliability and availability. This fault tree analysis makes it possible to graphically model all potential failure mechanisms of the navigation lock, per function.
- Standardization is a rather new concept in the management and engineering of navigation lock components. Therefore, the current management strategies are not discussing this possibility.
- None of the strategies expresses all the aspects in costs, which provides a clear overview of the cheapest solution.

4.5 Conclusion

Three management strategies are discussed for deciding among renovation, replacement or standardization of a component of a navigation lock. The goal of this chapter was to get a better understanding of the current decision making process, in order to create a new model which takes the essentials of the current decision making into account.

	RAMS	PROBO	OBR
1. Costs	+	+	++
2. Performance	++	++	+
3. Sustainability	+	+	+
4. Standardization	-	-	-
5. Expressed in costs	-	-	-

Table 11: Pro's and con's management strategies

Table 11 illustrates 5 points what the management strategies should discuss in order to make a decision between renovation, replacement or standardization of a component. The ++ shows on which points the strategy is focusing on, the + shows which points it mentions and the - shows what it doesn’t mention.

Currently, the RAMS, ProBO and OBR are making decisions based on one location. The concept of standardization is a rather new term in the world of navigation locks. Therefore, not all the pros and cons are known and thus standardization is not being discussed as one of the possibilities of renewal. Furthermore, none of the strategies is using a model where all

aspects are translated to costs. Converting all aspects to costs provides the opportunity for a clear overview of the most beneficial solution.
It can be concluded that in order to make a decision between renovation, replacement or standardization, first the benefits of standardization needs and the impact on the multiple locations need to be more clear. Therefore, a new model needs to be created. This model allows identification of the most beneficial solution based on three aspects.

5. Interviews

To investigate how currently the decisions are made for the renewal of navigation lock components, interviews with experts have been conducted. Next to the decision making process, also the opinion about standardization of navigation lock components is asked.
The goal of this chapter is to get a better understanding of the decision making process of the asset managers. By doing this the aspects which the asset managers base their decision on are known. This information can be used to create a new decision model.
This section first provides a six point summary of the interviews. First, the expert function is given. Second, data for the decision making process is presented. Third, maintenance is discussed. Fourth, the performance of the lock is discussed. Fifth, the aspects for the decision making are discussed. Sixth, the opinion of the expert about standardization is discussed. Thereafter a conclusion will be drawn about the decision making progress. The full interviews can be found in appendix IV.

5.1 Interviews summarized

Expert 1

1. Expert 1 an asset manager of the navigation locks in the southern part of the Netherlands.
2. A large amount of the data is not recorded and whenever it is recorded, in many cases the data is not structured. OBR is generic for RWS and can be used as a means to generate data for averages for input data of the different parameters for the model.
3. Each navigation lock has a contractor who does the maintenance on the gates. The contractor needs to solve the smaller repairs within a pre-arranged time, to minimize the blockage for the shipping industry. For big repairs, there is no pre-arranged time and this can take up to a month.
4. RWS has requirements for the availability of the navigation lock. This is presented in percentage per year. Spare parts and repair equipment are available near the navigation lock. Whether on the terrain itself or in a nearby depot. As a general rule: large and highly specific parts with a long delivery time need to be present.
   A spare gate is not always necessary, it depends on the situation per navigation lock. Costs of the blocking of the shipping industry is an important reason for the consideration whether to invest in a spare gate or not.
   If a navigation lock is not functioning for a certain period, Rijkswaterstaat handles a hourly rate for not functioning per hour for compensating the shipping industry. It depends on the intensity of the shipping industry and the damage done to the logistics what hourly rate is used.
5. The asset managers will focus on the performance, costs and risks for the decision whether to apply this standard component or not.
6. Whenever the market offers a standard component which can be applied to increase the availability and reliability of a navigation lock and with that lower the life cycle costs, a standard can have the preference. Because this results in a higher performance and lower costs, which are 2 out of 3 aspects.

Expert 2

1. Expert 2 is senior advisor on navigations locks of Rijkswaterstaat and is one of the members of the GPO (Grote Projecten en Onderhoud). He provides advise to asset managers how to deal efficiently with their decisions about investments.
2. For the question about the maintenance strategy, he directed me to the OBR for the general data. For more specific data he directed me to the asset managers.
3. Using visual inspections corrective maintenance is conducted. In the stages of contracting, a period is determined for the repair / replacement time.
   A good example for preventive maintenance is a conservation layer on the gates. The OBR has general rules for these standard types of maintenance. Furthermore, the conservation plans (IHP) go in more depth about this subject. However, there is no manual how to approach such difficulties. In case of gates, preventive measurements with inspections are used to estimate the replacement and renovation time.
4. In which case a blocking needs to be requested depends on consequences. Whenever it is a crowded route for the shipping industry the consequences could be related to high costs. Furthermore, it depends on the availability of the locks. Not all locks are open 24/7. So, it depends on the economic consequences.
   There is risks analysis available for every navigation lock. Navigation locks have an extremely high reliability requirement because the consequences can be high. 99% reliability seems high, however this is 1% not-reliable, which is 3,65 days nonfunctioning of the navigation lock. This can result in high costs for the shipping industry.
5. The triangle risk-costs-performance is flexible. Sometimes a risk is being accepted because the prevention costs are too high.
6. -

Expert 3

1. Expert 3 is the asset manager of Zeeland and the delta area.
2. Every two years a AM maturity check and AM decision making is done. At these checks the asset manager is deciding whether to renovate or replace the component by life cycle optimization.
3. For the management strategy a FMECA is used, which is part of ProBO. The FMECA shows what the risks and the consequences are and forms an essential part for the decision making.
4. Spare gates are available for every navigation lock. Blocking locks for water retention are also always available. Whenever a component of the navigation lock gets older, the costs increases and the availability decreases.
5. For deciding whenever a component needs to be replaced, renovated or maintained the triangle risks-costs-performance is used.
6. In case it is proven that the use of standardized components result in a higher performance and lower the life cycle costs, it is an obvious discussion that the asset managers choose for this option.

5.2 Conclusion interviews

By interviewing three experts more information about the current decision making process is gained. This information is needed in order to create a new decision model which, next to renovation and regular replacement, also takes standardization into the decision making process.

In general the asset managers are using the triangle performance-costs-risks to determine the decision between the three options; renovation, replacement or standardization. For a detailed and more specific approach, the Whole Life Costs of the component should be taken into account. In the Whole Life Costs approach the option with the lowest costs where the component still meets the functional requirements is chosen as optimal.

- The performance is measured by the reliability and the availability of the component of the navigation lock;
- The costs are determined in the beginning of the project and further specified during the project;
- The risks are related to performance and the costs and thus the triangle of these three aspects are flexible;

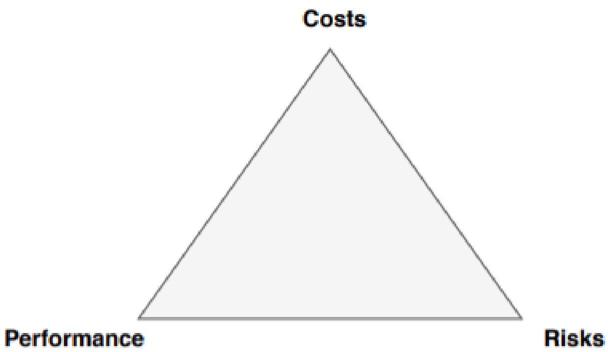


Figure 12: Current decision aspects of asset managers

Currently, the asset managers base their decision on the aspects given in figure 12.

- The asset managers use the management strategies that are represented by Rijkswaterstaat. However, it was found that the experts do not use one in particular. Thus, it can be concluded that all the strategies are sufficient enough to make a decision about the renewal of a navigation lock component.
- In case it is proven that the use of standardized components have a positive effect on aspects costs, performance or sustainability, asset managers will take this option into account.

6. Refined model

The previous chapter identified the key aspects which Rijkswaterstaat takes into account for the decision making between renovation or full renewal of a certain component. Chapter 3 described the conceptual model, which expressed all the different aspects in costs to get a clear overview of the possibilities. In addition to that, the weights in the conceptual model provides the opportunity to add weights to the aspects which can have an influence on the outcome, this will identify the optimum solution. However, the conceptual model did not take the advantages that standardization has, whenever it gets applied at multiple locks, into account. The goal of this chapter is to create a final model which takes next to renovation, regular replacement and standardization of a component at a single lock, also standardization at multiple locks into account. By applying standardization at multiple locks, the advantages of standardization are becoming clear. The first section will identify the key aspects for the decision making process. The second section will describe the additions to the conceptual model need to be added to come to the final model. The third section will describe the model of thought. The fourth section will describe the refined model, which is conceptual model combined with the additions. The fifth section will describe the final model. At the end a conclusion will be drawn.

6.1 Identification of the key aspects

The goal of this section is to identify what the key aspects are in the decision making process. By doing this, the provisional model can be turned into a final version.

Based on the literature and management strategies, there are 3 aspects which are taken into account to decide what the next step for the component is in terms renovation, replacement or standardization. These aspects are: costs, performance, and sustainability, see 3.1. However, the interviews indicate that the current way of deciding between these options mainly focus on the aspects costs, performance and risk, see chapter 5. The aspect sustainability is not mentioned as an important aspect by the experts. Although, as can be concluded out of the interviews: risk plays a more prominent role in the decision making process. However, as the literature indicates, risk results in an increase in the failure frequency of a component. The failure frequency is expressed in non-availability and non-reliability. As availability and reliability are parts of the performance aspect, these failure frequencies can be combined with the aspect performance. The failure frequency of a component can be shown in a fault tree analysis, which is discussed in chapter 4. Therefore risk can be implemented into the aspect performance. This results in figure 13.

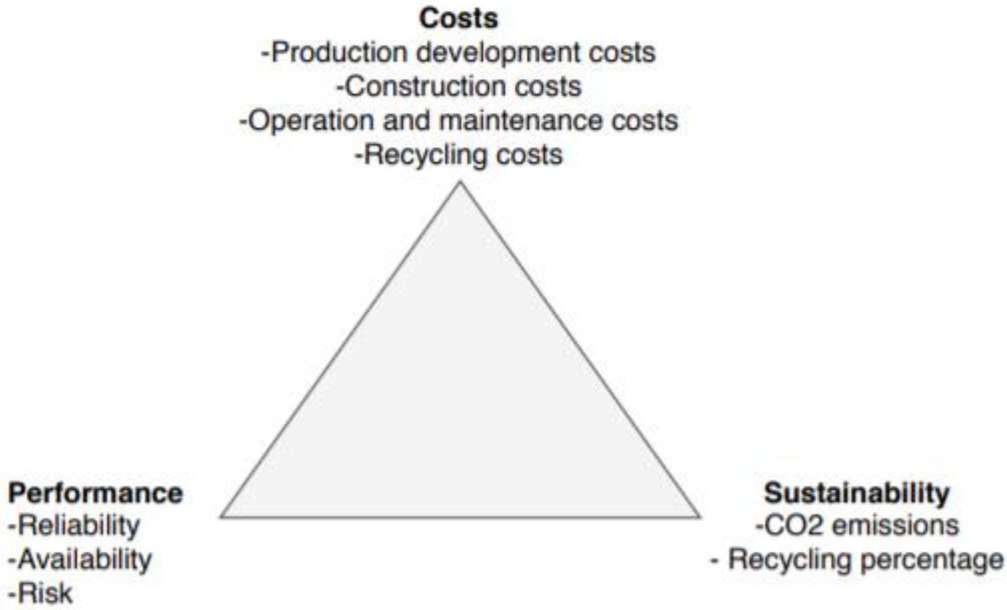


Figure 13: Relevant aspects with different forms

Figure 13 represents all the aspects and their forms. As can be concluded in the interviews: in the current situation the asset managers are making decisions per individual lock and do not take the effect of standardization of the entire arsenal into account because they are not really aware of the benefits. In addition to that, the aspect sustainability is not being considered in the decision making process. Furthermore, the currently used management strategies also do not take standardization into consideration because they currently focus on the one location and do not take the entire arsenal into account.
However, previous studies have shown that standardization of certain components can have a positive effect on the costs, performance or sustainability, see chapter 2. Thus, this indicates that there is need for a new decision model which shows the benefits of standardization, provides the opportunity to take the entire cluster into account and adds standardization into the possibilities.
So, whenever the benefits of standardization of components can be proven, this can be taken into account by the asset managers and other experts. The best way to prove the benefits of standardization is by expressing it in terms of costs, as discussed in chapter 3.5. By expressing it in one term, it provides an overview of the most beneficial option.

6.2 Additions to the provisional model

The conceptual model consist of three aspects and makes use of a multi-criteria analysis which provides the opportunity to make a decision between the three possibilities renovation, replacement or standardization of a lock component at a single lock.
As previous research has concluded: In case of standardization, the construction costs are generally a much larger part of the total life cycle than the maintenance part, the expected benefits will then be small or negligible. However, Slijk (2013) showed that, whenever standardization is used as a means to improve the performance, in terms of reliability and

predictability, it can be assumed that the positive effects of development and implementation of a standard can be advantageous for the economy.
Next to this, a recent study implicated that due standardization of certain components, millions can be saved in comparison of not standardization (Levinson, 2018). This cost reduction is the result of fewer spare gates required. The assumption was made that each lock needs a least 1 spare gate in its stock in case of not standardization. However, when at multiple locks standardization is applied, these locks can share a spare gate, under the condition that the minimum required availability will be maintained. This results in a less use of materials and is therefore a more sustainable solution.
Furthermore, in case of standardization it is sometimes inevitable that some changes to the civil structure must be made. Whenever standardization is leads to larger components, it is highly likely that the current civil structure will not be sufficient and needs to be changed. This suggests that standardization is only advantageous whenever more than 1 lock is involved. Earlier research showed that standardization of navigation lock gates, the gate chamber for example needed to be extended because of the bigger dimensions of the gates.
This chapter will show that the more locks are involved in the standardization process, the more advantageous it will be for some of the aspects. This will be done by means of calculations and represented in a table. Furthermore, an additional standardization table is added which calculates what the added value of multiple standardized components are. This table represents what the effects of standardization are per additional standardized navigation lock in terms of costs. The minimum number of standardized navigation locks to make standardization a more feasible solution than replacement and renovation can be calculated using an optimization procedure. This iterative process is shown appendix V (excel file, MCA & iterative tab).

6.3 Model of thought

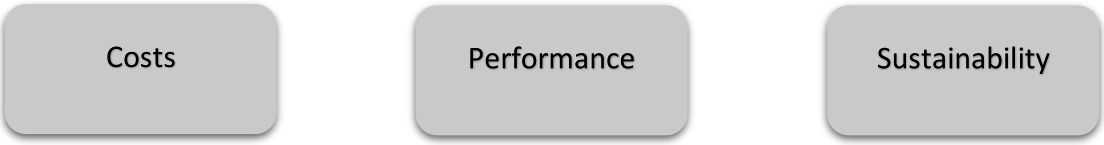
The model of thought is made to describe which steps the asset managers needs to make in the decision making process of the renewal of the component, whenever it has reached its lifetime.
The model of thought consists of seven steps and needs to be whenever a navigation lock component reaches the end of the life time. The steps are described below:

1. One of lock navigation lock component has reached its lifespan.
2. The total costs for all three possibilities are being calculated by means of the refined model.
3. Check if this lock is part of a cluster. If no, go to 4. If yes, go to 5.
4. Choose the cheapest option.
5. Calculate the costs for the other locks in terms of renovation, replacement and standardization.
6. Sum up the costs per possibility for the entire cluster and divide it by the total locks.
7. Fill in these costs into the Final model.

This model is fully explained in appendix VI. At the end this model can be combined with the final model to decide what the most beneficial option is.

6.4 Aspects of the refined model

The literature, management strategies and interviews indicates that the aspects; costs, performance and sustainability are relevant aspects for the infrastructure and form the foundation of the decision making process to renovate, replace or standardize a certain component of a navigation lock.



Costs	Performance	Sustainability
-Production development costs	-Reliability	-CO_2 emissions
-Construction costs	-Availability	-Recycling percentage
-Operation and maintenance costs	-Non-reliability	
-Recycling costs	-Non-availability	

Figure 14: Relevant aspects with different forms

Figure 14 represents the aspects on which the decision making process of renovation, replacement or standardization of a certain component are based on. Each of these aspects and how they translated to costs are explained further in the sections 6.4.1, 6.4.2, and 6.4.3.

6.4.1 Costs

Chapter 3 described the calculation of the costs relating to the life cycle phases for a single navigation lock. The production development, construction, and operating and maintenance costs are known by the asset manager and can directly can be implemented. However, recycling costs can not directly be translated into costs, the following formula (1) is created.

In addition to the recycling costs, it is assumed that in case of renovation a certain percentage of the replacement costs will reflect the renovation construction costs. Thus by multiplying the replacement costs of the component with this certain percentage will result in the renovation costs price.
This results in the formula (5):

*Replacement costs of the component * ..% = direct construction costs in case of renovation.*

This can be translated into the following table:

	Renovation	Replacement	Standardization
Production development costs	€A_1	€B_1	€C_1
Construction costs	€A_2	€B_2	€C_2
Operating and maintenance costs	€A_3	€B_3	€C_3
Recycling costs	€A_4	€B_4	€C_4
Total costs	€$A_{1,2,3,4}$	€$B_{1,2,3,4}$	€$C_{1,2,3,4}$

Table 12: Costs aspect

Table 12 shows what the costs are for the aspect costs in its different forms. After implementing the costs for each life cycle phase at each possibility, the total costs for each possibility is known. The output of the total costs for each possibility can later be used for the renovation, replacement or standardization of a navigation lock component at a single location. However, if standardization is used at multiple locations this results in a lower direct construction costs (Levinson, 2018). Hereby the author is relating to the fact that the amount of materials that is being used can be reduced because there are less spare gates needed in case of standardization at multiple navigation locks.

In addition to that, there is a possibility that standardization not only affects the construction costs but also one or more of the costs during the life cycle costs of the navigation lock, thus the; production development costs, operating and maintenance costs, and recycling costs. Therefore, an additional table is added which calculates what the costs are for applying the standardization of a component per navigation lock, whenever standardization is applied at multiple navigation locks.
Furthermore, in case of standardization it is inevitable that some changes to the civil structure must occur. The lock head requires adaptation, since the standardization method involves longer gates than the original gates. This results in adaptation of the sill, where a concrete slab needs to be added. Furthermore, the gate chamber needs to be bigger to create more space for the gates. This involves an increase of direct construction costs in case of standardization. However, the costs of the required adaptation costs have been neglected due to their minor contribution to the total costs (Levinson, 2018).

	Standardization (1)	Standarization (2)	Standardization (xx)
Production development costs	€S_1	€S_1	€S_1
Construction costs	€S_2	€S_2	€S_2
Operating and maintenance costs	€S_3	€S_3	€S_3
Recycling costs	€S_4	€S_4	€S_4
Total costs	€$S_{1,2,3,4}$	€$S_{1,2,3,4}$	€$S_{1,2,3,4}$

Table 13: Aspect costs standardization

To find the minimum amount of standardized navigation locks to make standardization a more feasible option than renovation and replacement an iterative process is used. This iterative process is indicated with the column standardization (xx).
Table 13 represents what the effects of standardization are per navigation lock on the aspect costs. The column standardization (1) calculates what the costs are in case 1 navigation lock standardized. The column standardization (2) calculates what the average standardization costs are in case the second navigation lock gets standardized.

6.4.2 Performance

The performance for each possibility needs to be known in order to calculate the non-performance. Performance is divided into the terms reliability and availability, which are expressed in percentages.

The reliability and availability for each component will be translated into the following table:

	Renovation	Replacement	Standardization
Reliability	$\%D_1$	$\%E_1$	$\%F_1$
Availability	$\%D_2$	$\%E_2$	$\%F_2$
Risk (non-reliability)	$\%D_3$	$\%E_3$	$\%F_3$
Risk(non-availability)	$\%D_4$	$\%E_4$	$\%F_4$
Total	$\%D_1+\%D_3$ & $\%D_2+\%D_4$	$\%E_1+\%E_3$ & $\%E_2+\%E_4$	$\%F_1+\%F_3$ & $\%F_2+\%F_4$

Table 14: Aspect performance

Table 14 shows the performance aspect in its different forms and how it relates to the possibilities. To compare the three possibilities, performance ultimately needs to be expressed in costs. By doing this, an overview will be provided which shows all differences between the possibilities. Because reliability and availability are expressed in percentages, these cannot directly be compared to costs and therefore needs to be translated to costs. As indicated in chapter 3, the non-performance of the system results in costs. Thus, the total performance costs relates to the non-reliability and non-availability costs. To do this, the document NIS (Netwerk Informatie Systeem) of Rijkswaterstaat can be used.

If certain costs can be charged per main waterway network for the non-performance of the lock, the performance requirements can be translated into costs. This will be done by converting the non-availability and non-reliability percentages to hours and then multiplying them by the hourly rate that is calculated if a lock does not function. Formula (2) will be used to calculate these costs.

This can be translated into the following table:

	Renovation	Replacement	Standardization
Reliability	€D_1	€E_1	€F_1
Availability	€D_2	€E_2	€F_2
Risk (non-reliability)	€D_3	€E_3	€F_3
Risk(non-availability)	€D_4	€E_4	€F_4
Total	€D_1+€D_3 & €D_2+€D_4	€E_1+€E_3 & €E_2+€E_4	€F_1+€F_3 & €F_2+€F_4

Table 15: Aspect performance translated to costs

Table 15 shows what the costs are per navigation lock are in case the component doors are being renovated, replaced or standardized. After implementing the reliability, availability and non-performance costs, the total costs for each possibility is known. The output of the total costs for each possibility will later be used in the conceptual model to decide whether to renovate, replace or to standardize a certain component of a navigation lock.

Furthermore, when standardization is used as a means to improve the performance, in terms of reliability and predictability, it can be assumed that the positive effects of development and implementation of a standard can be advantageous for the economy. Moreover, standardization is advantageous for the ease of the asset management by the operation and maintenance (Slijk, 2013).

Also the effect of one standardized lock versus multiple standardized locks needs to be taken into consideration to make a decision of the best option. Therefore, an additional table is added which calculates what the added value of multiple standardized navigation locks are.

	Standardization (1)	Standarization (2)	Standardization (xx)
Reliability	$\%S_1$	$\%S_1$	$\%S_1$
Availability	$\%S_2$	$\%S_2$	$\%S_2$
Risk (non-reliability)	$\%S_3$	$\%S_3$	$\%S_3$
Risk(non-availability)	$\%S_4$	$\%S_4$	$\%S_4$
Total	$\%S_1+\%S_3$ & $\%S_2+\%S_4$	$\%S_1+\%S_3$ & $\%S_2+\%S_4$	$\%S_1+\%S_3$ & $\%S_2+\%S_4$

Table 16: Aspect performance standardization

Table 16 shows what the influence of standardization is on the aspect performance per navigation lock. Furthermore, when standardization is used as a means to improve the performance, in terms of reliability and predictability, it can be assumed that the positive effects of development and implementation of a standard can be advantageous for the economy. Moreover, standardization is advantageous for the ease of the asset management by the operation and maintenance (Slijk, 2013).
There is the possibility that standardization not only affects the reliability due its over-dimension, but also the availability. Therefore, an additional table is added which calculates what the costs are for applying the standardization of a component per navigation lock, whenever standardization is applied at multiple navigation locks.

	Standardization (1)	Standardization (2)	Standardization (xx)
Reliability	€S_1	€S_1	€S_1
Availability	€S_2	€S_2	€S_2
Risk (non-reliability)	€S_3	€S_3	€S_3
Risk (non-availability)	€S_4	€S_4	€S_4
Total	€S_1+€S_3 & €S_2+€S_4	€S_1+€S_3 & €S_2+€S_4	€S_1+€S_3 & €S_2+€S_4

Table 17: Aspect performance standardization to cost

To find the minimum amount of standardized navigation locks to make standardization a more feasible option than renovation and replacement an iterative process is used. This iterative process is indicated with the column standardization (xx).
Table 17 represents what the effects of standardization are per navigation lock on the aspect performance translated into costs. The column standardization (1) calculates what the costs are in case 1 navigation lock standardized. The column standardization (2) calculates what the average costs are if the second navigation lock also get standardized.

6.4.3 Sustainability

The sustainability of each possibility needs to be calculated before making a decision about the renovation, replacement or standardization of a certain component. To this end, sustainability is divided into the terms CO_2 emissions and recycle percentage.
As explained in chapter 2, Rijkswaterstaat wants to be 100% circular in the year 2030 (Rijkswaterstaat, 2018). This includes that all navigation lock built after 2030 need to be made of recycled material. Moreover, a research has shown that the remaining lifespan of wood,

concrete and steel exerts minimal influence on the recycling percentage of the component (CE, 2016).
Navigation lock components are generally made out of wood, concrete and steel. All of these materials can be related to an emission factor (kg CO_2eq per unit). The total amount of used materials (in kg) needs to be calculated and translated into kg CO_2 per possibility. Appendix II provides an overview of the different kinds of materials and their emission factors. Formula (3) will be used to calculate the *CO_2 emission.*

This can be translated into the following table:

	Renovation	Replacement	Standardization
CO2 emission EQ (tons)	(tons)G_1	(tons)H_1	(tons)I_1
Non-Recycle percentage	%G_2	%H_2	%I_2
	$G_{1,2}$	$H_{1,2}$	$I_{1,2}$

Table 18: Aspect sustainability

Table 18 shows the sustainability aspect in its different forms and how it relates to the possibilities. To compare the three possibilities, sustainability ultimately needs to be expressed in costs. By doing this, an overview will be provided which shows differences among the possibilities. Formula (4) will be used to calculate this.

The non-recycling process is expressed as a percentage, this cannot directly be compared to costs and therefore needs to be translated to costs. If the non-recycle percentage is known for the component, this percentage can be multiplied with the total tons in weight, to calculate the tons which are non-recyclable. Whenever the total non-recyclable tons is known. The dump costs per ton for each material can be found at appendix III. Formula (1) can be used to calculate this.

It is assumed that the recycled part can be fully re-used again and the costs for recycling are neglectable.

All these prices together results in the can translated into the following table:

	Renovation	Replacement	Standardization
CO2 emission EQ (€)	€G_1	€H_1	€I_1
Recycle costs (€)	€G_2	€H_2	€I_2
Total costs (€)	€$G_{1,2}$	€$H_{1,2}$	€$I_{1,2}$

Table 19: Aspect sustainability to cost

Table 19 shows what the costs are per navigation lock are in case the component doors are being renovated, replaced or standardized. After implementing the CO_2 emission costs and recycle costs for each possibility, the total costs for each possibility is known. The output of the total costs for each possibility will later be used in the conceptual model to decide whether to renovate, replace or to standardize a certain component of a navigation lock.

	Standardization (1)	Standardization (2)	Standardization (xx)
CO2 emission EQ (tons)	(tons)G_1	(tons)H_1	(tons)I_1
Non-Recycle percentage	%G_2	%H_2	%I_2
	$G_{1,2}$	$H_{1,2}$	$I_{1,2}$

Table 20: Aspect sustainability standardization

Table 20 shows what the influence of standardization is on the aspect sustainability per navigation lock. Previous research shows that standardization ensures material reduction, in case of lock gates (Levinson, 2018). This material reduction results in less CO_2 emissions. Therefore, an additional table is added which calculates what the added value of multiple standardized components are.

If standardization is used at multiple locations this results in a lower direct construction costs (Levinson, 2018). Hereby the author is relating to the fact that the amount of materials that is being used can be reduced because there are less spare gates needed in case of standardization. The reduction of material usage results in less CO_2 emissions in the atmosphere.
Therefore, an additional table is added which calculates what the costs are for applying the standardization of a component per navigation lock, whenever standardization is applied at multiple navigation locks.

	Standardization (1)	Standardization (2)	Standardization (xx)
CO2 emission EQ (€)	€S_1	€S_1	€S_1
Non-Recycle percentage (€)	€S_2	€H_2	€I_2
Total (€)	€$S_{1,2}$	€$S_{1,2}$	€$S_{1,2}$

Table 21: Aspect sustainability standardization to cost

To find the minimum amount of standardized navigation locks to make standardization a more feasible option than renovation and replacement an iterative process is used. This iterative process is indicates with the column standardization (xx).
Table 21 represents what the effects of standardization are per navigation lock on the aspect sustainability translated into costs. The column standardization (1) calculates what the costs are in case 1 navigation lock standardized. The column standardization (2) calculates what the average costs are if the second navigation lock also get standardized.

6.5 Final model

Now that the total cost for the three possibilities are known. The numbers can be filled in the final model. The final model makes use of a multi-criteria analysis which provides the opportunity to make an decision between the three possibilities.

An additional table is added which calculates what the added value of standardization is for multiple navigation locks in terms of costs for all the aspects. By means of an iterative process the minimum amount of standardized navigation locks to make it a more feasible solution than replacement and renovation, can be calculated.
Going further onto that, risk in terms of non-reliability and non-availability has been added. This factor is added because earlier research shows that standardization of a certain component can have a positive influence on the reliability as compared to no standardization. This is due the fact that standardized lock gates are over dimensioned and are therefore structurally more reliable (Levinson, 2018).
Furthermore, if standardization is used at multiple locations this results in a lower direct construction costs (Levinson, 2018), because the amount of materials that is being used can be reduced; there are less spare gates needed in case of standardization. In addition to that, the author is relating to the fact that the amount of materials that is being used can be reduced because there are less spare gates needed in case of standardization. The reduction of material usage results in less CO_2 emissions in the atmosphere.

After implementing the additions to the conceptual model, this leads to the final model:

Possibilities / Aspects	**Weight**	**Renovation**	**Replacement**	**Standardization (1)**	**Standardization (xx)**
Costs (€)	x	A	B	C	S_1
Performance (€)	y	D	E	F	S_2
Sustainability (€)	z	G	H	I	S_3
Total (€)		xA+yD+zG	xB+yE+zH	xC+yF+zI	$xS_1+yS_2+zS_3$

Table 22: Final model

Table 22 illustrates the final model. To provide a clear overview all aspects are translated to costs in the final model. Furthermore, the decision maker has the option to put weight to certain aspects. The weights are positive numbers. In this way it gives the decision maker the opportunity to focus on a specific aspect.
The multi-criteria analysis makes it possible to take all three aspects into consideration and thereby allows identification of the best possibility. However, it makes it also possible to put weights on certain aspects and hereby focus on those.
The columns renovation, replacement and standardization (1) indicate what the costs of the component are for an individual lock. The additional column (standardization xx) shows at how many navigation locks standardization needs to be implemented to make it the cheapest solution. Furthermore, it shows what the average costs are per aspect and the total average costs, in case the minimum number of standardized navigation locks is known. Naturally, the iterative process doesn't imply that standardization is always the most feasible option.

6.6 Conclusion

The goal of this chapter was to create a final model which takes next to renovation, regular replacement and standardization of a component at a single lock, also takes standardization at multiple locks into account. Because then the advantages of standardization are becoming clear whenever it gets applied at multiple locks.

By adding the column standardization (xx) to the provisional model the minimum number of navigation locks to make a more feasible solution than replacement and renovation is shown. Although, there is a chance that the needed minimum standardized navigation locks are higher than the actual existing navigation locks. In that case standardization will automatically be removed from the possibilities.

Now the final model has been developed, a case study will be conducted to validate the final model. This case study will be a reference project called ‘sluis schijndel’ and the focus will lay on the component: steel mitre gates. As said earlier, steel mitre gates will be used because its high standardization suitability.

7. Case study

The previous chapter identified how the final decision model has been developed and can be used. The goal of this chapter is test this final model by means of a case study. The first section will describe which case study is used and why. The second section describes three aspects and how they are calculated. The third section describes the final model. At the end conclusions are drawn.

7.1 Case study: Sluis Schijndel

To illustrate the refined model and ultimately to make a decision between one of these possibilities by means of the final model, a case study will be conducted. This case study will handle the component: navigation locks gates, specified on steel mitre gates. Ultimately the decision model will determine what the most beneficial solution is, in terms of renovation, replacement or standardization, whenever a lock gate reached the point that it has to be renovated.

Clustering by color		Door height									
	Lock width (m)	4	5	6	7	8	9	10	11	12	13
1	5		3								
	6					3					
2	7	5	3								
	8		4	6		4			2		
	9										
3	10			2							
	11				1		1				
	12			9	1	1	2				
	13										
4	14		2	6	7		3	10			
	15										
5	16			1	2	4	5	2			
	17										
	18			1	2	2			3		1

Table 23: Five clusters (Levinson, 2018)

The previous study about standardizated mitre gates shows that the gates can be grouped into a minimum of five clusters. These five clusters are shown in table 24. The clusters are categorized based on the measurements of the lock widths. These clusters are made by the possibility that gates of different measurements can be applied at different locks by placing the gates under a different angle. Which results in the possibility that these locks can share their spare gate.

Each cell in table 23 has a number which shows how many gate sets with those dimensions (width and height) there are in that cluster. In total there are 37 navigation locks with 98 steel mitre gate sets. To give an example; in cluster 3, there are 2 gate sets which can implemented with a lock width of 12 meters and gate height of 9 meters.

For the aspects costs and sustainability earlier research about regular replacement and standardization will be used, combined with general available information. However, to validate what influence standardization has on the aspect performance, a reference project is taken. This reference project, Sluis Schijndel, will provide detailed information about the aspect performance of navigation locks in general.

Sluis Schijndel is located in the southern part of the Netherlands, province Noord-Brabant, in the Zuid-Willemsvaart. Sluis Schijndel is one of the 16 locks in this canal. Sluis Schijndel has two functions; leveling of ships and water retention. The main function of the navigation lock is to level ships. Therefore, this function will be elaborated in this case study. The Zuid-Willemsvaart is suitable for ships with the dimensions of 90 m x 6.7 m x 2.1 m (L x W x D), which corresponds to CEMT class ll. Sluis Schijndel is constructed in the year 1990, has a lock length of 110 meters and a lock width of 12.60 meters, gate has a height of 10.50 meters and the decay is 3.82 meters.

Figure 15: Navigation lock Schijndel (Schepers, 2013)

Sluis Schijndel, shown in figure 15, has a lock width of 12.60 meters, this case study will use cluster 3, marked in orange in table 4, to validate the final model. Cluster 3 consists of 6 navigation locks with a total of 16 gates sets. This cluster is chosen because it has the same dimensions as Sluis Schijndel and therefore the available data of Sluis Schijndel can be used to validate the final model.

This case study is done to prove that the final model functions. Therefore, and for sake of simplicity, it is assumed that cluster 3 consist of two locks. Although the third cluster has 6 navigation locks. The biggest and the smallest lock are calculated. The biggest navigation lock is taken into account because this lock delivers the spare gate for the other locks and the smallest lock, to maximize the visualization of what the effects of standardization are.

The biggest lock of the cluster, Koninginnensluis and the smallest lock of the cluster, Sluis Hulsen. Koninginnensluis has a lock width of 12 meters and a gate height of 9 meters. Sluis Hulsen has a lock width of 10 meters and a gate height of 6 meters.

For both locks, the data of the aspect performance will be derived from the reference project. As said, the reference project will only be used for the aspect performance because the other aspects are known.

7.2 Assumptions case study

As the refined model indicates, there are three aspects where the decision making process is based on: costs, performance and sustainability. This section illustrates how the costs of the aspects are calculated by means of a case study.

This research goes further on the following assumptions:

- in case of standardization each cluster can share a spare gate;

- Since the navigation locks in the MWW in program are currently on average 78% of their life span, it is assumed that the direct construction costs in case of renovation are 78% of the direct construction costs of replacement. The calculation is shown in appendix X;
- The operating time of Sluis Schijndel is 6.956 hours a year, because this indicated in the reference project (Schepers, 2013);
- It is assumed that either renovation, replacement or standardization won't affect the operating time of the lock, only the non-availability caused by failure of component will be taken into account. Therefore, the non-operating time of the lock will not be taken into account for the non-availability. Thus the non-availability caused by failure of components is 2,90%. The availability will therefore be 97,10% (Schepers, 2013).
- Appendix VIII 'invoerblad functie schutten' shows the non-reliability and non-availability per component. After conducting interviews it showed that certain crucial components for the functioning of the lock the MTTR can be reduced in case of standardization. This results in a lower repair time, thus a lower non-reliability. These components are marked in yellow in the appendix.
- The recycling costs are not taken into account at the aspect sustainability, because these costs are already taken into account at the aspect costs.
- For sake of simplicity all costs are rounded in the tables.

7.3 Model of thought

As described earlier, the model of thought is made to help the asset manager for the decision making process.

At first it is indicated that one of the lock components has reached its lifespan. Secondly, the total costs for all the three possibilities need to be calculated by means of the refined model. This will be calculated in section 7.4. The third step is to check if this lock is part of cluster. It shows that Sluis Schijndel is part of cluster 3. Thus, the costs for the other lock(s) in the cluster needs to be calculated. After that, the costs for each possibility for the entire cluster need to be summed up and the average need to be taken, to provide an overview of costs. These costs ultimately need to be filled into the final model, which is section 7.5.

7.4 Aspects of the refined model

This section will describe the second step of the model of thought; the calculation of each possibility by calculating the total costs of each aspect.

7.4.1 Costs

Chapter 6 described the calculation of the costs relating to the life cycle phases for single and multiple locks.

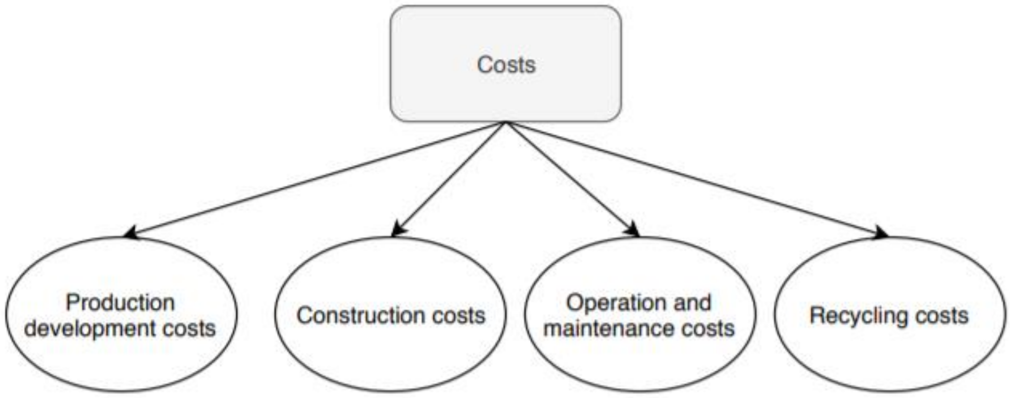


Figure 16: Costs aspect

These phases can be related to production development costs, construction costs, operating and maintenance costs, recycling costs, as illustrated in figure 16.

First the costs of each possibility will be discussed and calculated, for the biggest lock and the smallest lock. After that a conclusion will be drawn what the impact is whenever the whole cluster gets standardized in comparison to just 1 navigation lock.

7.4.1.1. Renovation

Product development costs (A_1)
The product development costs refer to the design costs of the gate. However, in case of renovation there are no additional design costs.

Direct construction costs (A_2)
These costs relate to the direct construction costs to renovate the steel mitre gates. These prices are for the renovation of the lock gates. This value depends on the current state of the gates. It is assumed that in case of renovation 78% of the gates cost replacement will reflect the renovation construction costs. The replacement costs are shown in table 5. For the biggest lock the replacement costs are €295,000.00 per gate set, thus €885,000.00 for the entire lock. Multiplying this amount with the percentage that is assumed for the gate replacement costs will result in the renovation costs price. The smallest lock are the replacement costs are €170,000.00 per gate set, thus €510,000.00 for the entire lock.
This results in the formula (5):

For the biggest lock : *€885,000.00 * 0.78 = €690,300.00*

For the smallest lock: *€510,000.00 * 0.78 = €397,800.00*

Operating and maintenance costs (A_3)
The operating and maintenance costs are related to the fixed and variable costs which helps to let the gate function after the renovation. In case of renovation the gates are made as new again.

To quantify these costs the OBR is used, which provides information about the yearly operating and maintenance costs (Rijkswaterstaat, 2010). This document shows that the yearly operating and maintenance costs in the Netherlands is €62.546.000 over a total of 121 navigation locks. The average of this number is taken to quantify the yearly operating and maintenance costs. The average operating and maintenance costs are calculated at €516.909,- per year.
This number is an overall average, thus this number will most likely not represent the real costs, because there is a great variance in the dimensions, the materials and different types of gates. However, there is no specific data available for the operating and maintenance costs for the bigger and the smaller lock. Thus there will be inconsistencies whenever this average will be applied to individual locks.

Recycling costs (A_4)
The recycling & disposal costs of the construction are costs related to removal- and the recycle costs of the component. However, in case of renovation it is assumed that nothing gets replaced and there are thus no recycling costs.

7.4.1.2. Replacement
Product development costs (B_1)
The product development costs refer to the design costs of the gate. The regular locks are considered as unique projects and therefore has each lock an unique gate. In this case it is assumed that the same design as before is used, because it is replaced with the exact same gate and therefore there are no extra product development costs.

Direct construction costs (B_2)
Previous research has calculated the cost estimate for the MWW lock gates, per gate set. Table 24 shows what the prices are per gate set. These cost relate to the direct construction of the steel mitre gates. These prices are for the regular replacement of the lock gates.

Cost per door set		Door height									
Lock width (m)	Optimum door length (m)	4	5	6	7	8	9	10	11	12	13
5	2,6		€ 114.955								
6	3,1					€ 148.033					
7	3,7	€ 118.537	€ 127.750								
8	4,2		€ 135.063	€ 148.033		€ 178.661			€ 236.323		
9	4,7										
10	5,2			€ 170.418							
11	5,7				€ 208.149		€ 267.451				
12	6,3			€ 196.319	€ 225.736	€ 258.668	€ 295.116				
13	6,8										
14	7,3		€ 191.758	€ 225.736	€ 264.499		€ 356.381	€ 409.499			
15	7,8										
16	8,4			€ 258.668	€ 308.047	€ 363.676	€ 425.555	€ 493.684			
17	8,9										
18	9,4			€ 295.116	€ 356.381	€ 425.555			€ 680.540		€ 890.082

Table 24: Cost estimate per gate set (Levinson, 2018).

These costs are based on the realization of the component, like the used materials and engineering hours. The biggest lock has 2 gate sets and 1 set of spare gates. The costs for replacing one gate set costs €295,116.00 thus €885,348.00 for the entire lock.

The smallest lock has also 2 gate sets and also a set of spare gates. The costs for replacing one gate set costs €170,418.00 thus €511,254.00 for the entire lock.

Operating and maintenance costs (B_3)

The operating and maintenance costs are related to the fixed and variable costs which are required for gate functioning after the replacement. The average operating and maintenance costs are calculated as €516,909.00 per year. It is assumed that the operating and maintenance costs are the same for the biggest and the smallest lock.

Recycling costs (B_4)

The recycling & disposal costs of the construction are costs related to removal and the recycling costs of the gate. As mentioned in chapter 6, first the non-recycle percentage of the gate needs to be known because this implies costs. If the non-recycle percentage is known for the component, this percentage can be multiplied with the total tons in weight, to calculate the tons which are non-recyclable. Whenever the total non-recyclable tons are known, disposal costs per ton for each material can be obtained using appendix III.

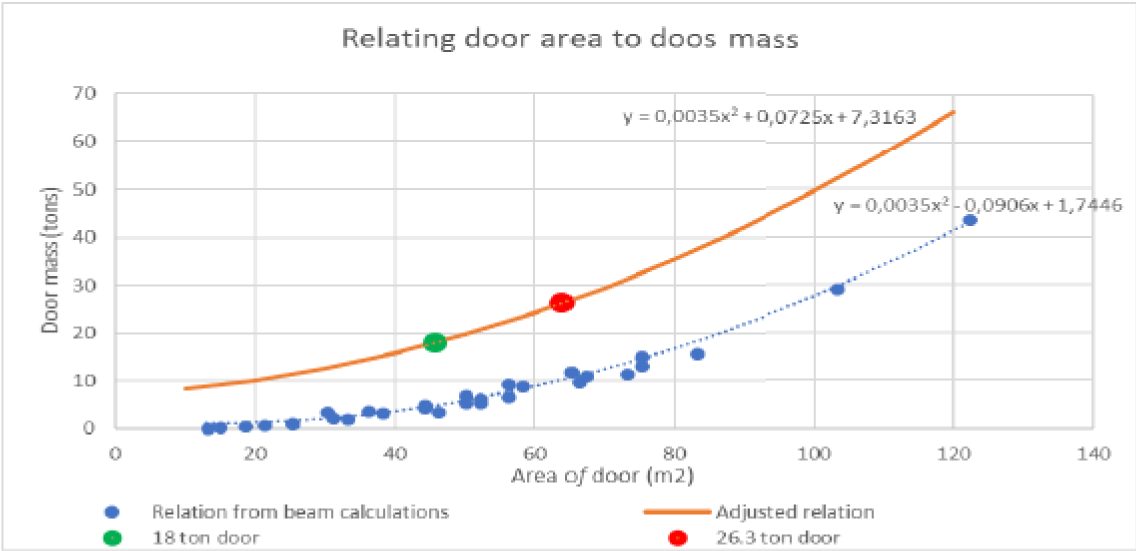


Figure 17: Relation between gate area to gate mass (Levinson, 2018)

Levinson (2018) made a graph where the relation between the gate area to gate mass is shown, see figure 17. In this way the weight of the gate can be calculated. It is assumed that in case of steel mitre gates that the old mitre gate can be recycled for 95%. So, the non-recycle percentage is 5%. The area of the 2 gate sets of the biggest lock in the cluster is: 2 x 6 (length) x 9 (height) = 108 area of gate in m^2. Which comes to the point that 1 gate set weights about 55 tons. In total there are 2 gate sets, so 110 tons. Thus 0,05 x 110 tons = 5.5 tons is non-recyclable and needs to be disposed. This costs: €215,- per ton, so €1200 for 5.5 tons.
For the smallest lock can the same calculation can be made; it has 2 get sets with 2 x 5 (length) x 6 (height) = 60 area of gate in m^2. Which come to the point that 1 gate set weights about 22 tons. In total there are 2 gate sets, so 44 tons. Thus 0,05 x 44 tons = 2.2 tons is non-recyclable and needs to be disposed. This costs: €215,- per ton, so €500 for 2.2 tons.

7.4.1.3. Standardization

Product development costs (C_1)

One of the costs that affects the choice of standardization is the product development costs. In case multiple lock gates can be categorized in one cluster, the production development costs are reduced. This is due the fact that each cluster has designed one unique gate set. Thus whenever this unique gate set is applied multiple times in one cluster, the production development costs only have to be added at the first set of gates. In case of standardization, the second lock will use the same sets of gates (although they can differentiate in height), thus the design of the first lock can be used.

Prior research refers to a price €1.100/ton in case of no standardization. In case of five unique gates, the design costs are reduced by 5/30 (Levinson, 2018). Thus, whenever applying standardization on these two locks, and do not taking the other locks into consideration, the design costs will be €1.100 x 29/30 = €1063,33. For the biggest gate set this means that the costs are €1063,33 x 55 tons = €58,465.00. For the second gate set it also will be around this price.

Direct construction costs (C_2)

The idea of making clusters in case of standardization the assumption is made that each cluster needs one set of spare gates, which results in lower direct construction costs. However, this is only the case whenever multiple locks are applying standardization.

Previous study calculated that benefit can be gained in case of standardization because the possibility to share the spare gate. As already mentioned earlier in this section; the author made the assumption that 1 set of spare gate per cluster is sufficient for each cluster (Levinson, 2018).

Cost per door set		Door height									
Lock width (m)	Optimum door length (m)	4	5	6	7	8	9	10	11	12	13
5	2,6		€ 99.205								
6	3,1					€ 127.185					
7	3,7	€ 130.012	€ 130.012								
8	4,2		€ 130.012	€ 142.201		€ 166.578			€ 203.144		
9	4,7										
10	5,2			€ 187.713							
11	5,7				€ 210.543		€ 253.666				
12	6,3			€ 187.713	€ 210.543	€ 230.836	€ 253.666				
13	6,8										
14	7,3		€ 225.212	€ 249.845	€ 274.478		€ 327.262	€ 351.894			
15	7,8										
16	8,4			€ 519.683	€ 557.895	€ 588.464	€ 626.676	€ 657.246			
17	8,9										
18	9,4			€ 519.683	€ 557.895	€ 588.464			€ 695.458		€ 764.240

Table 25: Cost estimate per gate set, where all gates are clustered into 5 categories (Levinson, 2018).

This results in table 25, which presents the prices of the lock gates in case standardization is applied, divided over 5 clusters.

In case of standardization of only 1 lock and due the changes of civil structures the spare gate also needs to be changed because the old spare gate won't fit. Thus 3 standardized gate sets need to be constructed. However, in case multiple locks get standardized, these locks can share their spare gates thus financial benefit can be gained.

Thus, the direct construction costs for the biggest gate costs 3 x €253,666.00 = €760,998.00. In case standardization is chosen for the second lock, these direct construction costs are 2 x €187,713.00 = €375,426.00.

Operating and maintenance costs (C_3)

The operating and maintenance costs are related to the fixed and variable costs for the gate function after the implementation of the standardized gates. The average operating and maintenance costs are again calculated at €516.909,- per year.

Recycling costs (C_4)

The recycling & disposal costs of the construction are related to removal and the recycle costs of the component. This amount is the same of for replacement because standardized doors and regular doors have approximately similar measurements. Thus, the biggest lock has €1,200.00 recycling costs and the smaller lock has €500.00 recycling costs.

This can be translated into the following table for the biggest lock and smaller lock together:

	Renovation	Replacement	Standardization
Production development costs	€ -	€ -	€ 116.900,00
Construction costs	€ 1.088.100,00	€ 1.396.600,00	€ 1.136.400,00
Operating and maintenance costs	€ 1.033.800,00	€ 1.033.800,00	€ 1.033.800,00
Recycling costs	€ -	€ 1.700,00	€ 1.700,00
Total costs	€ 2.121.900,00	€ 2.432.100,00	€ 2.288.800,00

Table 26: Summation of costs

Table 26 shows what the total costs are for the biggest and smallest lock together. However, to found what the most beneficial option is, the average has to be taken for each possibility.

	Renovation (2)	Replacement (2)	Standardization (2)
Production development costs	€ -	€ -	€ 58.400,00
Construction costs	€ 544.000,00	€ 698.300,00	€ 568.200,00
Operating and maintenance costs	€ 516.900,00	€ 516.900,00	€ 516.900,00
Recycling costs	€ -	€ 850,00	€ 800,00
Total costs	€ 1.060.900,00	€ 1.216.700,00	€ 1.144.300,00

Table 27: Average costs per possibility

Table 27 shows what the average costs are per navigation lock in case the component doors are being renovated, replaced or standardized. To find the minimum amount of standardized navigation locks to make standardization a more feasible option than renovation and replacement an iterative process is used. This iterative process is indicated with the column standardization (xx).

	Standardization (1)	Standardization (2)	Standardization (xx)
Production development costs	€ 116.900,00	€ 58.400,00	€S_1
Construction costs	€ 1.136.400,00	€ 568.200,00	€S_2
Operating and maintenance costs	€ 1.033.800,00	€ 516.900,00	€S_3
Recycling costs	€ 1.700,00	€ 800,00	€S_4
Total costs	€ 2.288.900,00	€ 1.144.300,00	€$S_{1,2,3,4}$

Table 28: Average costs standardization

Table 28 represents what the effects of standardization are per navigation lock on the aspect costs. The column standardization (1) calculates what the costs are in case 1 navigation lock standardized. The column standardization (2) calculates what the average standardization costs are in case the second navigation lock gets standardized.

7.4.1.4. Conclusion

- Renovation could be the most beneficial option in terms of total costs. However, this will depend on the current condition of the gates. If the gates are in a very bad condition it will have high construction costs and if the gates are in a good condition it will have relatively low construction costs. So, the decision is depending on the construction costs.
- Furthermore, the conclusion can be drawn that of all possibilities replacement is the most expensive one. This is due the high construction costs.
- Standardization of the whole cluster is cheaper on average than standardization of just one navigation lock. Due the possibility of sharing the spare gate, the construction costs are considerably lower and there are no production development costs because the design is already made for the entire cluster.
- As can be seen in the calculations; the more locks are standardized, the average will become lower. So, if a clusters contains more navigations locks, this could lead to other outcomes.

7.4.2 Performance

For each possibility the performance needs to be determined to ultimately make a decision about what the effects of standardization are on the aspect performance. Performance is divided into the terms reliability, availability and risks. The term risk can be mapped in a fault tree analysis, which expresses it in non-reliability (W) and non-availability (Q).
First the performance specified for lock gates will be discussed. After that, the performance of one lock in terms of renovation, replacement and standardization will be calculated. Followed by applying standardization to the second lock, the performance will be calculated. After that a conclusion will be drawn what the effects are whenever the whole cluster gets standardized in comparison to just 1 navigation lock.

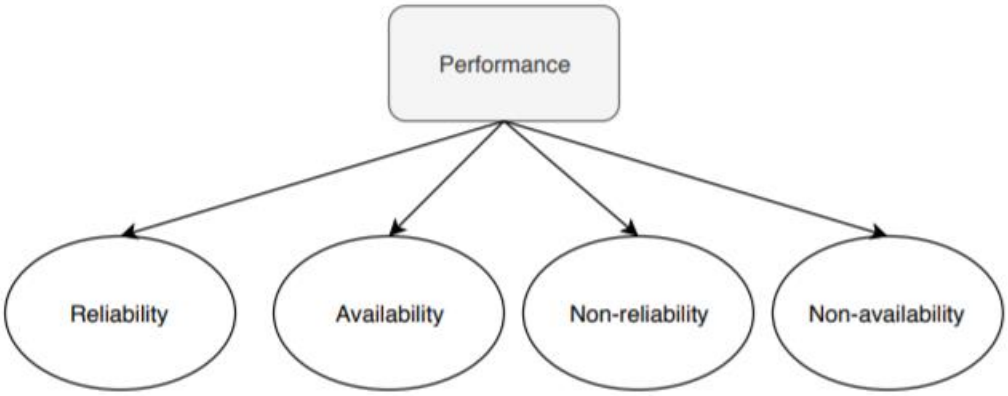


Figure 18: Aspect performance

Figure 18 shows the aspect performance with its different forms.

7.4.2.1. Renovation

Reliability (D_1)

The reliability depends on the non-reliability. Currently, Sluis Schijndel's reliability is 99,84%, as the reference project indicates. In case of renovation, the gates will be renewed and the same process continues.

Availability (D_2)

As described earlier, sluis Schijndel's availability depends on the failure of the components. In case of replacement, the gates will be renewed and the same process continues. Thus the non-availability caused by failure of components is 2,90%. It is assumed that the smallest lock has the same availability as the biggest lock. The availability will therefore be 97,10%.

Risk (non-reliability) (D_3)

The maximum reliability will be lowered by the non-reliability. In case of renovation, the gates will be renewed and the same process continues. As calculated in the reference project, the non-reliability of the function leveling ships is calculated at 13,89 failures a year. This is 1,60 x 10^{-3} per hour, i.e. 0,16%. It is assumed that the biggest lock has the same non-reliability as the smallest lock.

Risk (non-availability) (D_4)

The maximum availability will be lowered by the non-availability. In case of renovation, the gates will be renewed and the same process continues. Thus, the MTTR will not be reduced and therefore, the non-reliability is maintained. As calculated in the reference project; the non-availability of the function leveling ships is calculated at 2055,9 hours a year. This is 23,46% a year. The operating time of the lock is causing 20,6% of the non-availability and the failure of components is causing 2,86% of the non-availability. It is assumed that the biggest lock has the same non-availability as the smallest lock.

7.4.2.2. Replacement

Reliability (E_1)

The reliability is depended of the non-reliability. Currently, Sluis Schijndel's reliability is 99,84%, as the reference project indicates. In case of replacement, the gates will be renewed and the same process continues. Due failure of components, which has a failure rate per hour of 1,6 x 10 $^{-3}$, thus equals for 0,16%, it is has a reliability of 99,84%. It is assumed that the smallest lock has the same reliability as the biggest lock (thus sluis Schijndel).

Availability (E_2)

As described earlier, Sluis Schijndel's availability is depends on the failure of the components. In case of replacement, the gates will be renewed and the same process continues. Thus the non-availability caused by failure of components is 2,90%. It is assumed that the smallest lock has the same availability as the biggest lock. The availability will therefore be 97,10%.

Non-reliability (E_3)

The maximum reliability will be lowered by the non-reliability. In case of replacement, the gates will be renewed and the same process continues. As calculated in the reference project; the non-reliability of the function leveling ships is calculated at 13,89 failures a year. This is 1,60 x 10^{-3} per hour. Which equals 0,16%. It is assumed that the biggest lock has the same non-reliability as the smallest lock.

Non-availability (E_4)

The maximum availability will be lowered by the non-availability. In case of replacement, the gates will be renewed and the same process continues. Thus, the MTTR will not be reduced and therefore, the non-reliability keeps maintained. As calculated in the reference project; the non-availability of the function leveling ships is calculated at 2055,9 hours a year. This is 23,46% a year. The operating time of the lock is causing 20,6% of the non-availability and the failure of components is causing 2,86% of the non-availability. It is assumed that the biggest lock has the same non-availability as the smallest lock.

7.4.2.3. Standardization

Reliability (F_1)

In case of standardization, the gates will be renewed and a new process begins. Standardization of the gates won't have an effect on the reliability of the function of the lock. This is because the locks reliability can be guaranteed by the safety logs, which are available at each lock. Thus, the reliability keeps the same in this case of standardization of the gates. It is assumed that the smallest lock has the same reliability as the biggest lock.

Non-reliability (F_2)

In case of standardization of gate sets, the gates will be over-dimensioned and this will have an influence on the non-reliability factor. However, it is unknown how much more reliable the standardized gates are going to be, thus it is assumed that the standardized gates are 10% more reliable compared to non-standardized gates. This does not mean that the whole system gets 10% more reliable, because the gates are just a part of the whole system. This

indicates that the non-reliability of the gates are reduced by 10%. Therefore, the non-reliability factor of the 'failure of the gate' component is multiplied by 0.9. This ultimately results in a non-reliability 1,6 x 10^{-3} which equals 0,16%. Thus 99,84%.
As indicated before, the standardization of the lock gate won't affect the reliability because other components are more important for the reliability. The fault tree analysis shows that the 'afstandbediening' of the lock plays an important role for the non-reliability.

Availability (F_3)

As described earlier, sluis Schijndel's availability depends on the failure of the components. In case of standardization, the gates will be renewed and a new process begins. The non-availability caused by failure of components is 2,61%. It is assumed that the smallest lock has the same availability as the biggest lock. The availability will therefore be 97,39%. This is shown in appendix IX.

Non-availability (F_4)

When standardization is used; the spare gates can be on location in a shorter notice than in the current situation. This is because the same type of gate is available, easy moveable and easy installable (Levinson, 2018). Therefore, the MTTR will reduce. Whenever a component is faster repaired, the reliability and availability are better, and the whole system will function in a shorter period of time. Appendix IX shows the calculation of the non-availability in case of standardization. Non-availability in case of standardization is set on: 2,61%. It is assumed that the biggest lock has the same non-availability as the smallest lock.

	Renovation	Replacement	Standardization
Reliability	%99,84	%99,84	%99,84
Availability	%97,10	%97,10	%97,39
Non-performance (non-reliability)	%0,16	%0,16	%0,16
Non-performance (non-availability)	%2,90	%2,90	%2,61
Total	%100 & %100	%100 & %100	%100 & %100

Table 29: Performance per possibility

Table 29 shows the performance per possibility. To compare the three possibilities the non-performance needs to be expressed in costs. This can be done by the formula (2).

costs for non-performance = lost hours x penalty costs.

By means of interviews, the penalty costs are set on €500.00 per hour. Thus to calculate the costs for non-performance, the lost hours need to be multiplied by this rate.
2,90% equals 254 hours. 254 lost hours x €500 penalty costs = €127,000.00 in case of renovation and replacement.
In case of standardization the non-performances is 2,61% which equals 229 hours. 229 lost hours x €500 penalty costs = €114,500.00.

The same can be done for the non-reliability. 0,16% equals 14 hours. 14 lost hours x €500 penalty costs = €7,000.

	Renovation	Replacement	Standardization
Reliability	€D_1	€E_1	€F_1
Availability	€D_2	€E_2	€F_2
Non-performance (non-reliability)	€7.000	€7.000	€7.000
Non-performance (non-availability)	€127.000	€127.000	€114.500
Total	€134.000	€134.000	€121.500

Table 30: Costs per possibility

Table 30 shows the costs per possibility for the aspect performance. Also the effect of one standardized lock versus multiple standardized locks needs to be taken into consideration to make a decision of the best option. Therefore, an additional table is added which calculates what the added value of multiple standardized navigation locks are.

	Standardization (1)	Standardization (2)	Standardization (xx)
Reliability	%99,84	%99,84	%S_1
Availability	%97,39	%97,39	%S_2
Non-performance (non-reliability)	%0,16	%0,16	%S_3
Non-performance (non-availability)	%2,61	%2,61	%S_4
Total	%100 & %100	%100 & %100	%S_1+%S_3 & %S_2+%S_4

Table 31: Performance standardization

Table 31 shows the effect of standardization of a component on multiple locks for the aspect performance. To compare the three possibilities the non-performance needs to be expressed in costs. The same formula is used as in chapter 6.

	Standardization (1)	Standardization (2)	Standardization (xx)
Reliability	€S_1	€S_1	€S_1
Availability	€S_2	€S_2	€S_2
Risk (non-reliability)	€7.000	€7.000	€S_3
Risk (non-availability)	€114.500	€114.500	€S_4
Total costs performance	€121.500	€121.500	€$S_{1,2,3,4}$

Table 32: Performance costs standardization

Table 32 represents what the effects of standardization are per navigation lock on the aspect performance in translated to costs. The column standardization (1) calculates what the costs are in case 1 navigation lock standardized. The column standardization (2) calculates what the costs are for the second navigation lock, in case the same component gets standardized at 2 navigation locks.

7.4.2.4 Conclusion

- The non-reliability risk is a very small number because of the reliability of the lock can always be guaranteed due the use of logs to retain the water from one side to another.
- This section indicates that standardization of the gates won't have an impact on the reliability of the whole function. This can be explained by the fact that just a few component, over all components, are reduced by 10%.
- The availability of the gates causes the most potential costs. These costs are caused by the economical compensation for the shipping industry for not functioning of the system.
- The non-availability risk is reliable on the main time to repair the gates. Thus, the lower the repair time of the gates, the lower the costs.
- The conclusion can be made that standardization of the navigation lock gates results in a lower MTTR. Thus a better availability over the function of the whole system.

7.4.3 Sustainability
For each possibility the sustainability needs to be evaluated. Sustainability is expressed in terms of CO_2 emissions.
The navigation lock gate is made out of stainless steel. The emission factor for 1kg stainless steel equals 6.15 kg CO_2, see appendix II. So, the total amount of tons stainless steel used for the gates needs to be multiplied by 6.15 to have CO_2 emissions in tons.

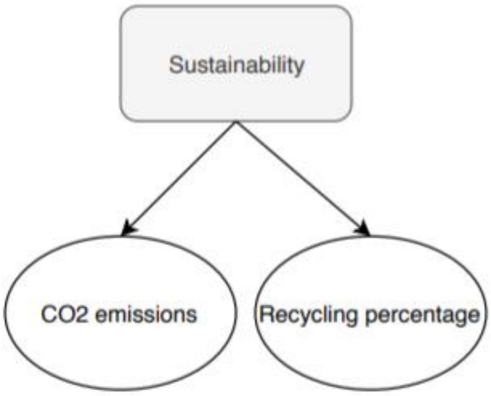


Figure 19: Aspect sustainability

Figure 19 shows the aspect sustainability and its different forms.

7.4.3.1. Renovation
In case of renovation of the first lock, it depends how much material is being renewed to make the gate according the requirements. It is assumed that the 78% needs to be renovated of the 3 sets of gates. Thus, 0.78 x 165 tons of steel = 124 tons in total. This comes down to 124 x 6.15 = 763 tons CO_2 emissions.
In case of renovation of the second lock, it is also assumed that 50% needs to be renovated. Which comes to the point that 1 gate sets weight about 22 tons. In total there are 2 gates sets and 1 spare gate set, so 66 tons. Thus, the CO_2 emissions in case of renovation comes down to 0.78 x 66 x 6.15 = 304 tons CO_2 emissions.
The recycling & disposal costs of the construction are costs related to removal- and the recycle costs of the component. However, in case of renovation it is assumed that nothing gets replaced and there are thus no recycling costs.

7.4.3.2. Replacement
In case of replacement of the first lock, it was calculated that each gate set of the first lock is around 55 tons. Thus, the whole lock consists of 165 tons of steel. This comes down to 165 x 6.15 = 1,015 tons CO2 emissions.
In case of replacement for the second lock, it is calculated that one gate set weights 22 ton. So, in case of replacement 3 gate sets needs to be replaced which is 66 tons. Which comes down to 66 x 6.15 = 406 tons CO2 emissions.
In case of replacement, the recycling costs are already taken into account.

7.4.3.3. Standardization

In case of standardization of the first lock the gates are over dimensioned. It is assumed that the gates are 10% over dimensioned. Thus, the whole lock consists of 182 tons of steel. This comes down to 88 x 6.15 = 1,119 tons CO_2 emissions.

In case of standardization at multiple locks, there is material reduction because there is no additional spare gate needed for the second lock.

It is assumed that the gates are 10% over dimensioned. Thus, one gate set for the second lock weights 1,10 x 22 = 24.2 tons. Thus, the calculation for the CO2 emissions is: 3 x 24.2 x 6.15 = 446 tons CO2.

In case of standardization, the recycling costs are already taken into account.

This can be translated into the following table for the biggest lock and smaller lock together:

	Renovation	Replacement	Standardization
CO2 emission EQ (tons)	1.010	1.421	1.565
Non-Recycle percentage	-	-	-
	$G_{1,2}$	$H_{1,2}$	$I_{1,2}$

Table 33: Sustainability per possibility

Table 33 shows the sustainability per possibility. To compare the results the factors are translated to costs with the following formula (4):

*CO_2 emission (Tons) * price per ton = CO_2 emission price*

Currently the price is set on 7.3 euro per ton.

This results in the following table:

	Renovation	Replacement	Standardization
CO2 emission EQ (€)	€7.500	€10.500	€11.500
Recycle costs (€)	€-	€-	€-
Total costs (€)	€7.500	€10.500	€11.500

Table 34: Costs per possibility

Table 34 shows the costs per possibility for the aspect sustainability. After implementing the CO_2 emission costs and recycle costs for each possibility, the total costs for each possibility is known. The output of the total costs for each possibility will later be used in the conceptual model to decide whether to renovate, replace or to standardize a certain component of a navigation lock.

	Standardization (1)	Standardization (2)	Standardization (xx)
CO2 emission EQ (tons)	1.119	783	(tons)I_1
Non-Recycle percentage	-	-	-
	$G_{1,2}$	$H_{1,2}$	$I_{1,2}$

Table 35: Sustainability average standardization

Table 36 shows what the influence of standardization is on the aspect sustainability per standardized navigation lock. To compare the three possibilities the non-performance needs to be expressed in costs.

	Standardization (1)	Standarization (2)	Standardization (xx)
CO2 emission EQ (€)	€8.200	€5.700	€S_1
Non-Recycle percentage (€)	€-	€-	€-
Total (€)	€$S_{1,2}$	€$S_{1,2}$	€$S_{1,2}$

Table 36: Standardization average costs

Table 36 represents what the effects of standardization are per navigation lock on the aspect sustainability translated in costs. The column standardization (1) calculates what the CO2 emissions are in case 1 navigation lock standardized. The column standardization (2) calculates what the CO_2 average emissions are for the second navigation lock, in case the same component gets standardized at 2 navigation locks.

7.4.3.4 Conclusions

- Renovation could be the most sustainable option. However, this will depend on the current condition of the gates. If the gates are in a very bad conditions, much materials needs to be used and result in a less sustainable situation than now is represented. However, if the gates are in a good condition it will most likely result in a more sustainable situation than completely replacing a new gate.
- Standardization leads to over dimensioning, thus more material is used per gate. Nevertheless, the effect of standardization over multiple locks will have a positive influence on the sustainability because a spare gate can be shared, which results in less material usage.
- Standardization of one lock isn’t having any positive influence on the sustainability because standardization is making use of over dimension, which results in more material.
- As can be seen in the calculations; the more locks are standardized, the average will become lower. So, if a clusters contains more navigations locks, this could lead to other outcomes.

7.5 Final model

Now that the total cost for the three possibilities are known. The numbers can be filled in the final model. In case the whole cluster gets renovated, replaced or standardized, it results in the following table. Depending on the weights giving to the aspects, the choice between the three possibilities can be determined.

Possibilities / Aspects	Weight	Renovation (2)	Replacement (2)	Standardization (2)	Standardization (xx)
Costs (€)	1	€ 1.040.000	€ 1.216.000	€ 1.144.500	€ -
Performance (€)	1	€ 134.000	€ 134.000	€ 121.500	€ -
Sustainability (€)	1	€ 3.900	€ 5.200	€ 5.700	€ -
Total (€)		€ 1.177.900	€ 1.355.000	€ 1.271.700	€ -

Table 37: Final model Sluis Schijndel

Table 37 shows what the average costs are of the component lock doors whenever it is applied at 2 locks. This final model is calculated for the standardization of the smallest cluster, which contains 2 locks. For sake of simplicity, it is assumed that all aspects are equally important, thus all the weights are set on 1.
The results show the costs have the highest impact on the decision making. The case study has shown that standardization of multiple locks leads to lower performance costs. Thus whenever standardization gets applied at multiple locks, it becomes the most beneficial option. To find the minimum to make standardization the most beneficial, an iterative process needs to be conducted.

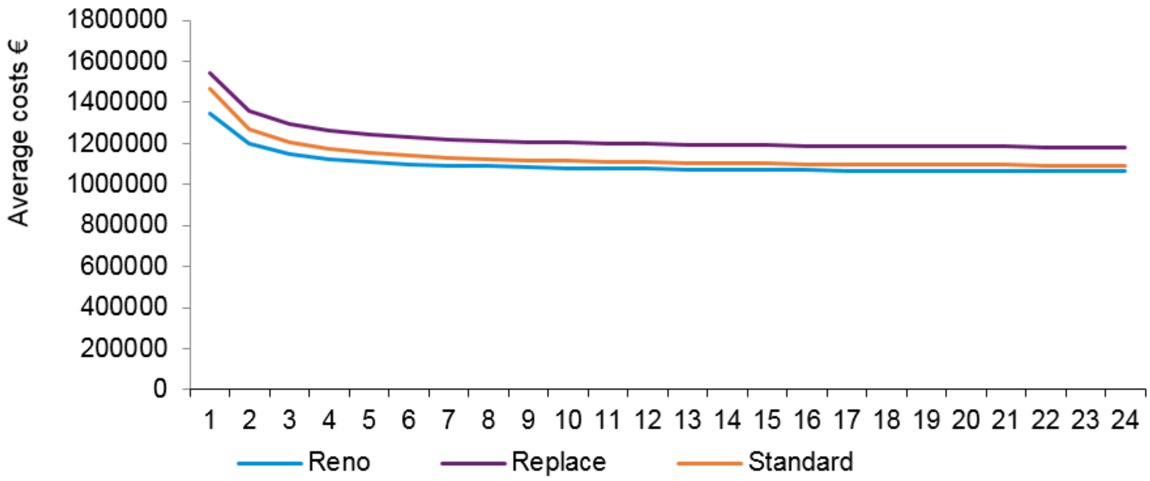


Figure 20: Average costs lock door

Figure 20 shows the average costs of the component lock at a navigation lock. The iterative process has calculated that at in case all weights are set on 1, the standardization will never be the most beneficial option because the renovation costs will always be lower.

7.6 Sensitivity analysis

A sensitivity analysis is conducted to show the influence on the results whenever the aspects or assumptions are changed. This is required to determine the level of influence each aspect or assumption has on the outcome of the final model.

At first, four analyses will be done about the change in the results whenever the weights of the aspects are changed. Secondly, the assumption that the direct construction costs in case of renovation are 78% of the replacement costs is changed.

7.6.1 Diversity of aspects

The first figure will provide an overview what the average costs are for each possibility in case only the aspect costs is considered. To determine the level of influence of the aspect costs on the outcome of the final model, the weights of the final model are set on 1 for costs, 0 for performance and 0 for sustainability. By doing this, the aspects performance and sustainability will not be taken into account in the final model, because all their values are multiplied by 0.

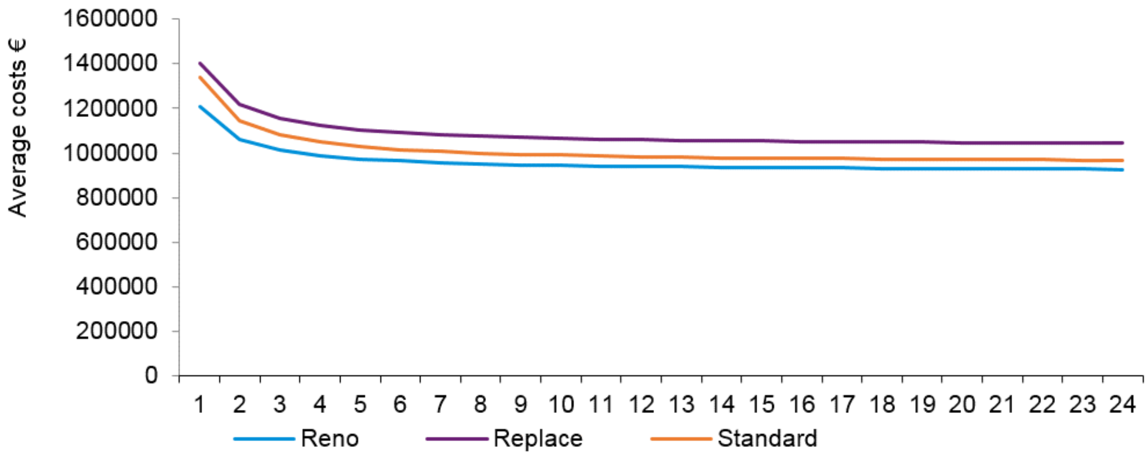


Figure 21: Aspect costs versus locks scenario 1

Figure 21 shows that for the aspect costs, the most beneficial possibility is renovation. This is outcome can be explained by the fact that the costs of renovation is based on an average of 78%. Thus, this will in all situations be cheaper than replacement, because the other costs will not change. However, in real situations this amount can variate for each location. Standardization has also higher costs than renovation, this can be explained by the fact that this possibility has production development costs and recycling costs, which renovation has not.

The second figure will illustrate what the average costs are for each possibility in case the aspect performance is considered. To determine the level of influence of the aspect performance on the outcome of the final model, the weights of the final model are set on 0 for costs, 1 for performance and 0 for sustainability. By doing this, the aspects costs and sustainability will not be taken into account in the final model, because all their values are multiplied by 0.

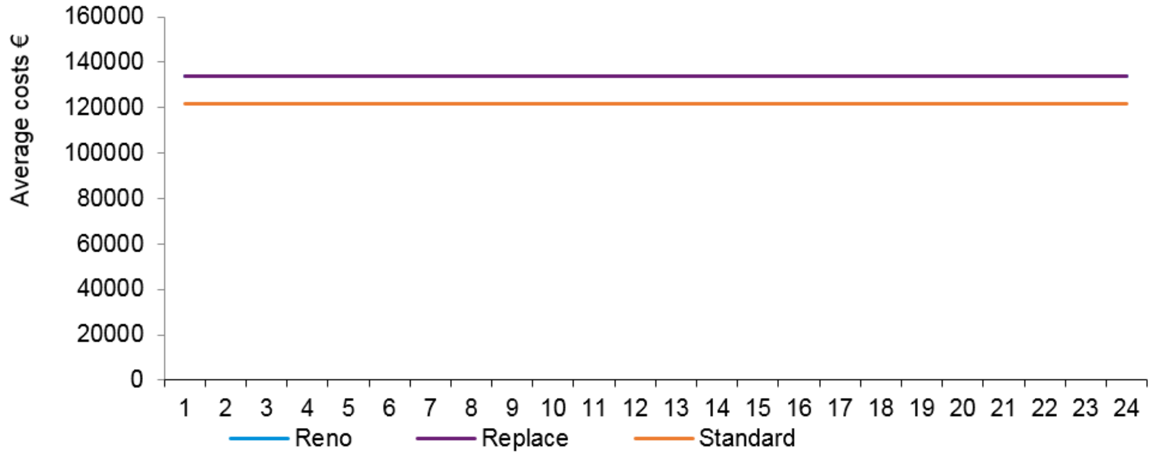


Figure 22: Performance costs versus locks scenario 2

Figure 22 shows the costs for each possibility for the aspect performance. As it shows, all the lines are linear. In case of renovation and replacement, the costs are €134,000.00 per lock and in case of standardization the costs are €121,500.00 per lock.
Renovation and replacement are visualized as one line, this is due the fact that both these possibilities score exactly the same in terms of performance. However, due standardization the availability increases, thus the non-availability decreases, which results in less costs per standardized lock compared to renovation and regular replacement.

The third figure will illustrate what the average costs are for each possibility in case the aspect sustainability is considered. To determine the level of influence of the aspect sustainability on the outcome of the final model, the weights of the final model are set on 0 for costs, 0 for performance and 1 for sustainability. By doing this, the aspects costs and performance will not be taken into account in the final model, because all their values are multiplied by 0.

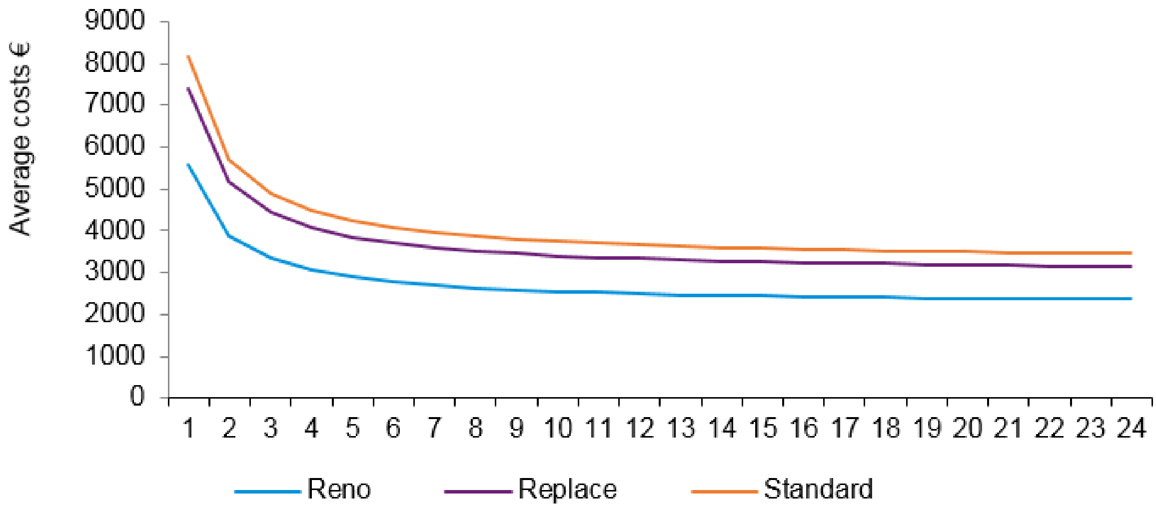


Figure 23: Sustainability costs versus locks scenario 3

Figure 23 shows that for the aspect sustainability, the most beneficial possibility is renovation. This is outcome can be explained by the fact that the assumption has been taken that in case of renovation 78% needs to be recycled. Compared to replacement and standardization, which both need 100% new gates, renovation will always have a lower CO_2 emission. However, in real situations this amount can variate for each location.

The fourth figure will illustrate what the average costs are for each possibility in case different weights are set to the final model, compared to the 1 on each individual aspect in section 8.5. As was concluded previous, the aspect costs has the biggest influence on the outcome in the final model. To determine the level of influence of these weights on the outcome of the final model, the weights of the final model are set on 1 for costs, 5 for performance and 2 for sustainability. By doing this, the aspects performance and sustainability will have a bigger influence and costs relatively lower.

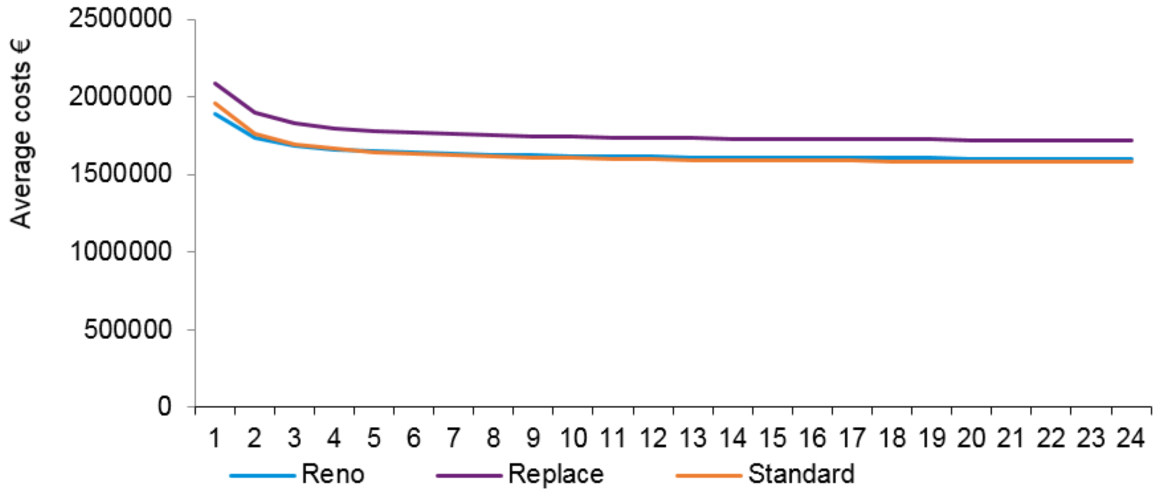


Figure 24: Costs versus locks scenario 4

Figure 24 shows that due the more influence of performance and sustainability, standardization becomes the most beneficial option after implementing standardization at 5 locks. This indicates that standardization is only beneficial whenever it gets implemented at more than 5 locks.

7.6.2 Diversity of assumptions

The fifth figure will illustrate what the average costs for each possibility is case the assumption is taken that the direct construction costs for renovation are 90%, instead of 78%, of the replacements costs of a new set of gates.

The fifth figure will provide an overview what the average costs are for each possibility in case the assumption is taken that the direct construction costs for renovation are 90%, instead of 78%, of the replacements costs of a new set of gates. By doing this, it shows the effect of this assumption on the outcome of the final model.

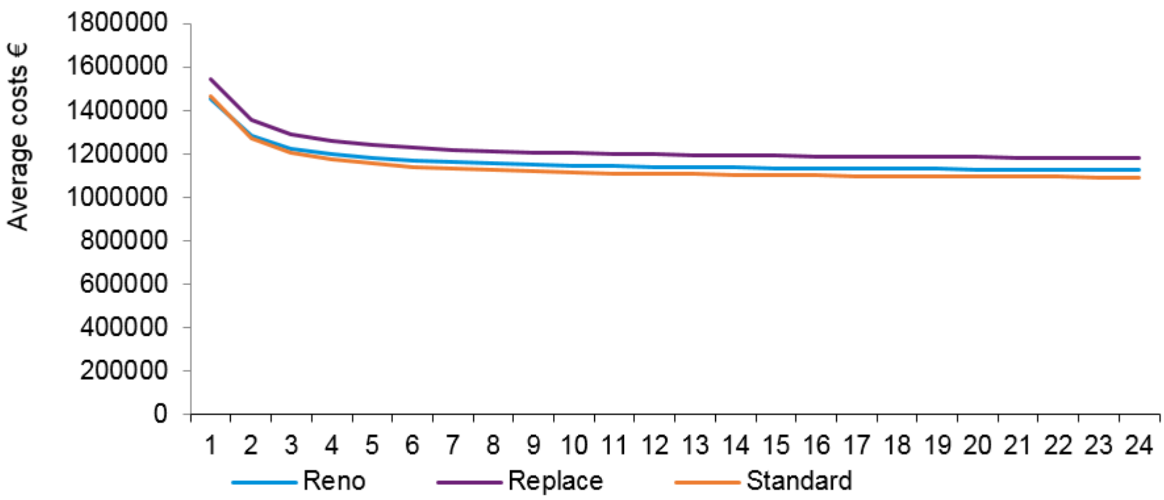


Figure 25: Average costs locks scenario 5

Figure 25 shows the costs for each possibility. This model is based on the assumption that all aspects are equally taken into account. The figure shows that renovation of the gates is cheaper in case of renovation at 1 lock. However, whenever the gates at more than 1 lock needs to get renewed, standardization becomes the most beneficial option.

The sixth figure will provide an overview what the average costs are for each possibility in case the assumption is taken that the direct construction costs for renovation are 50%, instead of 78%, of the replacements costs of a new set of gates. By doing this, it shows the effect of this assumption on the outcome of the final model.

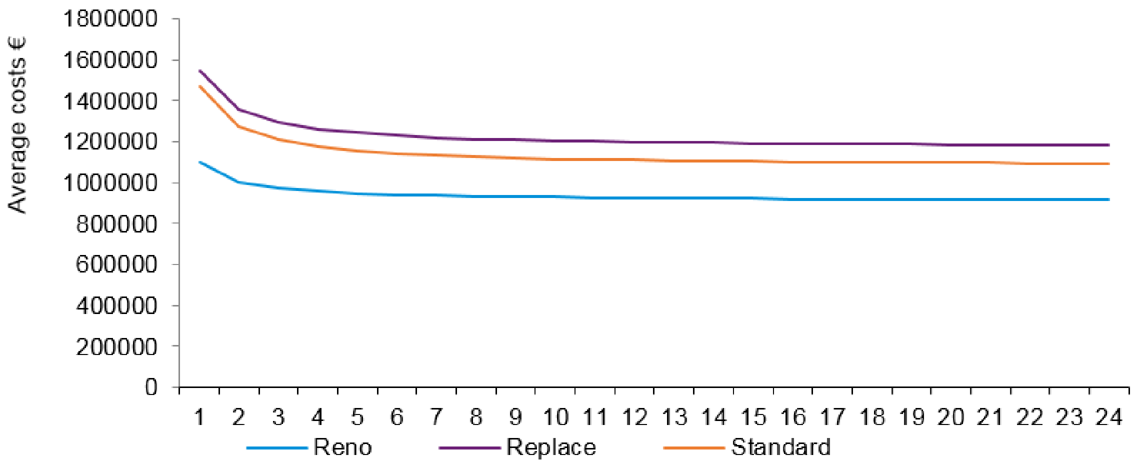


Figure 26: Average costs lock scenario 6

Figure 26 shows the costs for each possibility. This model is based on the assumption that all aspects are equally taken into account. The figure shows that whenever the direct construction costs are 50% of replacement costs that renovation will be significant lower than replacement and standardization. This indicates that the condition of the gates are crucial for the decision making process.

7.7 Conclusions & discussion case study

It can be said that the aspect costs has the biggest influence on the decision making between renovation, replacement or standardization for the component steel mitre gates. This is due that fact the operating and maintenance costs and construction costs are considerably high compared to the performance and sustainability costs. The average operating and maintenance costs are calculated at €516.909,- per year. This number is based on all locks managed by Rijkswaterstaat and refers to an overall average, see table 10. Therefore, this number will most likely not represent the real costs, because there is a great variance in the dimensions, the materials and different types of gates. However, there is no specific data available for the operating and maintenance costs for the bigger and the smaller lock. Thus there will be inconsistencies whenever this average will be applied to individual locks.

Furthermore, the costs of renovation are lower than the other possibilities because the direct construction costs are assumed to be 78% of the replacement costs of a new gate. The costs aspects are highly depended on the state of the gates. Standardization will have the biggest influence at the bigger clusters, because in case of standardization only 1 spare door is needed for the cluster. This will result in a cost reduction per navigation lock in case of standardization between €100,000.00 and €900,000.00, depending on the width and height of the doors.

Secondly, the performance costs has an influence on the outcome. The general performance of a lock is high. However, by applying standards the repair time will be reduced and therefore result in a lower non-availability costs. It is shown that standardization of the mitre gates has a positive influence on the performance aspect. Each navigation lock that gets standardized will result in a costs reduction of €12,500.00. Thus, by applying standard lock gates at multiple locks will save a considerable amount of money.

As third, sustainability has the smallest influence on the outcomes. For this aspect it is also assumed that small operations to the lock result in less CO_2 emissions than bigger operations. Therefore, renovation has the lowest CO_2 emissions compared to regular replacement and replacement by a standard. The results show that standardization of 2 navigation lock will not lead to a positive effect on the sustainability, on as well renovation as the replacement. However, graph 23 shows that standardization can have a positive influence on sustainability costs, it won't have a drastic effect because the gain in costs of each standardized lock is very small. Thus, if more locks will apply standard gates, this will ultimately be seen in the sustainability costs.

Ultimately, comparing figure 20 and figure 24, it shows that the weights on each aspect in the final model can have a big influence on the outcome. By adjusting the weights, the results can drastically change. So, result of when the standardization is the most beneficial option, will highly depend on the asset managers preference on the weights. As the costs will have a high impact on the results, followed by performance and sustainability will have the lowest impact.

8. Conclusion & Discussion

The goal of this thesis was to develop a decision model which helps the asset manager to choose between the possibilities renovation, replacement or standardization of navigation lock components for the MultiWaterWerk program. This chapter first discusses the conclusion, followed by a discussion and after that recommendations are given.

8.1 Conclusion

The conclusion of this study is presented according to the structure of this report, answering each of the sub-questions separately and finally answering the main research question.

Sub-question 1: Which aspects need to be taken into consideration for the development of the model?
Throughout this research it was found that three aspects; costs, performance and sustainability need to be taken into consideration for the development of the model.

Sub-Question 2: How are currently the decisions made about renovation, replacement or standardization?
Throughout this research it was found that the most common strategies and the experts are using different aspects to determine the renewal of a navigation lock component. The interviews indicate that costs, performance and risk are important aspects for deciding making process between these possibilities. However, the management strategies indicate that costs, performance and sustainability form the foundation of the decision making process. After conducting research about the how risk and performance is measured, it was found that risk can be expressed in non-availability and non-reliability, which are also a part of the performance aspect. For this reason risk can be implemented into the aspect performance. Thus, the aspects which need to be taken into consideration for the development of the model are: costs, performance and sustainability.
The concept of standardization is a rather new concept in the world of navigation locks. Therefore, not all the pros and cons are known and thus standardization is not being discussed as one of the possibilities of renewal.

Sub-Question 3: Which effects does standardization have on the performance, costs and sustainability in contrary to regular replacement in general?
Currently, the management strategies and experts are focusing on one location and do not take the multiple locations into account. Standardization of components can lead to the ability to share spare components with other navigation locks. By doing this, material can be saved which saves costs and is better for the environment. Next to that, standardization of a certain component could lead to a faster functioning of the system, because of the availability of this component.

Sub-Question 4: Which effects does standardization have on the performance, costs and sustainability on the component lock gates?

Research shows that standardization of the component lock gates has a positive effect on the performance. Considering the fact that a standardized gate has a lower Mean Time To Repair and therefore a lower non-availability. This results in a higher availability of the navigation lock and thus less economic damages. Furthermore, if standardization takes place at multiple locations, the locks in the same cluster have the possibility to share their spare gate. This results in less direct construction costs and reduces produced CO_2 emissions.

Main research question:
How does a decision model looks like* which helps the asset manager to choose between renovation, replacement or standardization of navigation lock components for the MultiWaterWerk program*?

The final decision model makes use of a multi-criteria analysis which provides the opportunity to make an decision between the three possibilities. With the final model the decisionmaker can decide which aspects are most important. This can be done by putting weights to the aspects costs, performance and sustainability.

Possibilities / Aspects	**Weight**	**Renovation**	**Replacement**	**Standardization (1)**	**Standardization (xx)**
Costs (€)	x	A	B	C	S_1
Performance (€)	y	D	E	F	S_2
Sustainability (€)	z	G	H	I	S_3
Total (€)		xA+yD+zG	xB+yE+zH	xC+yF+zI	$xS_1+yS_2+zS_3$

Table 38: Final decision model

Table 39 shows the final decision model. The final model provides an overview of the total average costs for all the aspects and shows the most optimum solution, in terms of renovation, replacement or standardization. The possibility with the lowest outcome, is the most optimum solution. The additional column standardization (xx) shows what the minimum number of navigation locks is to make a more feasible solution than replacement and renovation. Furthermore, it shows what the average costs are per aspect and the total costs, in case the minimum number of standardized navigation locks is known.

8.2 Discussion

This research is based on the assumption that currently each navigation lock has a set of spare gates available. Therefore, the costs of the gates have a big influence on the decision making between renovation, replacement or replacement by a standard. However, in reality it is possible that not every navigation lock has a set of spare gates available, the influence of performance will be higher because there is no spare gate available which makes the repair time of the lock higher. Moreover, in this scenario the spare gates could function as a definitive solution whenever one gate set not function properly anymore. Thus, this will result in a longer life time of the gates and the replacement costs are considerably lower because an existing component is being used.

It has shown that the direct construction costs of renovation has a big influence on the outcome decision making between the three possibilities The direct construction costs of renovation for the gates in a navigation lock is based on an average, because there is no data available about these renovation costs in the real situation due the fact that the condition of the gate is unknown. Furthermore, for the operating and maintenance costs are based on an average. This average is made by taking all the operating and maintenance costs of the known locks of Rijkswaterstaat and divide them by the total locks. However, these locks have different forms, different dimensions and different type of materials. Thus, if real data was implemented in the model, it would result in a more realistic outcome.

The aspect sustainability is in comparison with the other aspects very low, this can be explained due the fact that sustainability only considers CO_2 emission. Whenever, other methods are used for the calculation of sustainability, this could lead to other costs. For example that in case of replacement or standardization, the component gets replaced by a completely new and more sustainable component, which has lower maintenance costs and overall lower CO_2 emissions. Moreover, in case of the component lock doors, it results in a very low sustainability costs in comparison with the other aspects costs. If cheaper elements, but more polluting components are being considered, the sustainability costs will relatively be higher.
The aspect performance is based the non-performance, which relates to the quantity of ships. However, when the non-performance costs is calculated with the economic damage related to flood damages in case the lower parts of the country will flood, these costs will drastically increase. This will result in a smaller difference between costs of the aspects costs and performance.

In the final model, it is assumed that the weights are evenly distributed over the three aspects. This includes that each aspect has the same influence on the results as the other aspects. However, if the aspects are not evenly distributed, the weights need to be converted. This can be done by calculating the total costs and the costs per aspect individually. This results can be expressed in percentage by dividing the costs per aspects by the total costs and multiplying this by 100%.
This results in the following formula (6):

*(Costs per aspects (€) / Total costs (€)) * 100%= weight of aspect in percentage*

To evenly weight the aspects, the weights of the biggest aspect need to be divided by the weight of the smaller aspects. This results in the multiply factor for the smaller aspects compared to the biggest aspect.
This results in the following formula (7):

Weight biggest aspect (%) / weight smaller aspect (%) = multiply factor

As was concluded in the case study, the aspect costs has the biggest influence on the outcome of the result. To illustrate how the procedure to evenly distribute the weights works, the case study is used.

Possibilities / Aspects	Weight	Renovation (2)	Replacement (2)	Standardization (2)	Standardization (xx)
Costs (€)	1	€ 1.040.034,00	€ 1.216.060,00	€ 1.144.436,00	€ -
Performance (€)	1	€ 134.000,00	€ 134.000,00	€ 121.500,00	€ -
Sustainability (€)	1	€ 3.894,00	€ 5.186,50	€ 5.712,50	€ -
Total (€)		€ 1.177.928,00	€ 1.355.246,50	€ 1.271.648,50	€ -

Table 39: Final model sluis schijndel

This results in the following:

Aspect costs: € 1,040.034.00 / € 1,177,928.00 = 0.8829 → 88.29%

Aspect performance: € 134,000.00 / € 1,177,928.00 = 0.1138 → 11.38%

Aspect sustainability: € 3,894.00 / € 1,177,928.00 = 0.0033% → 0.33%

The biggest aspect is the aspect costs, which has the biggest influence on the results with its 88%.

To evenly weight the aspects with respect to costs, the percentage of costs is divided by the percentage of performance, which results in the multiply factor: 88.29/11,38 = 7.758.

To evenly weight the aspects with respect to costs, the percentage of costs is divided by the percentage of sustainability, which results in the multiply factor: 88.29/0.33 = 267.55.

So, to evenly distribute and compare the three aspects with each other, the weights of performance and sustainability need to be multiplied with the multiply factor, for every point that costs increases. Thus, if the weight of the costs goes up with 1, the weight of performance goes up with 7.76, and the weight of sustainability goes up with 267.55.

The current management strategies can still be used for maintenance of the components. However, whenever the clusters are considered it is wise to use the final decision model to validate whether to invest in standardization or not.

8.3 Recommendations

The goal of MultiWaterWerk is to obtain a better reliability and availability, lower life cycle costs and a more predictable estimation of the construction cost and time.
Currently, a large amount of the data is not recorded and whenever it is recorded, in many cases the data is not structured as experts indicated. So, to reach this goal, it is recommended to record more data and save this data in a structured way. Data about the duration time and costs of small repairs, renovations and replacement of lock gates or other components of the navigation locks.

A follow-up study could be done about what Rijkswaterstaat considers the most important aspects for the MultiWaterWerk program with respect to the weights of the aspects in the final model.

Another possibility for a follow-up study could be about the influence of different types of lock gates, in terms of materials, and how does that affect the outcome of the decision model. Further research could be done to other components of a navigation lock, which have a high suitability for standardization, like; control system and movement equipment's.

This research investigated what the impact of standardization was compared to renovation and regular replacement by the assumption that one spare gate per cluster is sufficient. However, further research could be done about the minimum amount of spare doors needed to guarantee the performance levels for each particular cluster.

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Appendices

Appendix I: MWW lock data

Appendix I shows a table which provides information about all the locks in the MWW program. Among this information the estimated end of the technical life span of the locks is given (Wilschut, 2017).

lock#	naam	region	navigation route	x-coordinate	y-coordinate	hightwater	exceedence	retention	HW retention	locking length	lock width	chambers
1	Sluis III	ZN	7. Maasroute	130533	399297	No	n.v.t.	One sided	Single retention	65	5	2
2	Driewegsluis	NN	5. Amsterdam - Noord-Nederland	235748,5	582746,4	Ja	1/300	One sided	Single retention	47	6	1
3	Ottersluis	WNZ	3. Westerschelde - Rijn	111903	422858	No	n.v.t.	One sided	Single retention	39	7	1
4	Helsluis	WNZ	1. Rotterdam - Duitsland	113280	424836	No	n.v.t.	One sided	Single retention	39	7	1
5	Noordersluis Kleine westelijke sluis	MN	2. Amsterdam - Rijn	135811	451536	No	n.v.t.	Two sided	Single retention	55	7	1
6	Sluis 0	ZN	7. Maasroute	150060	411080	No	n.v.t.	One sided	Single retention	124,2	7	1
7	Sluis Panheel (oude kolk, noord)	ZN	7. Maasroute	188176	354024	No	n.v.t.	One sided	Single retention	145	7,5	2
8	Dorkwerdersluis	NN	5. Amsterdam - Noord-Nederland	229893	586088	Ja	1/100	One sided	Single retention	70	7,5	1
9	Sluis bij Den Hommel	MN	2. Amsterdam - Rijn	134085	454904	Ja	n.v.t.	One sided	Single retention	29	8	1
10	Sluis V	ZN	7. Maasroute	167410	391460	No	n.v.t.	One sided	Single retention	82,39	8	1
11	Sluis 15	ZN	7. Maasroute	180360	364912	No	n.v.t.	One sided	Single retention	65	8	1
12	Sluis II	ZN	7. Maasroute	127800	400930	No	n.v.t.	One sided	Single retention	65	8	1
13	Sluis IV	ZN	7. Maasroute	142497	389940	No	n.v.t.	One sided	Single retention	65	8	1
14	Grote Kolksluis	ON	5. Amsterdam - Noord-Nederland	201360	517120	Onbekend	Onbekend	Two sided	Double retention	Unknown	8	1
15	Sluis Hulsen	ZN	7. Maasroute	181089	365485	Nee	n.v.t.	One sided	Single retention	70,68	9,5	1
16	Kleine Sluis	WNN	8. Kustcorridor	100923	497655	Ja	1/10000	One sided	Single retention	111	11	1
17	Noordersluis Grote oostelijke sluis	MN	2. Amsterdam - Rijn	135842	451567	Nee	n.v.t.	One sided	Single retention	120	12	1
18	Zuidersluis	MN	2. Amsterdam - Rijn	135515	450868	Ja	onbekend	Two sided	Single retention	120	12	2
19	Wilhelminasluis, Andel	ZN	1. Rotterdam - Duitsland	131680	422900	Nee	n.v.t.	Two sided	Single retention	110	12	1
20	Koninginnensluis	MN	2. Amsterdam - Rijn	134797	446485	Ja	n.v.t.	One sided	Double retention	220	12	2
21	Noordersluis	WNN	2. Amsterdam - Rijn	125969	488304	Ja	1/1250	Two sided	Double retention	72	14	1
22	Zuidersluis	WNN	2. Amsterdam - Rijn	125942	488266	Ja	1/1250	Two sided	Double retention	72	14	1
23	Stevinsluizen	MN	5. Amsterdam - Noord-Nederland	132115	549355	Ja	1/10000	Two sided	Double retention	138,75	14	2
24	Lorentzsluizen kamer 1	MN	5. Amsterdam - Noord-Nederland	151684	564705	Ja	1/10000	Two sided	Double retention	137,8	14	1
25	Lorentzsluizen kamer 1	MN	5. Amsterdam - Noord-Nederland	151684	564705	Ja	1/10000	Two sided	Double retention	137,8	14	1
26	Terhorne sluis	NN	5. Amsterdam - Noord-Nederland	180529	561983	Ja	1/100	One sided	Single retention	260	14	2
27	Henriettesluis (Schutsluis Engelen)	ZN	7. Maasroute	146135	415673	Nee	n.v.t.	One sided	Single retention	92	14	1
28	2e Sluis Bewesten Utrecht (Muntsluis)	MN	2. Amsterdam - Rijn	134589	455821	Nee	n.v.t.	One sided	Single retention	120	14	1
29	Sluis Linne	ZN	7. Maasroute	192560	354230	Nee	n.v.t.	One sided	Single retention	267,8	16	1
30	Schutsluis Sambeek oost	ZN	7. Maasroute	196224	405947	Nee	n.v.t.	One sided	Single retention	260	16	1
31	Sluis Roermond	ZN	7. Maasroute	196500	358250	Nee	n.v.t.	One sided	Single retention	266,5	16	1
32	Schutsluis Belfeld oost (oude sluis)	ZN	7. Maasroute	205579	370472	Nee	n.v.t.	One sided	Single retention	260	16	2
33	Sluis Heumen	ZN	7. Maasroute	187080	420210	Ja	1/1250	Two sided	Single retention	250	16	2
34	Middensluis	WNN	2. Amsterdam - Rijn	125955	488284	Ja	1/1250	Two sided	Double retention	95	18	1
35	Zuidersluis	WNN	8. Kustcorridor	101432	497856	Ja	1/10000	One sided	Single retention	104	18	1
36	Prinses Marijkesluis oostelijke sluis	MN	2. Amsterdam - Rijn	152985	440660	Ja	1/1250	One sided	Single retention	260	18	1
37	Prinses Marijkesluis westelijke sluis	MN	2. Amsterdam - Rijn	152969	440630	Ja	1/1250	One sided	Single retention	260	18	1
38	Sluis Eefde	ON	6. Rijn - Oost-Nederland	213017	463916	Ja	Onbekend	One sided	Single retention	140	12	1
39	Sluis Delden	ON	6. Rijn - Oost-Nederland	243142	473971	Nee	n.v.t.	One sided	Single retention	140	12	1
40	Sluis Hengelo	ON	6. Rijn - Oost-Nederland	251809	474061	Nee	n.v.t.	One sided	Single retention	140	12	1
41	Sluis St. Andries	ZN	7. Maasroute	152941	423283	Ja	1/1250	Two sided	Single retention	110	14	1
42	Sluis Lith zuid (oud)	ZN	7. Maasroute	159614	424475	Nee	n.v.t.	Unknown	Single retention	113,5	14	1
43	Sluis 16	ZN	7. Maasroute	174613	361809	Nee	n.v.t.	Unknown	Single retention	76	15,8	1
44	Sluis Weurt oost	ZN	7. Maasroute	185000	429520	Ja	1/1250	Two sided	Single retention	266	16	2
45	Sluis Bosscherveld	ZN	7. Maasroute	176148	319757	Ja	1/250	Unknown	Single retention	132	16	1
46	Sluis Born west	ZN	7. Maasroute	183778	338557	Nee	n.v.t.	Unknown	Single retention	136	16	1
47	Prinses Beatrixsluis westelijke sluis	MN	2. Amsterdam - Rijn	135929	447341	Ja	1/1250	Two sided	Single retention	225	18	1
48	Prinses Irenesluis Oude sluis (sluis 1)	MN	2. Amsterdam - Rijn	150366	442083	Ja	1/1250	Two sided	Single retention	350	18	2
49	Prinses Beatrixsluis oostelijke sluis	MN	2. Amsterdam - Rijn	135954	447333	Ja	1/1250	Two sided	Single retention	225	18	1
50	Middensluis, Terneuzen	ZD	4. Westerschelde	45601	372920	Ja	1/1250	Two sided	Single retention	140	20	1
51	Middensluis	WNN	8. Kustcorridor	101432	497856	Ja	1/10000	Two sided	Single retention	200	25	1
52	Noordersluis	WNN	8. Kustcorridor	102100	498030	Ja	1/10000	Two sided	Single retention	400	47,3	1
	Locks within scope of research											
	Locks outside of scope of research											

lock #	door type	material	#of do	HW outer	LW outer	average out	max locking lvl	min locking lvl	bottom lvl	sill depth	H lock head (NAP)	H door (N.	water type	HW inner	LW inner	average in	max locking lvl	min locking lvl
1	Mitre gate	Wood	2	7,85	7,5	7,7	12,85	7,2					Fresh	12,85	12,35	12,55	7,7	12,85
2	Rolling gate	Wood	3	2,3	0,33	0,53	n.v.t.	n.v.t.	-4,5	-2,95	2,25	4,92	Fresh	0,9		-1,28	n.v.t.	n.v.t.
3	Mitre gate	Wood	2	3,3	0,65		2,49			-2,2	2,8	2,57	Fresh				2,49	
4	Mitre gate	Wood	2	3,5	0,64	0,64	2,49			-1,65	3,05	2,67	Fresh				2,49	
5	Mitre gate	Wood	4	0,8	0	0,45				-3,1	2,38		Fresh	-0,2	-0,5	-0,4		
6	Mitre gate	Steel	2										Fresh					
7	Mitre gate	Steel	2	22,76	20,7			20,6		17,9	29,5		Fresh	28,9	28,58	28,65		28,58
8	Rolling gate	Steel	2	0,9	0,33	0,53	n.v.t.	n.v.t.	-5,95	-2,38	2,8	5,4	Fresh	-0,73	-1,05	-0,93	n.v.t.	n.v.t.
9	Mitre gate	Wood	2						-1,8	-3,1	2,38	2,38	Fresh	-0,2	-0,5	-0,4		
10	Mitre gate	Wood	2										Fresh					
11	Mitre gate	Steel	2	28,85	28,35	28,65			26	26		33,98	Fresh	34,1	33,25	33,61		
12	Mitre gate	Wood	2	5,4	4,95	5,15	7,55	4,95					Fresh	7,85	7,5	7,7	7,55	4,95
13	Mitre gate	Wood	2	12,85	12,2	12,55			9.7	10,1	15,41	15,03	Fresh	15,03	14,75	15		
14	Mitre gate	Wood	4	1,8	-1,74								Fresh	1,2	-0,9	-0,16		
15	Mitre gate	Wood	2			28,65							Fresh			31,65		
16	Mitre gate	Steel	2	5,15	-3	0,97/-0,73	2	-1,5	-5,9	-3,75	5,85	4,85	Salt	-0,3	-0,5	-0,4		
17	Mitre gate	Wood	2	0,8	0	0,45			-3	-3,73	2,38		Fresh	-0,2	-0,5	-0,4		
18	Mitre gate	Wood	5	0,8	0	0,45			-3.25	-3,73			Fresh	-0,2	-0,5	-0,4		
19	Waaierdeur	Steel	2	5,23		0,95	4,5			-2,14	5,86	5,23	Fresh	3,5		0,65		
20	Mitre gate	Steel	4	6,5	-1,15	1,09	4,7	-0,4		-2,25		7,12	Fresh	0,8	0,3	0,45		
21	Mitre gate	Steel	3	0,7	-3,17	-0,4 tot -0,2				-4,5	2,5	1,85	Fresh	0,89	-0,71	-0,4		
22	Mitre gate	Steel	3	0,7	-3,17	-0,4 tot -0,2				-4,5	2,5	1,85	Fresh	0,89	-0,71	-0,4		
23	Mitre gate	Steel	6	4,5			1,8			-4,4	5	4,88	Salt	1,2	-1,13	-0,4 tot -0,2		
24	Mitre gate	Steel	5	4,75			1,8			-4,4	5,25	5,13	Salt	1,2	-1,13	-0,4 tot -0,2		
25	Mitre gate	Steel	5	4,75			1,8			-4,4	5,25	5,13	Salt	1,2	-1,13	-0,4 tot -0,2		
26	Mitre gate	Steel	4	-0,52		n.v.t.	0	n.v.t.	-4,5	-4,66	n.v.t.	n.v.t.	Fresh			-0,52	n.v.t.	n.v.t.
27	Mitre gate	Wood	2										Fresh					
28	Mitre gate	Steel	2	0,8	0	0,45				-3,33	2,32		Fresh	-0,2	-0,5	-0,4		
29	Mitre gate	Steel	3		20,7	20,85				16,6	22,6	23,35	Fresh		16,7	16,85		
30	Mitre gate	Steel	3			11,1						11,9	Fresh			7,65		
31	Mitre gate	Steel	3		16,7	16,85				11,9	21,25	20,55	Fresh		14,05	14,1		
32	Mitre gate	Steel	2		11	14,05				7,45		15	Fresh			14,1		
33	Mitre gate	Steel	3	12,46	7,41		12,15	8,3	3,35	3,35	13,4	13,4	Fresh	8,3	7,6			
34	Mitre gate	Steel	3	0,7	-3,17	-0,4 tot -0,2				-4,5	2,5	1,85	Fresh	0,89	-0,71	-0,4		
35	Mitre gate	Steel	2	5,15	-3	0,97/-0,73	2	-1,5	-8,5	-7,85	5,85	4,85	Salt	-0,3	-0,5	-0,4		
36	Mitre gate	Steel	2	8,15	1,2					-2,35		9	Fresh	5,55				
37	Mitre gate	Steel	2	8,15	1,2					-2,35		9	Fresh	5,55				
38	Vertical lift	Steel	2		1,55				-1	0		9,95	Fresh	10,1	9,9	10		
39	Vertical lift	Steel	2	10,42	8,65				6,55	6,56	21,52		Fresh	16,5	14,35			
40	Vertical lift	Steel	2	16,5	14,3					12,2	25,8		Fresh	25,37	23,35	25		
41	Vertical lift	Steel	2	10,05	4,86				-3	-3	10,55	10,5	Fresh	6,96	4,2			
42	Vertical lift	Steel	2							-3			Fresh					
43	Vertical lift	Steel	2	34,1	33,25						36,43		Fresh	36,1	35,4	35,68		
44	Rolling gate	Steel	3	14,66	4,22					3	15,1	13	Fresh	8,6	7,6	7,6 tot 8,5		
45	Vertical lift	Steel	2	44,17	43,9				40,4	36,4	46	47,3	Fresh	40,48	40,3	40,35		
46	Vertical lift	Steel	2		43,9								Fresh		32,5	32,65		
47	Vertical lift	Steel	2	6,4	-1,15					-4,5	6,5		Fresh	-0,2	-0,5	-0,4		
48	Vertical lift	Steel	3	8,4	1,2				-2,3	-5,5	9,1	9,1	Fresh	-0,2	-0,5	-0,4		
49	Vertical lift	Steel	2	6,4	-1,15					-4,5	6,5		Fresh	-0,2	-0,5	-0,4		
50	Rolling gate	Steel	4	5,8					-7,58				Fresh			2,13		
51	Mitre gate	Steel	6	5,15	-3				-10,6	-10	5,85	5,85	Salt	-0,3	-0,5	-0,4		
52	Rolling gate	Steel	2	5,15	-3				-15,5	-15	5,85	5,85	Salt	-0,3	-0,5	-0,4		

lock #	bottom lvl	sill depth	lock head (NAP	door (NAP	water type	constructed	end LC	lvling type	# openings	#valves	drive mechanism	drive mechanism	remote ctrl	setting dry	ship class	lockings/year	lvling time
1					Fresh	1916	2025	Culverts	Unknown	Unknown	Elektromechanical	Elektrohydraulisch	Yes	Unknown	CEMT II	Unknown	Unknown
2		-2,95	2,3	4,79	Fresh	1934	2043	Unknown	4	2	By hand	By hand	Yes	Unknown	CEMT II	Unknown	Unknown
3		-2,2	2,8	2,57	Fresh	1863	2035	In doors	2	2	Elektrohydraulic	Elektrohydraulisch	Yes	Yes	CEMT I	5188	Unknown
4		-2,2	3,05	2,67	Fresh	1863	2035	In doors	2	2	Elektromechanical	Handmatig	Yes	Yes	CEMT 0	4605	Unknown
5		-3,1	2,38		Fresh	1937	2046	In doors	4	2	Elektrohydraulic	Elektrohydraulisch	Yes	No	CEMT Va	4254	<3 min
6					Fresh	1931	2040	In doors	Unknown	Unknown	Elektromechanical	Elektrohydraulisch	Yes	Unknown	CEMT II	19	Unknown
7		25,5	29,5		Fresh	1930	2039	Culverts	Unknown	Unknown	Elektromechanical	Elektromechanisch	Yes	Yes	CEMT II	5049	Unknown
8	-5,9	-3	2,8	5,4	Fresh	1929	2038	Culverts	Unknown	Unknown	Elektrohydraulic	Elektromechanisch	Unknown	Yes	CEMT II	3577	Unknown
9	-3,1	-3,1	2,38	2,38	Fresh	1937	2046	In doors	Unknown	2	Elektromechanical	Elektromechanisch	Yes	No	CEMT Va	Unknown	Unknown
10					Fresh	1920	2035	Unknown	Unknown	Unknown	Unknown	Unknown	Yes	Unknown	CEMT II	Unknown	Unknown
11	30,35	30,8		33,98	Fresh	1930	2051	Culverts	32	4	Elektrohydraulic	Elektromechanisch	Yes	Yes	CEMT II	5177	< 15 min
12					Fresh	1916	2025	Culverts	Unknown	Unknown	Elektromechanical	Elektrohydraulisch	Yes	No	CEMT II	Unknown	Unknown
13	11,9	12,26	15,41	15,03	Fresh	1920	2058	Culverts	8	Unknown	Elektrohydraulic	Elektrohydraulisch	Yes	Yes	CEMT II	Unknown	Unknown
14					Fresh	1942	2057	In doors	Unknown	Unknown	Elektromechanical	Elektromechanisch	Unknown	Unknown	CEMT III	Unknown	Unknown
15					Fresh	1932	2032	Culverts	Unknown	Unknown	Elektromechanical	Elektromechanisch	Yes	Unknown	CEMT II	Unknown	Unknown
16	-7,5	-3,75		3,5	Fresh	1876	2051	In doors	4	4	Elektrohydraulic	Elektrohydraulisch	Yes	No	CEMT IV	Unknown	Unknown
17	-3,9	-3,73	2,38	2,35	Fresh	1937	2046	In doors	6	2	Elektrohydraulic	Elektrohydraulisch	Yes	No	CEMT Va	767	<5 min
18	-3,25	-3,73		2,35	Fresh	1937	2046	In doors	Unknown	2	Elektrohydraulic	Elektrohydraulisch	Yes	No	CEMT Va	7174	Unknown
19		-2,89	5,86	5,23	Fresh	1896	2033	In doors	4	4	Elektromechanical	Elektromechanisch	Yes	No	CEMT Va	4481	Unknown
20		-2,7		3,55	Fresh	1885	Onbekend	In doors	4	4	Elektromechanical	Elektrohydraulisch	Yes	Yes	CEMT Va	3897	Unknown
21		-4,5			Fresh	1870	2059	In doors	4	4	Elektrohydraulic	Elektrohydraulisch	Yes	No	CEMT III	14773	< 7,5 min
22		-4,5			Fresh	1870	2059	In doors	4	4	Elektrohydraulic	Elektrohydraulisch	Yes	No	CEMT III	2030	< 7,5 min
23		-4	3	2,88	Fresh	1930	2051	In doors	Unknown	Unknown	Elektromechanical	Elektrohydraulisch	Yes	Unknown	CEMT Va	7583	Unknown
24		-4	3	2,88	Fresh	1931	2051	Culverts	Unknown	Unknown	Elektromechanical	Elektrohydraulisch	Yes	Unknown	CEMT Va	10689	Unknown
25		-4	3	2,88	Fresh	1931	2051	Culverts	Unknown	Unknown	Elektromechanical	Elektrohydraulisch	Yes	Unknown	CEMT Va	10689	Unknown
26	-4,5	-4,66	2,08	5,75	Fresh	1948	2057	In doors	2	2	Elektromechanical	Elektromechanisch	Yes	No	CEMT IV	Unknown	Unknown
27					Fresh	1898	2035	Culverts	Unknown	Unknown	Elektromechanical	Elektromechanisch	Yes	No	CEMT IV	7859	Unknown
28		-4,18	2,32		Fresh	1906	Onbekend	In doors	Unknown	2	Elektromechanical	Elektromechanisch	Yes	No	CEMT Va	Unknown	Unknown
29		13,45	24	21,95	Fresh	1921	2035	Culverts	36	6	Elektromechanical	Elektromechanisch	Yes	Yes	CEMT Va	6033	<7 min
30			12,6	11,9	Fresh	1925	2034	In doors	Unknown	Unknown	Elektromechanical	Elektromechanisch	Yes	Unknown	CEMT Va	9016	Unknown
31		10,7	17,75	17,05	Fresh	1926	2035	Culverts	36	6	Elektromechanical	Elektromechanisch	Yes	Yes	CEMT Va	6880	<7 min
32		8,45	15,6	15	Fresh	1926	2035	In doors	Unknown	Unknown	Elektrohydraulic	Elektromechanisch	Yes	Yes	CEMT Va	6291	Unknown
33	3,35	3,35	12,5	12,5	Fresh	1927	2036	Culverts	26	Unknown	Elektromechanical	Elektrohydraulisch	Yes	No	CEMT Vb	Unknown	< 21 min
34		-4,5			Fresh	1870	2059	In doors	4	4	Elektrohydraulic	Elektrohydraulisch	Yes	No	CEMT IV	15187	< 7,5 min
35	-8,5	-7,85		3,5	Fresh	1876	2051	In doors	6	6	Elektrohydraulic	Elektrohydraulisch	Yes	No	CEMT Va	Unknown	Unknown
36		-2,35			Fresh	1937	2046	In doors	8	4	Elektromechanical	Elektromechanisch	Yes	Unknown	CEMT VIb	0	Unknown
37		-2,35			Fresh	1937	2046	In doors	8	4	Elektromechanical	Elektromechanisch	Yes	Unknown	CEMT Vb	0	Unknown
38		6,5		10,6	Fresh	1933	2051		6	6				Yes	CEMT Va	14618	Unknown
39	12,1	12,25	17	16,5	Fresh	1933	2042		n.v.t.	n.v.t.				No	CEMT Va	10735	Unknown
40	21,1	21,25	25,8		Fresh	1935	2044		6	6				No	CEMT Va	1508	Unknown
41	-3,2	-3	8,25	8,78	Fresh	1934	2043		n.v.t.	n.v.t.				Unknown	CEMT Va	14050	<8 min
42		-1			Fresh	1936	2045		Onbekend	Onbekend				No	CEMT Va	10229	Unknown
43		32,43	36,43		Fresh	1930	2039		n.v.t.	n.v.t.				No	CEMT II	4081	Unknown
44		3	11,04	11,04	Fresh	1927	2030		2	6				Yes	CEMT Vb	11873	Unknown
45	36,4	40,4	46,03	45,5	Fresh	1930	2039		n.v.t.	n.v.t.				Yes	CEMT Va	4900	Unknown
46					Fresh	1933	2042		Onbekend	Onbekend				Yes	CEMT Va	4237	Unknown
47		-4,5			Fresh	1933	2055		6	6				Yes	CEMT Vb	19624	<7 min
48	-4,7	-5,5	9,1	9,1	Fresh	1937	2046		6	6				Unknown	CEMT Vb	13094	Unknown
49		-4,5			Fresh	1938	2055		6	6				Yes	CEMT Vb	20210	<7 min
50					Salt	1910	2034		Onbekend	Onbekend				Unknown	CEMT VIb	7538	Unknown
51	-10,6	-10		2,5	Fresh	1891	2047		10	10				No	CEMT VIa	Unknown	< 12 min
52	-15,5	-15		5	Fresh	1923	2051		4	4				Yes	CEMT VIa	Unknown	Unknown

Appendix II: CO_2 emissions

Emission factors in kg CO2-equivalent per unit						
Categories			Label		Default value	
Category 1	Category 2	Category 3	Title	Unit	Emission factor (kg CO2eq per unit)	Uncertainty
Conversion	Gas	GWP	GWP CH4	kg	25.00	0%
Conversion	Gas	GWP	GWP N2O	kg	298.00	0%
Energy	Electricity	Country	Canada	kWh	0.19	10%
Energy	Heat	Combustible	Black coal	kWh	0.32	
Energy	Heat	Combustible	Brown coal	kWh	0.40	10%
Energy	Heat	Combustible	Brown coal briquette	kWh	0.40	10%
Energy	Heat	Combustible	Brown coal coke	kWh	0.50	10%
Energy	Heat	Combustible	CNG	kWh	0.18	
Energy	Heat	Combustible	Coal coke	kWh	0.39	10%
Energy	Heat	Combustible	Crude oil	kWh	0.27	5%
Energy	Heat	Combustible	Diesel (kWh)	kWh	0.30	5%
Energy	Heat	Combustible	Diesel (liter)	liter	2.79	5%
Energy	Heat	Combustible	Ethane	kWh	0.20	
Energy	Heat	Combustible	Fuel oil (kWh)	kWh	0.29	5%
Energy	Heat	Combustible	Fuel oil (liter)	liter	3.19	5%
Energy	Heat	Combustible	Gas flared	kg	3.53	
Energy	Heat	Combustible	Kerosene	kWh	0.27	5%
Energy	Heat	Combustible	LNG (kWh)	kWh	0.21	5%
Energy	Heat	Combustible	LPG (liter)	liter	1.69	10%
Energy	Heat	Combustible	Natural gas	kWh	0.21	5%
Energy	Heat	Combustible	Petroleum coke	kWh	0.35	10%
Energy	Heat	Combustible	UNG	kWh	0.18	
Energy	Heat	Organic combustible	Biodiesel (kWh)	kWh	0.01	
Energy	Heat	Organic combustible	Biodiesel (liter)	liter	0.81	
Energy	Heat	Organic combustible	Bioethanol	kg	1.21	10%
Energy	Heat	Organic combustible	Biogas (kg)	kg	1.61	
Energy	Heat	Organic combustible	Biogas (kWh)	kWh	0.02	
Energy	Heat	Organic combustible	Biogas (m3)	m3	0.12	
Energy	Heat	Organic combustible	Biomass (kg)	kg	0.11	10%
Energy	Heat	Organic combustible	Biomass (kWh)	kWh	0.03	10%
Energy	Heat	Organic combustible	Methanol	kg	0.30	
Energy	Heat	Organic combustible	Petrol, 85% ethanol	kg	1.16	
Energy	Heat	Steam	Steam	kg	0.61	0%
Material	Building	Insulation	Glasswool	kg	1.35	
Material	Building	Insulation	Insulation	kg	1.86	
Material	Building	Insulation	Mineral wool	kg	1.20	
Material	Building	Insulation	Wool	kg	0.15	
Material	Building	Insulation	Wool r.	kg	3.17	
Material	Construction material	Cement	Cement	kg	0.89	20%
Material	Construction material	Concrete	Concrete (kg)	kg	0.15	20%
Material	Construction material	Concrete	Concrete (m3)	m3	263.00	
Material	Construction material	Concrete	Reinforced concrete	kg	0.36	20%
Material	Construction material	Fibre	Fibreglass	kg	2.60	20%
Material	Construction material	Gravel	Gravel	ton	4.32	
Material	Construction material	Lime	Lime	kg	0.74	
Material	Construction material	Other	Anthracite	kg	0.53	10%
Material	Construction material	Other	Other	kg	3.00	80%
Material	Construction material	Sand	Sand	kg	0.01	
Material	Iron metal	Iron	Cast iron	kg	1.51	
Material	Iron metal	Iron	Iron	kg	1.91	
Material	Iron metal	Steel	Reinforced steel	kg	1.49	
Material	Iron metal	Steel	Stainless steel	kg	6.15	
Material	Iron metal	Steel	Steel	kg	1.77	
Material	Iron metal	Steel	Steel r.	kg	0.88	10%
Material	Iron metal	Steel	Steel v.	kg	3.29	10%
Material	Non iron metal	Aluminium	Aluminium	kg	8.14	
Material	Non iron metal	Aluminium	Aluminium r.	kg	2.01	30%
Material	Non iron metal	Aluminium	Aluminium v.	kg	11.89	30%
Material	Non iron metal	Copper	Copper	kg	2.77	50%
Material	Non iron metal	Copper	Copper v.	kg	3.83	
Material	Non iron metal	Glass	Glass	kg	0.85	
Material	Non iron metal	Glass	Glass r.	kg	0.73	20%
Material	Non iron metal	Glass	Glass v.	kg	4.40	20%
Material	Non iron metal	Lead	Lead	kg	1.64	30%
Material	Non iron metal	Lead	Lead r.	kg	0.53	
Material	Non iron metal	Lead	Lead v.	kg	2.61	
Material	Non iron metal	Nickel	Nickel	kg	11.53	30%
Material	Non iron metal	Other	Other metal	kg	4.40	80%
Material	Non iron metal	Zinc	Zinc	kg	3.41	20%

Appendix III: Dump costs

This table shows the dump costs for non-recyclable materials. Source: https://recyclingkampen.nl/tarieven-2-2/

Afvalstroom	1000 kg (excl. BTW)	1000 kg (incl. BTW)	100 kg (inc
Bedrijfsafval	€ 198.35	€ 240,00	€ 24,00
Grof Huisafval	€ 198.35	€ 240,00	€ 24,00
Matrassen	€ 198.35	€ 240,00	€ 24,00
Schoon Riet	€ 198.35	€ 240,00	€ 24,00
Vloerbedekkiing	€ 198,35	€ 240,00	€ 24,00
Bouw-en sloopafval	€ 177,69	€ 215,00	€ 21,50
Gips	€ 177,69	€ 215,00	€ 21,50
Dakleer	€ 177,69	€ 215,00	€ 21,50
Harde kunststoffen	€ 177,69	€ 215,00	€ 21,50
Hout C-kwaliteit	€ 177,69	€ 215,00	€ 21,50
Hout B-Kwaliteit	€ 62,00	€ 80,00	€ 8,00
Asbest (verpakt in folie)	€ 198,35	€ 240,00	€ 24,00
Schoon Puin	€ 15,00	€ 18,50	€ 1,85
Grond (schoon)	€ 24,80	€ 30,00	€ 3,00
Grof Tuinafval	gratis	gratis	gratis

Appendix IV: Interviews

This appendix shows the conducted interviews.

Interview expert 1

Dit is een interview betreft het onderhoud van de sluisdeuren van de sluizen in het programma MultiWaterWerk. Hieruit wordt het risicoprofiel en de onderhoudsstrategie bepaald.

Deze vragen hebben alleen betrekking op de deuren van de sluis.

In het groen zijn de vragen concreter opgeschreven. Gate middel van o.a. deze vragen wil ik de hoeveelheid reservedeuren bepalen per cluster. Een aantal sluizen van het programma MultiWaterWerk wordt gestandiseerd en is geclusterd in 5 groepen, hiervan ga ik het aantal reservedeuren bepalen.

1. **1.** Wat zijn de afmetingen van de sluisdeur?
Kan variëren afhankelijk van de afmetingen van de sluis en schepen. Breedte van een puntdeur in het algemeen ca 5-8 m, hoogte 8- 10 m maar afwijkingen komen voor.

2. **2.** Hoeveel sluisdeuren heeft de sluis?
Uitgaande van puntdeuren 4 stuks (meest voorkomende oplossing) maar ook andere aantallen komen voor: hef en zwaaideuren meestal 2 per sluis, maar ook 8 deuren (dubbelkerende sluizen met puntdeuren) en andere oplossingen komen voor. Daarnaast heeft een sluis meestal ook een set reservedeuren die in opslag liggen.

3. **3.** Hoeveel sluizen heeft u in beheer?
in ZN ca 50

4. **4.** Onderhoudshistorie (wanneer werd wat onderhouden en hoelang duurde dit);

a. Werkelijke reparatietijden
b. Werkelijke inspectie- en onderhoudsintervallen
c. Werkelijke inspectie- en onderhoudsgatelooptijden
daarvoor zou je onderhoudsloggingen en P-IHP's moeten raadplegen, de info is er wel is een erg uitgebreide dataset. Het lijkt handig om eerst de vraag te specificeren voordat we alle data gaan opzoeken.

➔ Onderhoudsloggings en P-IHP's (prestatie instandshoudingsplan).
- Onderhoudsloggings en P-IHP's volgende sluizen:
  - Sluis lll avb: vaste balk voor benedendeur
  - Sluis 0 –niet meer in beheer bij RWS-
  - Sluis Panheel avb: vaste balk voor benedendeur?
  - Sluis V –buiten gebruik-
  - Sluis 15 avb: geen
  - Sluis ll avb: geen
  - Sluis lV avb: geen
  - Sluis Hulsen –buiten gebruik-
  - Wilhelminasluis, Andel avb: geen
  - Henriettesluis (schutsluis Engelen) – niet meer in beheer bij RWS-

- Sluis Linne avb: geen
- Schutsluis Sambeek oost avb: ?
- Sluis Roermond avb: ?
- Schutsluis Belfeld oost (oude sluis) avb: ?
- Sluis Heumen avb: geen

- Hierbij de vraag de onderhoudshistorie van de sluisdeuren (wanneer werd wat onderhouden, hoelang duurde dit), specifiek per sluis.
  Bovenstaande informatie is erg veel uitzoekwerk en niet gestructureerd beschikbaar. Ook onze P-IHP's zijn op dit moment op dit punt niet zover dat je er gebruik van kunt maken voor een dergelijke analyse.
  Het enige redelijk bruikbare bestand is misschien het OBR. Mogelijk dat GPO-ICO ergens nog data heeft die ooit verzameld is hierover.

5. Onderhoudsstrategie (wat voor vervangings- reparatie strategie is van toepassing op de sluisdeur op het moment?);

a. Is er een handleiding van wat en wanneer vervangen dient te worden? Daarvoor is ons onderhoudsregime van toepassing dat bestaat uit een zgn OBR (het onderhoudsboekje), inspectiestrategie en programmeringsinformatie (maatregelen en budgetplanning met bijbehorende spelregels)

➔ Is dit een algemeen onderhoudsregime, of is dit per sluis? Zo ja, dan aan Erik-Jan document vragen. Zo nee, heeft u dit document voor mij?

➔ OBR is generiek voor heel RWS en landelijk via intranet te raadplegen.

➔ Via Rups en DISK zijn per object de maatregelen te raadplegen en de inspectieplanning en rapportages in te zien.

b. Hoe is de communicatie binnen de organisatie (project team, de aannemer)? Ziet u verbeterpunten hierin?
is een erg algemene vraag die nadere toelichting vraagt. We hebben tal van informatiesystemen en documenten die we hierin gebruiken.

➔ Hoe is de communicatie binnen het project team (dus indien er een bijvoorbeeld een aanvaring met een deur en deze dient vervangen te worden, via welke weg wordt er gecommuniceerd)?

➔ Bij een aanvaring of andere storing of gebrek zal de dienstdoende operator deze constateren. Via een centraal punt wordt een storingsmelding naar onze opdrachtnemers gedaan die dan in actie komen. Bij een grote verstoring zal er ook een RWS medewerker ter plaatse gaan die beoordeelt hoe ernstig de schade is en eventueel een deur vervangen of verwisseld moet worden. Daar zullen de betrokken disciplines vanuit RWS en ON overleg over voeren. Bij een schadevaring speelt ook nog dat politie en verzekeringsmaatschappijen een rol spelen bij de afhandeling. Het wel of niet vervangen van een deur is overigens altijd een RWS beslissing.

c. Hoe is de communicatie naar buiten (gebruikers)? Ziet u verbeterpunten hierin? Informatie aan scheepvaart loopt via het systeem van de "Berichtgeving aan de Scheepvaart (de zgn BAS berichten). Bij gepland onderhoud wordt ook omgevingscommunicatie en gerichte communicatie met betrokken partijen gevoerd.
Dit loopt in het algemeen goed.

6. Is er een tijdsnorm voor correctief onderhoud? Is hier documentatie van? (per onderdeel / object ?
We hebben herstel tijden die onze ON-ers moeten halen bij het optreden van een storing.
➔ Is hier documentatie van zodat ik hier inzicht in kan krijgen? (Bijvoorbeeld dat de aannemer binnen 8 uur een nieuwe sluisdeur installeert?)
Voor een eenvoudige storing of gebrek dient er storingsherstel plaats te vinden conform onze contracteisen. Daar staat meestal in dat er binnen een bepaalde tijd een deskundige monteur ter plaatse dient te zijn (1 uur meestal) en/of dat er functioneel herstel (het object moet zijn functie weer kunnen vervullen) binnen meestal 2 uur moet zijn. Dit is voor storingen zoals elektro en mechanische zaken in aandrijvingen, sensoriek etc. ook redelijk haalbaar. Bij een grote schade zoals een aanvaring is het situationeel en gelden er geen hersteltijden, dat zou ook niet redelijk zijn. Immers het is zeer afhankelijk van de situatie en de omvang van de schade hoelang herstel gaat duren. Dat kan uren, dagen, weken en zelfs maanden zijn.

7. Is er een tijdsnorm voor preventief onderhoud? Is hier documentatie van? (per onderdeel / object)
Er is een maximale tijd dat onze objecten op jaarbasis niet beschikbaar mogen zijn en een procentuele beschikbaarheidseis (prestatieafspraken tussen Ministerie van IenW en RWS).
→ in welke documenten worden deze afspraken vastgelegd en kan ik hier inzicht in krijgen? Weegt mee in de bepaling van het aantal reservedeuren per cluster.
Ligt vast in de SLA afspraken tussen ministerie en RWS zijn opvraagbaar bij WVL.
Overigens weegt dit in principe wel mee maar in de praktijk wordt er niet op gestuurd omdat de reservedeuren per cluster nauwelijks bijdragen aan de uren niet beschikbaarheid. Het is meer een afweging die in de ontwerpfase wordt gemaakt.
Daarbij spelen kosten en onderhoudsstrategie voor het object een rol.

8. Wanneer dient een stremming te worden aangevraagd? (voor welke werkzaamheden dient er een stremming worden aangevraagd)
Voor alle werkzaamheden waarbij hinder voor de scheepvaart is moet een stremming worden aangevraagd (alle werkzaamheden worden gemeld, als er geen hinder is dan ook geen stremming uiteraard). We streven naar minimale hinder.

9. Is de huidige onderhouds-/vervangingsstrategie afdoende gezien de beschikbaarheid van het onderdeel?
In het algemeen wel

a. Verbeterpunten op een bepaald vlak? (klopt de werkelijke reparatietijd met de geplande reparatietijd, werkelijke inspectie- en onderhoudsintervallen met de geplande tijd, en de werkelijke inspectie- en onderhoudsgatelooptijden met de geplande?) valt moeilijk generiek iets van te zeggen, in het algemeen klopt het wel.

➔ Is hier documentatie van? Bijvoorbeeld; vervanging deur. Gepland: 10 uur. Werkelijke tijd: 9 uur. Ik ben bang van niet. zouden we in de toekomst wel moeten krijgen gate verbeterde vastlegging van gegevens. Enige mogelijkheid is dat je in de gegevens van VWM gaat zoeken dit is een handmatige zoekactie.

10. Zijn hulpmiddelen en speciaal gereedschap nodig voor het uitvoeren van werkzaamheden en zijn deze beschikbaar (schotbalken, reservedeur etc.)
Ja, deze zijn beschikbaar, onderhoudstoestand hiervan varieert.

→ Is er een overzichtslijst met hulpmiddelen en het gereedschap, kan ik hier inzicht in krijgen? Moet mogelijk zijn maar is erg versnipperde informatie dus zou veel uitzoek werk vragen. Vraag is even wat je er aan hebt. Je mag er vanuit gaan dat de benodigde materialen beschikbaar zijn of geleverd kunnen worden gate een ON. Als er speciale zaken nodig zijn dan zijn deze in het algemeen bij het object bijgeleverd. Of alle zaken nog daadwerkelijk aanwezig zijn en in goede onderhoudstoestand is onzeker. Dit heeft mede te maken met in het verleden gemaakte keuzes t.a.v. beheer en onderhoud.

11. Is er speciale kennis en kunde nodig om het onderhoud uit te kunnen voeren?

a. Is het onderhoud uitbesteed, en in welke vorm? Ja, afhankelijk van het soort onderhoud aan generieke of specialistische partijen. Vrijwel alle disciplines zijn betrokken (staal, beton, hout, werktuigbouw, IA, conservering etc etc)

b. Hoe wordt hierover gecommuniceerd? ??? onduidelijk wat je hier bedoeld , communicatie tussen disciplines vindt meestal plaats binnen het kader van projecten en contracten.

12. Is de benodigde technische documentatie beschikbaar (formulieren, checklists)? Ja, inspectieformulieren etc. in het system Disk

→ Kan ik inzicht krijgen in het system Disk? Ja zou via Erik-Jan moeten gaan, hij kan beoordelen of jij geauthoriseerd mag/kan worden.

13. Is er een back-up beschikbaar (noodgenerator bij energie uitval)?

a. Indien de sluisdeuren niet meer open willen i.v.m. software storing, wat gebeurt er dan? Handmatig? Diverse opties, afhankelijk van oorzaak en ernst storing. Variërend van herstel op afstand tot lokaal bedienen tot handmatig of met hulpmiddelen bedienen.

14. Welke reserveonderdelen zijn aanwezig? Welke zijn noodzakelijk? meestal een complete set deuren met bijbehorende middelen zoals schuiven, aandrijfwerken etc. maar het varieert per object. Regel is min of meer dat grote onderdelen die specifiek voor het object zijn en een lange vervaardigings of levertijd kennen als reserve aanwezig zijn.

→ Is er een lijst van reserveonderdelen, waar ik inzicht in kan krijgen? Zie 10.

15. Hoe is de bereikbaarheid van de onderdelen? Op terreinen van RWS of in magazijn van RWS of derden. Vaak groot materieel nodig om onderdelen te verplaatsen of te vervoeren.

16. Zijn er fysieke beperkingen die gevolgen hebben voor het onderhoud aan het onderdeel (bijvoorbeeld: is de sluisdeur te groot om die ter plekke te onderhouden / op te slaan?) Ja, situatie afhankelijk en ook milieutechnische eisen kunnen tot beperkingen leiden.

17. Wat zijn de storing-/faalfrequenties van onderdelen van de sluisdeur? (documentatie) zie vraag 4

18. Het document RINK zegt het volgende: 'De kans op aanvaring van sluisdeuren wordt bepaald op basis van informatie uit de SOS-database van RWS en/of de interviews van de beheerders'. Kunt u mij uw inschatting geven van dit risico en heeft u wellicht informatie uit de SOS-database van RWS? → Excel

Kans op aanvaren is reëel: in ons areaal orde 1-2 maal per jaar waarbij schade zodanig is dat sluis gestremd is. Duur en ernst van schade kan zeer uiteen lopen.

➔ Is hier een verslaglegging van, zodat ik inzicht krijg ik de kosten en de duur van de reparatie?

➔ Zou op projectniveau uitgezocht moeten worden aan de hand van een specifieke casus. Die zijn er wel maar kost tijd en geld om het uit te zoeken.

19. Hoe nuttig is een reservedeur volgens u? (zeer zeker nodig, zeker nodig, nodig, niet echt nodig, niet nodig. Bijvoorbeeld: de kans dat een schip er tegenaan vaart is bijzonder klein) → Excel
Is afhankelijk van situatie en belang van vaarweg. Reserve deur kan ook functie hebben voor regulier onderhoud (deuren wisselen). Omdat het vervaardigen van een deur lang duurt en een stremming van die duur zelden acceptabel is wordt in het algemeen gekozen voor het hebben reserve deuren. Standaardisatie kan het aantal benodigde deuren wel beperken.

20. Wat is de getraindheids-/opleidingsniveau van de medewerkers? lijkt me moeilijk objectief vast te stellen en welke medewerkers gaat het hier over. In het algemeen zijn medewerkers van RWS en ON voldoende competent

21. Wat zijn de kosten van een sluisdeur? (documentatie) Sterk verschillend afhankelijk van grootte en materiaal. Houten deuren orde 100-200 kEuro, stalen of kunststof deuren 500 kEure en meer.

➔ Wellicht is hier documentatie van de aangegeven sluizen in vraag 4. Ramings gegevens opvragen bij kostenpool GPO, is mogelijk wel bedrijfsgevoelige informatie.

22. Wat zijn de kosten van beheer en onderhoud en welke onderdelen betreft dit? (documentatie)
OBR

➔ OBR geeft algehele areaal weer. Is er ook een document beschikbaar over in de vraag 4 genoemde sluizen specifiek? Nee meer dan OBR is er niet voor een algemeen beeld, in RUPS staan voor de komende 5 jaar met enige nauwkeurigheid de geplande onderhoudsmaatregelen per object. Maar dat is maar een deel van de totale kosten omdat de kosten van vast onderhoud niet zijn uitgesplitst naar onderdelen van de objecten en niet alle maatregelen in de komende 5 jaar aan bod zijn.

23. Wat zijn de kosten indien een sluis niet meer functioneel is (per uur/per dag?) Bedoel je hier schade voor transport? Is afhankelijk van de vaarweg intensiteit. Verliesuren schepen zijn orde 100 – 1000 Euro per uur, maar ook schade in logistieke keten en betrouwbaarheid van modaliteit vaarweg spelen een rol.

➔ De orde ligt dus tussen de 100 en 1000 eu per uur. Zijn hier gradaties per intensiteit? Welke gradaties zijn dat? (Weegt mee in de bepaling van aantal reservedeur in het cluster.) Dan zou je dit per sluis moeten gaan onderzoeken die basisinfo (scheepsaantallen, afmetingen, vracht etc) is er wel maar vraagt dus wel uitzoekwerk.

24. Is er een risicoanalyse aanwezig (document over: Falen onderdelen, systeem falen, menselijk falen, externe gebeurtenissen, etc. in relatie tot risico's en de gevolgen hiervan)? Ja, gefragmenteerd.

Kan ik inzicht krijgen in deze documenten? P-IHP's en PRA's

25. Worden de verschillende beveiligingen getest? Hoe?
Testplannen

26. Is er een aanvaarbeveiliging aanwezig? Welk type?
afhankelijk van object en risico's (bijvoorbeeld hoogwater, kwetsbaarheid type deur)

➔ Voor de in vraag 4 aangegeven sluizen, welke type aanvaarbeveiliging is aanwezig?
Zie vraag 4

27. Hoe wordt omgegaan met de niet-beschikbaarheid van de sluis, ten gevolge van preventief vast en variabel onderhoud (uren per jaar)?
Planning zie ook vraag 7 en 8

28. Heeft de sluis bijzonderheden? (voorbeeld: cultuurhistorische waarde en mag daarmee niet gesloopt worden, bron: sluizenboekje RWS.)
Komt allemaal voor in ons areaal.

29. Heeft u nog toevoegingen?
natuurlijk maar de vraag is wat wil je nog weten ;-)

Interview expert 2:
Transcript
Luca: mijn aanname is dat er bij elke sluis een reservesluisdeur aanwezig is. Dit is niet altijd het geval. Hierbij wordt een afweging van kosten/baten analyse uitgevoerd. Dus welke risico heeft het en weegt dit op tegen de kosten van een extra deur? Levertijden van materiaal moet ook worden nagedacht, want bijvoorbeeld bij sluis eefde was de sluisketting kapot gegaan, welke een levertijd van 3 maanden heeft en er geen reserve voor was.

Dit is een interview betreft het onderhoud van de sluisdeuren van de sluizen in het programma MultiWaterWerk. Hieruit wordt het risicoprofiel en de onderhoudsstrategie bepaald.

Gate middel van o.a. deze vragen wil ik de hoeveelheid reservedeuren bepalen per cluster. Een aantal sluizen van het programma MultiWaterWerk wordt gestandiseerd en is geclusterd in 5 groepen, hiervan ga ik het aantal reservedeuren bepalen.

Deze vragen hebben alleen betrekking op de deuren van de sluis.

1. Wat houdt uw functie precies in?
Ik geef advies aan sluisbeheerdes of hun aanpak.

2. Onderhoudshistorie (wanneer werd wat onderhouden en hoelang duurde dit);
a. Werkelijke reparatietijden
b. Werkelijke inspectie- en onderhoudsintervallen
c. Werkelijke inspectie- en onderhoudsgatelooptijden

Generieke data is beschikbaar zoals OBR. Voor de meer gedetaileerde informatie is het beter om met assetmanagers te spreken.

3. Onderhoudsstrategie (wat voor vervangings- reparatie strategie is van toepassing op de sluisdeur op het moment?);
a. Is er een handleiding van wat en wanneer iets vervangen dient te worden?
b. Hoe is de communicatie binnen de organisatie (project team, de aannemer)? Ziet u verbeterpunten hierin?
c. Hoe is de communicatie naar buiten (gebruikers)? Ziet u verbeterpunten hierin?

Wederom hiervoor geldt hetzelfde als bij vraag 2: Generieke data is beschikbaar zoals OBR. Voor de meer gedetaileerde informatie is het beter om met assetmanagers te spreken.

4. Is er een tijdsnorm voor correctief onderhoud? Is hier documentatie van (per onderdeel / object)
Er zijn specifieke inspecties of ze visueel iets vinden. Hierin is van te voren bij de contractvorming afgesproken binnen welk tijdsbestek iets vervangen / onderhouden dient te worden.

5. Is er een tijdsnorm voor preventief onderhoud? Is hier documentatie van? (per onderdeel / object)

Bij preventief doet dat hangt er maar net vanaf bij een sluis bij ga je niet wachten tot hij gatemidden geroest is. Dan is het conservering is typisch een voorbeeld van preventief onderhoud. Hierover kan gediscussieerd worden, want echt als een dikke roest plekken op zitten kan je zeggen: ben ik kan niet te laat? Maar het gaat puur om de functie als je nog prima schut dan is die dus nog functioneel en is conserveren altijd preventief. Maar bij bewegingswerken daar ligt het weer anders, daar wil je natuurlijk ook het liefst niet meemaken dat alles vastloopt en dat er niet meer geschut kan worden. En dus dat je dan opeens alles moet vervangen. Er zijn genoeg andere componenten welke je kapot kan laten gaan en als die kapot gaan, laat je die repareren. In de OBR staat daar een algemene richtlijn voor en in de instandshoudingsplannen iets meer specifiek maar het wordt al snel maatwerk. Er is geen handleiding om zo iets aan te pakken. Aan de assetmanagers kan je de instandshoudingsplannen vragen. Daar in staat de strategie in voor bepaalde onderdelen van de sluis. Maar als je het puur alleen over de sluisdeur zelf hebt; dan heb je het altijd over preventief met een inspectie regime om het moment van vervanging en renovatie te bepalen.

6. Wanneer dient een stremming te worden aangevraagd? (voor welke werkzaamheden dient er een stremming worden aangevraagd)
Het ligt aan het gevolg van de stremming. Als het om een vaarroute gaat waarbij dagelijks heel veel schepen voorbij komen, dient deze ruime tijd van te voren worden aangevraagd. Indien het gaat om slechts een klein riviertje/kanaaltje waarbij slechts enkele schepen voorbij komen, kan dit ook een aantal dagen van te voren. Of buiten bedientijden, want sommige sluizen zijn nachts niet open. Dus het ligt aan de prioriteit en gebruikswijze van de sluis.

7. Is de huidige onderhouds-/vervangingsstrategie afdoende gezien de beschikbaarheid van het onderdeel?
Het wordt nog niet gestructureerd bijgehouden maar we zijn het wel van plan om het te gaan doen. De werkelijke reparatie tijd kan heel relevant zijn voor de niet-beschikbaarheid van de sluis. Want als er grote verschillen in zitten, moet dit worden meegenomen in de berekeningen. Presentatie instandhoudingsplannen worden reparatietijden gedefinieerd en daarbij is het relevant om terugkoppeling te krijgen van de aannemers / in de praktijk. Als je met Menno Nagelhout en Vincent van Loenen praat kan je hier informatie uit krijgen. In de realiteit gaat dit lastig want de monteurs schrijven hun uren niet specifiek op (schrijven nu met reistijd e.d.)

8. Zijn hulpmiddelen en speciaal gereedschap nodig voor het uitvoeren van werkzaamheden en zijn deze beschikbaar (schotbalken, reservedeur etc.)
Uiteraard. Echter gebeurt niet veel en vaak op een nabij gelegen depot vervoerd. De aannemer zorgt dat er zo spoedig mogelijk speciaal gereed aanwezig is om de sluis in de juiste vorm te herstellen.

9. Is er speciale kennis en kunde nodig om het onderhoud uit te kunnen voeren?
a. Is het onderhoud uitbesteed, en in welke vorm?
b. Hoe wordt hierover gecommuniceerd? (communicatie tussen disciplines)
Dat is er zeker nodig. Want de meeste inspecties zijn visueel en daarna wordt beoordeeld hoelang de sluisdeur nog functioneel is en of wanneer er een vervolg inspectie komt. Over het algemeen wordt dit uitbesteed aan de aannemers.

➔ Hebben jullie vaste aannemers?

Wij zijn een overheidsinstantie dus is een open aanbesteding, iedereen kan zich ervoor inschrijven. Echter is het vaak wel een select groepje dat wint, vooral gate hun specialisme in het vakgebied.

10. Is de benodigde technische documentatie beschikbaar (formulieren, checklists)?
DISK. Technisch archief in dit gebouw. Hierin staan de gegevens, zoals schema, berekeningen, etc.. Kan ook bij het district liggen.

11. Welke reserveonderdelen zijn aanwezig? Welke zijn noodzakelijk?
Dit is vooraf afgesproken in het contract met de aannemer. Welke noodzakelijk zijn hangt onder andere af van de levertijd van het product. Indien het een lange levertijd heeft en invloed heeft op het functioneren van de sluisdeur, zal deze hoogstwaarschijnlijk als noodzakelijk worden beschouwd.

12. Is er een risicoanalyse aanwezig (document over: Falen onderdelen, systeem falen, menselijk falen, externe gebeurtenissen, etc. in relatie tot risico's en de gevolgen hiervan)? → welke risico's spelen een rol bij een sluisdeur?
Niet voor alle sluizen. Zijn er mee bezig om het op te bouwen. Bij buitencatorgieren wordt bijvoorbeeld mensenlijke falen (denk aan goed onderhoud) zeer uitdrukkelijk meegenomen, maar bij kleinere sluzien wat minder. Dit komt gate de extreme betrouwbaarheideis. 99% lijkt veel, echter komt dit neer 3.65 dagen niet functioneren. Technisch falen en mensenlijke handelen.

<u>99% betrouwbaarheid → 1% niet betrouwbaar. 8760 uren in een jaar. 1% = 87,60 uur per jaar niet betrouwbaar. 87,60 uur / 24 (uren in een dag) = 3,65 dagen niet meer functioneren.</u>

→ Ik zag geen concrete cijfers erin staan over bepaalde ratings van risico's, kan ik die ergens vinden?
Dat klopt. Bij de kwalitatieve analysis is dat sowieso daar worden ze niet meengenomen, want dat is niet in te schatten. Maar bij de quantitatieve analyse kom je daar wel dingen tegen hierover.
Externe risico's is belangrijk voor sluisdeuren (denk aan aanvaring). Dingen als vreemde voorwerpen in de kolk, zoals bomen.

→ En hoe zit het met ijsvorming?
Bestaan defrosting installaties. Maar ijs heeft geen invloed op de deur zelf, maar wel op de schutfunctie.

Voor het aanvaringrisico zijn kwantificeringsmodelen voor. Dit kan Arjen mij sturen. Dit is een soort spreadsheet met een database die erachter zit.
Risico analyse van keersluis is misschien interessant. Hoe wordt in de praktijk hiermee omgegaan.

Kan ook onderscheid maken tussen grote type sluizen. Bijvoorbeeld bij sluizen waarbij CEM I klasse schepen gateheen moeten is de mogelijke schade veel lager dan bij CEM V. dit houdt in dat een aanvaring van een CEM V een veel grotere impact heeft, hoewel de kans dat CEM

V schepen schade maken is kleiner want de kapitein is meer ervaring in het algemeen en is bewust wat voor schade hij kan doen.

Vincent, Gerard en Menno → assetmanagers. Risico analyse, basis specificaties. → storings faalfrequenties.

13. Wat zijn de storing-/faalfrequenties van onderdelen van de sluisdeur? (documentatie)
Deze kun je opvragen bij de assetmanagers. Wat definieer je onder falen?

➔ Dat hij niet meer functioneert.
Een roestende sluisdeur, kan nog functioneren, dus hoeft niet perse onderhoud. Kan een goedkopere optie zijn.

14. Zijn er bepaalde risico's die geaccepteerd worden? (bijvoorbeeld: als er net een aanvaring is geweest, wordt de reservedeur erin gehangen. Dit houdt in dat er voor een bepaalde tijd even geen reservedeur is. De kans dat er binnen het tijdsbestek van het repareren van de oude deur een nieuwe aanvaring is met de net geplaatste reservedeur, waargate er weer een nieuwe reservedeur moet komen is klein. Echter bestaat deze kans wel.) → Wat zijn de minimale beschikbaarheidseis en betrouwbaarheideis van de sluizen in het MWW programma?
Momenteel geen standaard sluizen. Indien er standaardsluizen zijn (dus standardization). Er is geen minimale betrouwbaarheid en beschikbaarheidseis want niet alle sluizen zijn 24/7 open. En de kans dat hij stoort in het spitsuur is klein. Voor de kleinere sluizen.
De hoogte van de betrouwbaarheid en de beschikbaarheideis wordt ingevuld gate de aannemer. RWS geeft gate van: moet minimaal zoveel uur per jaar functioneert.
Risico, kosten, prestatie is een driehoek die constant in beweging is. En soms is een risico acceptabel omdat een de kosten te hoog zijn.

15. Hoe wordt omgegaan met de niet-beschikbaarheid van de sluis, ten gevolge van preventief vast en variabel onderhoud (uren per jaar)?
Er is een protocol met verschillende afwegingen. Je kan niet een belangrijk kanaal 3 weken lang stilleggen bijvoorbeeld.
Een storing bijvoorbeeld is ongepland onderhoud. Het wordt steeds kritischer en zijn eisen aan. Echter aan het vervangen van bijvoorbeeld een sluisdeur omdat deze is aangevaren, kunnen niet echt eisen worden gesteld omdat overmacht is.
Maar gepland onderhoud is moet goed van te voren gepland worden.

16. Het document RINK zegt het volgende: 'De kans op aanvaring van sluisdeuren wordt bepaald op basis van informatie uit de SOS-database van RWS en/of de interviews van de beheerders'. Kunt u mij uw inschatting geven van dit risico en heeft u wellicht informatie uit de SOS-database van RWS?
Er is een kromme met investering versus onderhoud. Wanneer het optimum is. Rest van documenten via Erik-Jan en Martijn regelen.

17. Hoe nuttig is een reservedeur volgens u? (zeer zeker nodig, zeker nodig, nodig, niet echt nodig, niet nodig. Bijvoorbeeld: de kans dat een schip er tegenaan vaart is bijzonder klein)
Afhankelijk van de sluis: helemaal niet of heel erg nodig. Afhankelijk van de grote vaarweg, beschikbaarheideis, betrouwbaarheidseis,functies.

18. Wat zijn de kosten van een sluisdeur? (documentatie)

19. Wat zijn de kosten van beheer en onderhoud en welke onderdelen betreft dit? (documentatie)

20. Wat zijn de kosten indien een sluis niet meer functioneel is (per uur/per dag?)

Vraag 18+19+20 kunnen via assetmanagers en Erik-Jan geregeld worden. Daarnaast is het handig om contact op te nemen met Tirza Zwanenbeek. Zij is ook een assetmanager en nauw betrokken geweest bij onderhoud aan sluizen.

→Zitten er kosten aan verbonden indien een sluis onverhoopt niet meer functioneert.

Indien de sluis een dagje eruit ligt heeft dat geen invloed op RWS. Echter als dit voor een langere periode is zoals bij sluis Eefde (3 maanden) daar werden ze wel verantwoordelijk gesteld.

21. Heeft u nog toevoegingen?

Kosten zijn een belangrijke factor voor RWS. Kosten baten analyse prominent naar voren laten komen. (denk bijvoorbeeld aan monumenten status)

Verder: de functie van waterhuishouding belangrijker gaat worden. Waterstanden in verband met global warming, en dus de water huishouding, welke de kan functie kan beïnvloeden.

Interview expert 3:
Dit is een interview betreft het onderhoud van de sluisdeuren van de sluizen in het programma MultiWaterWerk. Hieruit wordt het risicoprofiel en de onderhoudsstrategie bepaald.

Deze vragen hebben alleen betrekking op de deuren van de sluis.

In het groen zijn de vragen concreter opgeschreven. Gate middel van o.a. deze vragen wil ik de hoeveelheid reservedeuren bepalen per cluster. Een aantal sluizen van het programma MultiWaterWerk wordt gestandiseerd en is geclusterd in 5 groepen, hiervan ga ik het aantal reservedeuren bepalen.

1. Wat zijn de afmetingen van de sluisdeur?

Afhankelijk van de sluis. B.v roldeuren (Hansweert, Krammer):

Afmetingen roldeuren hxbxd	27,8 m x 14,6 m x 4,69 m

2. Hoeveel sluisdeuren heeft de sluis?
Afhankelijk van de sluis. Duwvaartsluizen met roldeuren: 2 per kolk. Puntdeuren (bv Zandkreek) 8 stuks (2 ebdeuren en 2 vloeddeuren per hoofd)

3. Hoeveel sluizen heeft u in beheer?
District Noord: Roompotsluis, Zandkreeksluis, Grevelingensluis, Bergse Diepsluis, Hansweertsluizen (2 kolken), Kreekraksluizen (2 kolken), Krammersluizen (2 kolken), Krammer Jachtensluis

4. Onderhoudshistorie (wanneer werd wat onderhouden en hoelang duurde dit);

a. Werkelijke reparatietijden:
vraag moet specifieker, elke reparatie, vast- of variabel onderhoudstaak, project, renovatie of modificatie is anders

➔ Hier gaat het specifiek over stalenpunten. Zijn hier onderhoudsloggings en P-IHP's van? Kan ik hier inzicht in krijgen. (wanneer werd wat onderhouden, hoelang duurde dit), specifiek per sluis.

b. Werkelijke inspectie- en onderhoudsintervallen:
Idem

➔ Hier gaat het specifiek over stalenpunten. Zijn hier onderhoudsloggings en P-IHP's van?

c. Werkelijke inspectie- en onderhoudsgatelooptijden:
Idem

➔ Hier gaat het specifiek over stalenpunten. Zijn hier onderhoudsloggings en P-IHP's van?

Separaat bijgevoegd de relevante P-IHP info. NB. P-IHp focust op variabel en klein variabel onderhoud. Ik zal nagaan of je toegang kunt krijgen tot ons OMS systeem.

5. Onderhoudsstrategie (wat voor vervangings- reparatie strategie is van toepassing op de sluisdeur op het moment?);

a. Is er een handleiding van wat en wanneer vervangen dient te worden?

Ja in de P-IHP's; prestatiegestuurde instandhoudingsplannen. Daarnaast voor vast onderhoud onderhoudsconcepten

➔ Heeft u deze documenten voor mij, wat betreft de stalen puntdeuren?

Zie boven

b. Hoe is de communicatie binnen de organisatie (project team, de aannemer)? Ziet u verbeterpunten hierin?

Ik zit niet in het projectteam

c. Hoe is de communicatie naar buiten (gebruikers)? Ziet u verbeterpunten hierin? Middels belangengroeperingen, overleggen met stakeholders, Berichten aan de Scheepvaart, internet

6. Is er een tijdsnorm voor correctief onderhoud? Is hier documentatie van? (per onderdeel / object ?

er is een PIN voor Onvoorziene niet beschikbaarheid, 0,2% van een jaar (~17 uur/jaar). Wij hanteren deze norm per object, dus niet per onderdeel (deur)

➔ Kunt u hier een voorbeeld van geven wat gerelateerd is aan de stalenpuntdeur? (Is dit voor alle stalen puntdeuren gelijk? Kunt u hier de waardes van geven?)

Ja: falen deuraandrijving zorgt voor een bepaalde ONB, preventief onderhoud aan de deuraandrijving of bv conservering voor VNB. Zie hiervoor de in de mail bijgevoegde OHS. Dit is vaak situatieafhankelijk.

7. Is er een tijdsnorm voor preventief onderhoud? IS hier documentatie van? (per onderdeel / object)

idem, echter deze is 0,8%

➔ Kunt u hier een voorbeeld van geven wat gerelateerd is aan de stalenpuntdeur? (Is dit voor alle stalen puntdeuren gelijk? Kunt u hier de waardes van geven?) **Zie boven**

8. Wanneer dient een stremming te worden aangevraagd? (voor welke werkzaamheden dient er een stremming worden aangevraagd)

Voor werkzaamheden die de (veilige) systeemfunctie beinvloeden.

9. Is de huidige onderhouds-/vervangingsstrategie afdoende gezien de beschikbaarheid van het onderdeel?

We hebben nu te maken met "uitgesteld onderhoud". Dit zorgt ervoor dat de onderhoudskosten (berekende verwachting) hoger worden en onderhoudsduren toenemen.

a. Verbeterpunten op een bepaald vlak? (klopt de werkelijke reparatietijd met de geplande reparatietijd, werkelijke inspectie- en onderhoudsintervallen met de geplande tijd, en de werkelijke inspectie- en onderhoudsgatelooptijden met de geplande?)

➔ Zijn hier documenten van? Wat was in eerste instantie berekend en wat is het werkelijk?

➔ **Die zijn er maar die kan ik niet verstrekken. Algemeen zie je dat de kosten omhoog gaan (agv faalkosten en ongunstigere marktwerking als iets "snel gefixt moet worden") en dat de beschikbaarheid omlaag gaat**

10. Zijn hulpmiddelen en speciaal gereedschap nodig voor het uitvoeren van werkzaamheden en zijn deze beschikbaar (schotbalken, reservedeur etc.):

situatieafhankelijk, maar reservedeuren zijn voor alle sluizen beschikbaar, schotbalken voor sommige sluizen evenals droogzetkuipen en hijsjukken

11. Is er speciale kennis en kunde nodig om het onderhoud uit te kunnen voeren? Ja

a. Is het onderhoud uitbesteed, en in welke vorm?
RWS besteed al het werk uit (onderhoud, renovatie, modificatie, nieuwbouw)
b. Hoe wordt hierover gecommuniceerd?
Aanbestedingskalender.nl

12. Is de benodigde technische documentatie beschikbaar (formulieren, checklists)?
Er is een veelvoud aan technische documentatie beschikbaar, veelal op objectniveau. Denk aan onderhouds- en storingsdata, Instandhoudingsplan, tekeningen en inspectiegegevens.
➔ Kan ik inzicht krijgen in de onderhouds- en storingsdata, instandhoudingsplan en inspectiegegevens van de sluizen welke stalenpuntdeuren hebben?
➔ **Ik zal vragen of je toegang kunt krijgen tot ons OMS (onderhoudsmanagement systeem))**

13. Is er een back-up beschikbaar (noodgenerator bij energie uitval)?
Verschilt per sluis, in sommige gevallen is er een Noodstroomaggregaat beschikbaar of een voorziening als een UPS, of een aansluiting voor een mobiel aggregaat
a. Indien de sluisdeuren niet meer open willen i.v.m. software storing, wat gebeurt er dan? Handmatig?
Zou in sommige gevallen kunnen, maar gebeurt alleen als uiterste noodmaatregel. Gestuurd wordt op oplossen storing en duurzaam functieherstel

14. Welke reserveonderdelen zijn aanwezig? Welke zijn noodzakelijk?
Afhankelijk van de sluis.
➔ Is er een overzichtslijst met hulpmiddelen en reserveonderdelen, en kan ik hier inzicht in krijgen?
➔ **Zie boven**

15. Hoe is de bereikbaarheid van de onderdelen?
Idem
➔ Worden de onderdelen op het terrein opgeslagen en/of in het magazijn van derden?
➔ **Opslag op het terrein (bv reservedeur)**

16. Zijn er fysieke beperkingen die gevolgen hebben voor het onderhoud aan het onderdeel (bijvoorbeeld: is de sluisdeur te groot om die ter plekke te onderhouden / op te slaan?). Zeker, maar ook ivm wet en regelgeving (b.v. geluidshinder gate werkzaamheden)

17. Wat zijn de storing-/faalfrequenties van onderdelen van de sluisdeur? (documentatie)
object afhankelijk
➔ Denk dat vraag 12 overlapt met deze.

18. Het document RINK zegt het volgende: 'De kans op aanvaring van sluisdeuren wordt bepaald op basis van informatie uit de SOS-database van RWS en/of de interviews van de beheerders'. Kunt u mij uw inschatting geven van dit risico en heeft u wellicht informatie uit de SOS-database van RWS? →
Nee
➔ SOS-database en RINK krijg ik via Erik-Jan Houwing.

→ Kunt u mij een inschatting geven hoe vaak er een sluisdeur wordt aangevaren? Wat de oorzaak en het gevolg hiervan zijn? Bijvoorbeeld: 1 maal per 2 jaar wordt de deur aangevaren dusdanig dat de reservedeur erin gezet moet worden.

→ **Zie OMS**

19. Hoe nuttig is een reservedeur volgens u? (zeer zeker nodig, zeker nodig, nodig, niet echt nodig, niet nodig. Bijvoorbeeld: de kans dat een schip er tegenaan vaart is bijzonder klein)
Zeer zeker nodig ivm systeemfunctie tijdens gepland onderhoud of calamiteiten, ook als waterkerende functie.

→ Bij hoeveel van de sluizen is een reservedeur aanwezig? **Bij alle**

20. Wat is de getraindheids-/opleidingsniveau van de medewerkers?
Ligt aan de medewerkers. Operators op de sluis hebben de benodigde papieren (veelal NAUTOP 2), verder van een enkele LTS-er tot MTS/HTS/HBO en Master niveau

21. Wat zijn de kosten van een sluisdeur? (documentatie).
Welke kosten? Capex, Opex?

→ Aanschaf van een sluisdeur, dus de constructiekosten en de plaatsing ervan.

→ **Uit P-IHP (terug te vinden in OHS Macro):**

<table>
<tr><td>Zandkreeksluis - Schutsluis: NB. decompositie momentopname; aandrijvingen deur# onafhankelijk, deuren zelf deurplaats onafhankelijk!</td><td>Puntdeuren vervangen: 1 x 80 jr, 48 uur per deur(set, puur de wissel), ~50 ton a 10 euro/kg, hout en hefbok etc 1 ton, 100% new</td></tr>
<tr><td><table><tr><th>Interval [jr]</th><th>Uitvoeringskosten in k€</th></tr><tr><td>80</td><td>1200</td></tr></table></td><td></td></tr>
</table>

→

22. Wat zijn de kosten van beheer en onderhoud en welke onderdelen betreft dit? (documentatie)
Verschilt per sluis
→Van kleinschalig onderhoud, naar grootschalig. Geheel vervanging van de deur.

→ **Zie OHS**

23. Wat zijn de kosten indien een sluis niet meer functioneel is (per uur/per dag?)
Kun je het beste vragen aan collega's van WVL

24. Is er een risicoanalyse aanwezig (document over: Falen onderdelen, systeem falen, menselijk falen, externe gebeurtenissen, etc. in relatie tot risico's en de gevolgen hiervan)?
Ja: FMECA's

→ Kan ik hier inzicht in krijgen? Is hier documentatie van?

→ **Zie OHS**

25. Worden de verschillende beveiligingen getest? Hoe?
Functionele testen

26. Is er een aanvaarbeveiliging aanwezig? Welk type?
Remming- en geleidewerken

27. Hoe wordt omgegaan met de niet-beschikbaarheid van de sluis, ten gevolge van preventief vast en variabel onderhoud (uren per jaar)?
Zie vraag 6/7

28. Heeft de sluis bijzonderheden? (voorbeeld: cultuurhistorische waarde en mag daarmee niet gesloopt worden, bron: sluizenboekje RWS.)
Ligt aan de sluis. Geen enkele RWS sluis is hetzelfde.

- ➔ Ik zal DISK nagaan en checken of ze een momumentenstatus hebben.
- ➔ In district noord heeft geen enkele sluis een monumentenstatus. In district zuid de oude middensluis.

29. Heeft u nog toevoegingen?
Toegevoegd ter informatie de objectbeschrijving van sluis Hansweert

Appendix V: MCA & iterative

In case all weights are 1.

	gewichten
costs	1,00
performance	1,00
sustainability	1,00

		reno	vervang	standaard
toale kosten per sluis alle aspecten	sluis 1	€ 1.346.778	€ 1.544.866	€ 1.467.241
	sluis 2	€ 2.397.706	€ 2.710.493	€ 2.543.297
	sluis 3	€ 3.448.634	€ 3.876.120	€ 3.619.353
	sluis 4	€ 4.499.562	€ 5.041.747	€ 4.695.409
	sluis 5	€ 5.550.490	€ 6.207.374	€ 5.771.465
	sluis 6	€ 6.601.418	€ 7.373.001	€ 6.847.521
	sluis 7	€ 7.652.346	€ 8.538.628	€ 7.923.577
	sluis 8	€ 8.703.274	€ 9.704.255	€ 8.999.633
	sluis 9	€ 9.754.202	€ 10.869.882	€ 10.075.689
	sluis 10	€ 10.805.130	€ 12.035.509	€ 11.151.745
	sluis 11	€ 11.856.058	€ 13.201.136	€ 12.227.801
	sluis 12	€ 12.906.986	€ 14.366.763	€ 13.303.857
	sluis 13	€ 13.957.914	€ 15.532.390	€ 14.379.913
	sluis 14	€ 15.008.842	€ 16.698.017	€ 15.455.969
	sluis 15	€ 16.059.770	€ 17.863.644	€ 16.532.025
	sluis 16	€ 17.110.698	€ 19.029.271	€ 17.608.081
	sluis 17	€ 18.161.626	€ 20.194.898	€ 18.684.137

In case the weights are 1 for costs, 5 for performance and 3 on sustainability.

	gewichten
costs	1,00
performance	5,00
sustainability	3,00

		reno	vervang	standaard
toale kosten per sluis alle aspecten	sluis 1	€ 1.893.916	€ 2.095.684	€ 1.969.579
	sluis 2	€ 3.485.282	€ 3.803.239	€ 3.538.147
	sluis 3	€ 5.076.648	€ 5.510.794	€ 5.106.715
	sluis 4	€ 6.668.014	€ 7.218.349	€ 6.675.283
	sluis 5	€ 8.259.380	€ 8.925.904	€ 8.243.851
	sluis 6	€ 9.850.746	€ 10.633.459	€ 9.812.419
	sluis 7	€ 11.442.112	€ 12.341.014	€ 11.380.987
	sluis 8	€ 13.033.478	€ 14.048.569	€ 12.949.555
	sluis 9	€ 14.624.844	€ 15.756.124	€ 14.518.123
	sluis 10	€ 16.216.210	€ 17.463.679	€ 16.086.691
	sluis 11	€ 17.807.576	€ 19.171.234	€ 17.655.259
	sluis 12	€ 19.398.942	€ 20.878.789	€ 19.223.827
	sluis 13	€ 20.990.308	€ 22.586.344	€ 20.792.395
	sluis 14	€ 22.581.674	€ 24.293.899	€ 22.360.963
	sluis 15	€ 24.173.040	€ 26.001.454	€ 23.929.531
	sluis 16	€ 25.764.406	€ 27.709.009	€ 25.498.099
	sluis 17	€ 27.355.772	€ 29.416.564	€ 27.066.667

Appendix VI: Model of thought
Own illustration.

Assumptions for this model.

- Renovation

  In case of renovation, the life span is extended by repairing / renewing the existing component by making it usable again to current standards. The remaining life span will be

100 years. The spare gates must be removed from the current position. This will take between 2 to 4 weeks (source: interview Arnoud).

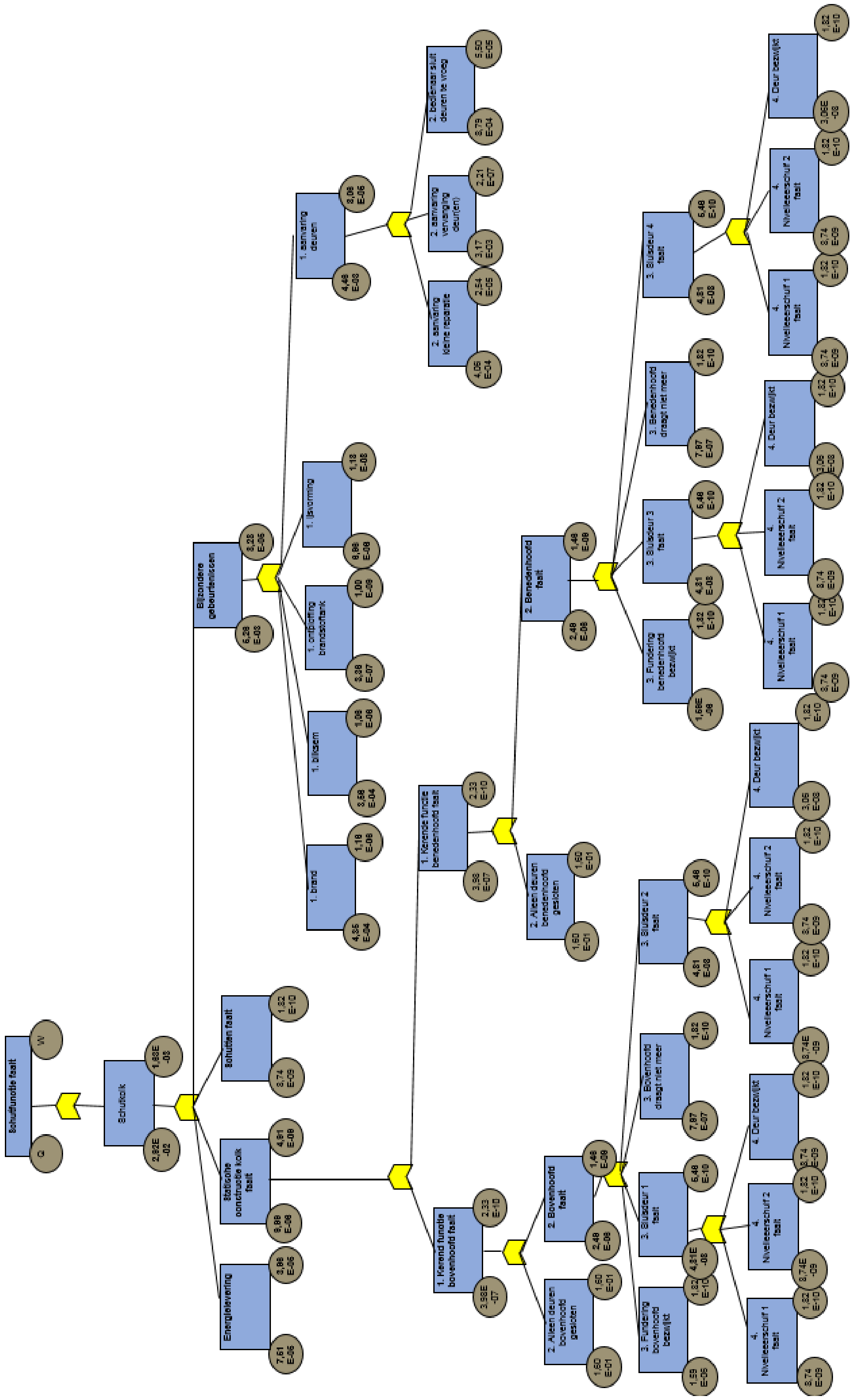
- Replacement
  Completely replace the existing gates. This results in a new lifespan of 100 years. The gates are being replaced by exactly the same type of gates as previous but completely new.
- Standardization
  Completely replace the existing gates by a standard. The replacement by a standard of the spare gate by building it completely new, according to the new requirements.
- Performance
  The reliability (R) and availability (A) of the lock, expressed in percentage. This is extracted from the fault-tree analysis.
- Risk
  Risk = chance x consequence in case of failure of the function. This is expressed in terms of costs. This refers to the economic damage that occurs when a lock does not functions. Chance it occurs. The consequences whenever it occurs, expressed in costs.
- Performance (RA) of the lock gate is mapped for the renovation, replacement and stnadardiation.
- The average annual costs to the end of the life span are mapped for renovation, replacement and standardization.
- The risks are mapped for renovation, replacement and standardization.
- The preventive (fixed / variable, small/large) maintenance has been carried out at the right time.
- Whenever the lock gate is not used anymore, it is broken up into components and recycled.
- Gates with a long life span, it is preferred that the life span can be extended by maintenance. This is related with sustainability and recycling of the component.
- The current laws and regulations are adhered to.
- The current situation is considered, which includes that not all gates are (steel) mitre gates.
- All lock heads must be prepared for standardization, before standardization can be implemented.
- Currently, each navigation lock has 1 spare gate.

Explanation of the model

1. One of lock navigation lock component has reached its lifespan.
2. The costs for all three possibilities are being calculated: renovation, replacement and standardization.
3. Check if this lock is part of a cluster. If no, go to 4. If yes, go to 5.
4. Choose the cheapest option.
5. Calculate the costs for the other locks in terms of renovation, replacement and standardization.
6. Sum up the costs per possibility for the entire cluster and divide it by the total locks.
7. Fill in these costs into the final model.

Appendix VII: Fault-tree analysis

Own image. Numbers are derived from Schepers (2013).



Appendix VIII: invoerblad functie schutten

functioneren van sluis. Schutten.		alles wat hier beschreven wordt heeft invloed op de beschikbaar en betrouwbaarheid van de sluis.							
W = niet- Betrouwbaarheid (Reliability) / faalfrequentie per uur (faalfrequentie)	**Huidig**	99,84%	**Nieuwe**	99,84%	**Verschil**	0,00%	8760	uren in een jaar	
Q = niet - beschikbaarheid (availability) in uur per jaar of %	**Huidig**	76,49%	**Nieuwe**	76,80%	**Verschil**	-0,31%	minder niet-beschikhaarheid = meer beschikbaarheid		
Bedientijden / functioneringstijden in ui	6956								
percentage t.o.v. totaal per jaar	79,41%	maximaal te behalen							
						welke hebben direct invloed op de deur			
Schutkolk schutfunctie	**Wat?**	**Kans**	**Q (niet-besc**	**W**	**Bron**	**Reparatietijd (uren)**	**Q**	**W**	**Bron**
Totaal per jaar			**255,44**	**14,2722**			**228,57**	**14,2724**	
Totaal per uur			**2,92E-02**	**1,63E-03**			**2,61E-02**	**1,63E-03**	
Energielevering			**7,51E-05**	**3,96E-05**			**7,51E-05**	**3,96E-05**	
1. uitval energienet			5,66E-05	3,88E-05	Generiek data zoals TAW en EJ		5,66E-05	3,88E-05	
1. railfout verdeelinstallatie			6,48E-06	2,70E-07	Generiek data zoals TAW en EJ		6,48E-06	2,70E-07	
1. schakelaar inkoop voeding faalt			1,20E-05	5,00E-07	Generiek data zoals TAW en EJ		1,20E-05	5,00E-07	
Statische constructie kolk faalt			**9,99E-06**	**4,91E-09**			**9,90E-06**	**4,84E-09**	
1. fundering kolk bezwijkt			1,59E-06	1,82E-10	Generiek data zoals TAW en EJ		1,59E-06	1,82E-10	
1. technische ruimte bedienhuis bezwijkt			2,62E-07	1,82E-10	Generiek data zoals TAW en EJ		2,62E-07	1,82E-10	
1. kolkwand bezwijkt			2,62E-07	1,82E-10	Generiek data zoals TAW en EJ		2,62E-07	1,82E-10	
1. wand benedenhoofd bezwijkt			7,97E-07	1,82E-10	Generiek data zoals TAW en EJ		7,97E-07	1,82E-10	
1. wand bovenhoofd bezwijkt			7,97E-07	1,82E-10	Generiek data zoals TAW en EJ		7,97E-07	1,82E-10	
1. benedenhoofd draagt niet meer			7,97E-07	1,82E-10	Generiek data zoals TAW en EJ		7,97E-07	1,82E-10	
1. bovenhoofd draagt niet meer			7,97E-07	1,82E-10	Generiek data zoals TAW en EJ		7,97E-07	1,82E-10	
1. fundering bovenhoofd bezwijkt			1,59E-06	1,82E-10	Generiek data zoals TAW en EJ		1,59E-06	1,82E-10	
1. fundering benedenhoofd bezwijkt.			1,59E-06	1,82E-10	Generiek data zoals TAW en EJ		1,59E-06	1,82E-10	
1. statische constructie deuren			1,24E-06	2,91E-09			1,15E-06	2,84E-09	
2. deur 1 faalt			**3,09E-07**	**7,28E-10**			**2,87E-07**	**7,10E-10**	
bezwijkt			2,61E-07	1,82E-10	Generiek data zoals TAW en EJ		2,61E-07	1,82E-10	
3. nivelleerschuif 1 faalt			8,74E-09	1,82E-10	Generiek data zoals TAW en EJ		8,74E-09	1,82E-10	
3. niveleerschuif 2 faalt			8,74E-09	1,82E-10	Generiek data zoals TAW en EJ		8,74E-09	1,82E-10	
3. deur bezwijkt			3,06E-08	1,82E-10	Generiek data zoals TAW en EJ	van 168 naar 48 uur = 0,28	8,75E-09	1,64E-10	

	niet-beschikbaarheid (Q)		Faalfrequentie (W)	
	%	u/j	1/u	1/j
huidige situatie Schutten	2,92%	255,44	1,63E-03	14,2722
nieuwe situatie schutten	2,609%	228,57	1,63E-03	14,2724
Verschil nieuwe situatie schutten	0,307%	26,87	0,00	0,00

conclusie: er kan een hogere beschikbaarheid van 0,31%

Appendix IX: Mean Time to Repair calculation

Current situation, thus renovation and replacement, versus standardization of the lock gates. To find out if standardization is a good alternative in for renovation or regular replacement. Sluis Schijndel is taken as a reference project.

Renovation & Replacement

For the function 'leveling ships' all factors are taken into consideration which have an influence on standardization and can be solved by spare gates. As earlier described, at this moment there is one spare gate for each lock. One of these components is 'constructive failure of the gate' and the other one is 'collision with a vessel, which results in replacement of the gate'. This shows that when the gate fails due constructive causes; the non-availability (Q) of a gate is calculated at 3.06 E-8 and the non-reliability (W) at 1.82 E-10. This is based on a repair time of 168 hours. In addition, the collision replacement gate is calculated at Q = 3.17 E-03 and W = 2.21 E-07. This is based on a repair time of 1440 hours (Uitgangspunten Document RINK, 2013)

The non-availability is expressed percentage per year and hours per year. The non-reliability is expressed in 1 per hour and 1 per year.

To explain this in a further detail:

In the event that one of the gates stops working: Q = (4 * 3.06 E-08) + 3.17 E-03 = 3.17 E-03.

The reliability (failure frequency) of one of the gates no longer functions W = (4 * 1.82 E-10 + 2.21 E-07 = 2.22 E-07

The dominant factor is the collision replacement component.

Final calculation: non-availability and non-reliability

Q = factor 1: number of gates * gate collapses
factor 2: (1 / number of gates being struck *) collision replacement gate

W = factor 1: number of gates * gate collapses
factor 2: (1 / number of gates being struck *) collision replacement gate

Q * number of hours in the year = hours not-available per year.
W * number of hours in the year = non-reliability per year.

Q = 3.17 E-03 * 8760u = 27.79 hours not available per year. (for no standardization)
W = 2.22 E-07 * 8760u = 0.00194 per year non-reliability. (for no standardization)

By means of standardization, Rijkswaterstaat wants lower unavailability (ie higher availability) and lower non-reliability (ie higher reliability). This involves looking at the non-standardization versus standardization option.

Standardization

As explained earlier, the repair time is reduced through standardization, resulting in a better reliability and availability.

In this situation all factors are taken into account which have a direct influence on the gate. This is the collapse of the gate and in case of collision, such that the gate needs to be replaced. This shows that the factor 'the failure of the gate'; the non-availability (Q) of gate 1 is calculated at 3.06 E-8 and the non-reliability (W) at 1.82 E-10. It is assumed that the repair time is 168 hours. However, by standardization this repair time can be accelerated to 48 hours. This means that the acceleration percentage of 48/168 = 0.286. This results in Q = 8.75 E-09 and W = 5.21 E-11.

In addition to the 'collapse of the gate' factor, the 'replacement gate replacement' factor also plays a role. It is assumed that the repair time is not 1440 hours but is accelerated to 48 hours. This results in an acceleration percentage of 48/1440 = 0.0333. The factor 'replacement gate replacement' which is Q = 1.05 E-04 and W = 7.30 E-09 per gate.

To explain this in a further detail:

In the event that one of the gates no longer functions, results in: Q = (4 * 8.75 E-09) + 1.05 E-04 = 1.05 E-04.

The reliability (failure frequency) of one of the gates no longer functions W = (4 * 5.21 E -11) + 7.3 E-09 = 7.51 E-09.

The dominant factor is the collision replacement component.

Final calculation: non-availability and non-reliability

Q = factor 1: number of gates * gate collapses
factor 2: (1 / number of gates being struck *) collision replacement gate

W = factor 1: number of gates * gate collapses
factor 2: (1 / number of gates being struck *) collision replacement gate

Q * number of hours in the year = hours not available per year.
W * number of hours in the year = non-reliability per year.

Q = 1.05 E-04 * 8760u = 0.9188 hours not available per year. (for standardization)
W = 7.51 E-09 * 8760u = 0.00006574 not reliable per year. (for standardization)

Conclusion

In case of replacement it results in:
Q = 3.17 E-03 * 8760u = 27.79 hours not available per year. (per non-standardized gate)
W = 2.22 E-07 * 8760u = 0.00194 non-reliability per year. (per non-standardized gate)

In case of standardization it results in:
Q = 1.05 E-04 * 8760u = 0.9188 hours not available per year. (per standardized gate)
W = 7.51 E-09 * 8760u = 0.00006574 not reliable per year. (per standardized gate)

Availability is expressed in percentage and hours per year. In the current situation the non-availability is set on 255,44 hours a year. In case of standardization this will be 228,57 hours a year. This results in 26,8712 hours more availability by using a standardized gate, per year. Which is more than a day more available per year on the whole system. Which is an improvement of: 26,8712 / 8760 hours = 0,3067%.

The reliability is expressed in 1 per hour and 1 per year. In the current situation the non-reliability is set on 1,623E-03 per hour and 14,2132 per year. In case of standardization this will be 1,622E-3 per hour and 14.2113 per year. This results in an improvement of 0,0019 per year. This indicates that the use of standardized gates has a negligible effect on the reliability.

Discussion
The outcome of the negligibility of the reliability was is a logical conclusion because whenever a navigation lock gate will fully lose its function, the lock manager will use stop logs to prevent any more damage, or lose it water retention function.

Appendix X: Average end of life span of MWW locks

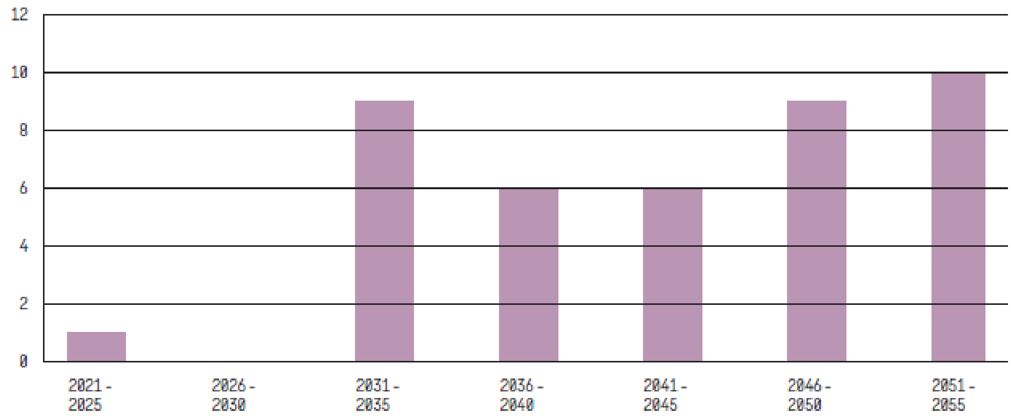


Table 40: End of life span of MWW locks (van Erp, 2017).

This table shows when the expected end of the life span of the MWW locks are reached.

Life span of a lock door is 100 years, the same as a navigation lock (van Erp, 2017).

Quantify locks	end life span	year now:	2019	percentage (%) life span
1	2021		2	98
9	2031		12	88
6	2036		17	83
6	2041		22	78
9	2046		27	73
10	2051		32	68

This table shows the calculation at which percentage of their life span the lock has reached.

	quantify locks				
	1	0,98	0,98		
	9	0,88	7,92		
	6	0,83	4,98		
	6	0,78	4,68		
	9	0,73	6,57		
	10	0,68	6,8		**average percentage life span of locks**
total lock	**41**		**31,93**	**total locks / life span per lock**	**78%**

This table shows that the average life span of the MWW locks in percentage. By calculating the average percentage, an assumption about the state of the gates can be made.