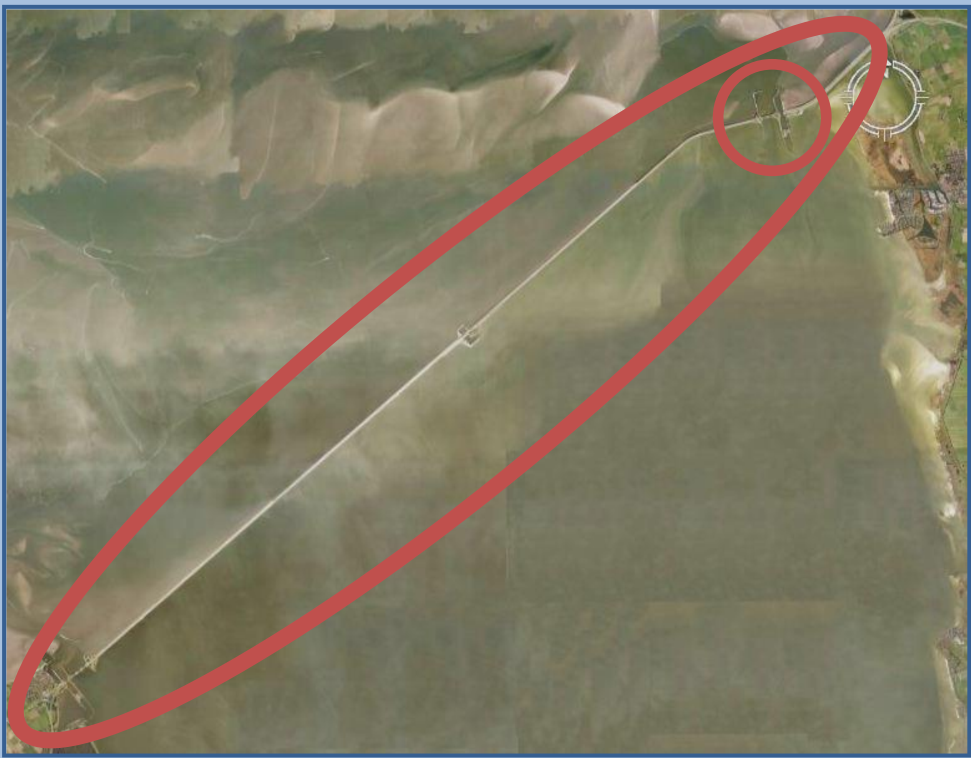
Reducing congestion at the Afsluitdijk

Analysis of the congestion and improvements within the current infrastructural situation



H.C.J. Lurinks

December, 2008

INFRA CONSULT + ENGINEERING

TU Delft

Delft University of Technology

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Analysis of the congestion and improvements within the current infrastructural situation

Master Thesis

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Transport, Infrastructure & Logistics
December, 2008

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Preface

This report contains the master thesis of Rik Lurinks. The thesis consists of an analysis of the congestion for road traffic and navigation at the Afsluitdijk and its lock complexes and improvements within the current infrastructural situation to reduce the congestion. This master thesis is the final assignment of the master Transport Infrastructure & Logistics at Delft University of Technology.

Without the support and assistance from various people, working at various organizations and departments, I would not have been able to successfully complete this master thesis. Therefore I would like to take this opportunity to thank INFRA consult + engineering for accommodating my research and the Dutch Directorate for Public Works and Water Management, IJsselmeergebied, the Centre for Traffic and Navigation and Delft University of Technology for supplying a lot of information and their assistance during the entire research.

The realization of my master thesis took place simultaneously with a difficult period of my life; therefore I am very grateful for the support and understanding of all members of my graduation committee:

- John Baggen
- Ernst Bolt
- Enne de Boer
- Kees Klap
- Frank Sanders

Finally I want to express my gratitude to all great friends and family who have stimulated and encouraged me during my studies at Delft University of Technology. A special expression of gratitude goes to my mother, her partner, my sister and especially my father who unfortunately is not among us anymore.

Rik Lurinks
Den Haag, December 2008

Summary

This research focuses on the congestion of navigation and road traffic at the Afsluitdijk and its lock complexes. Most of the time research focuses on only one modality, but in this research the accessibility problems for navigation as well as road traffic are taken into account.

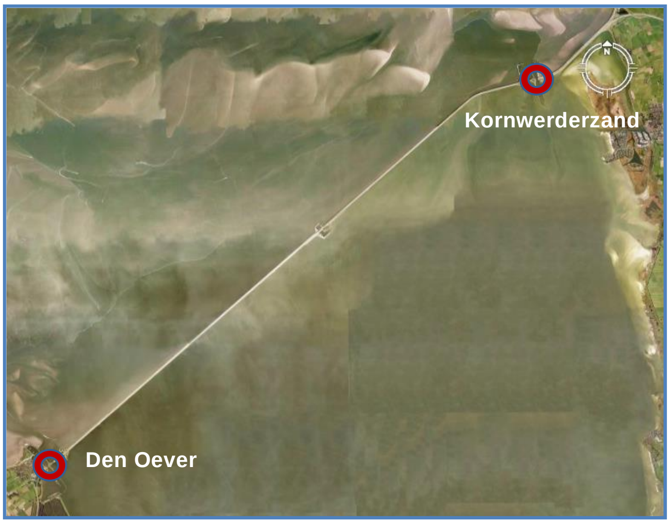


Figure 1: Locations of the lock complexes at Den Oever and Kornwerderzand (Google Earth, 2008)

As presented in Figure 1, there are two lock complexes at the Afsluitdijk. One is situated in Den Oever and the other is located at Kornwerderzand.
Concerning the congestion at the Afsluitdijk two situations can be distinguished. The first problem is the local congestion of road traffic and navigation at the lock complexes and secondly there is the possibility for road traffic to have delay at both lock complexes.
Both complexes have comparable layouts and accessibility problems only there is more nuisance and traffic at the Lorentz complex at Kornwerderzand. Therefore, this lock complex and its traffic flows are the central subjects concerning the local congestion at the lock complexes. Figure 2 shows the layout of the Lorentz lock complex with the outer harbor separating the locks and bridges and both lock chambers.

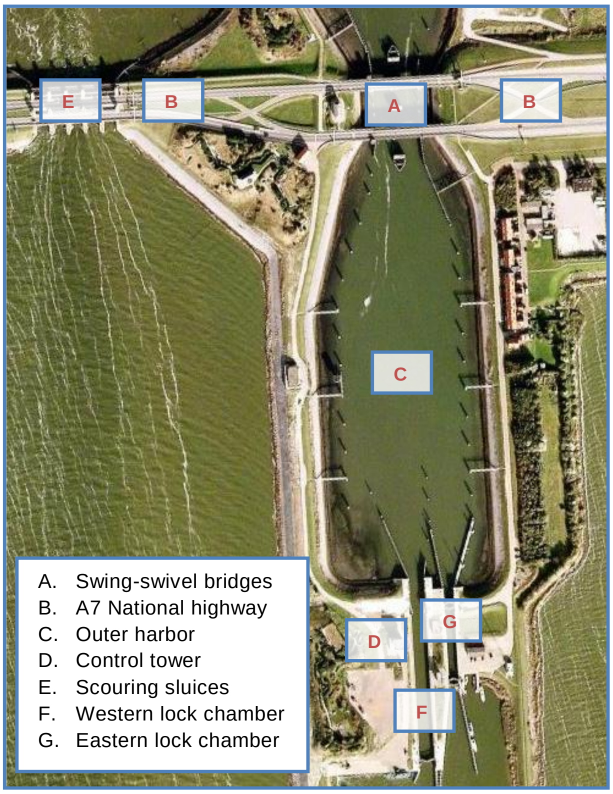


Figure 2: Layout of the Lorentz lock complex at Kornwerderzand (Google Earth, 2008)

In most cases the waiting times at the individual lock complexes are acceptable for road traffic and it's assumed that it is not acceptable to wait for both lock complexes at the Afsluitdijk. Nowadays there is little tuning between the service of the swing-swivel bridges at Den Oever and Kornwerderzand, therefore it's possible that motorists have to wait twice.

The congestion and resulting waiting times cause nuisance for both modalities. Furthermore there is economical damage which is caused by delays for navigation, professional, recreational, and road traffic. Another motive for this research is the lack of clarity with regard to the level of nuisance.

Despite the fact that it is very clear that there is nuisance and economical damage for both modalities at the Lorentz lock complex, previous research has no unambiguous stand on the level of nuisance.

The goal of this research is to answer the central research question.
Is the amount of congestion at the Afsluitdijk and its Lorentz lock complex acceptable, by which factors is the congestion influenced and which of these factors can be influenced within the current infrastructural situation to reduce congestion?

To answer this question; information is collected about the Afsluitdijk, its infrastructure and the traffic at the Afsluitdijk. Next an inventory of all components influencing the congestion at the lock complexes is made and their interaction is analyzed and determined. All components, and their interactions, are presented with the usage of a diagram of connections. This diagram of connections is presented in Figure 3. The diagram of connections is divided in three main parts; *"Road Traffic"*, *"Intersection"* and *"Navigation"*. Within the main parts of the diagram of connections there are lots of components influencing the main subjects of this research "Waiting time road traffic" and *"Waiting time navigation".*
Important components influencing the *"Waiting time road traffic"* are the intensity and composition of road traffic and "the duration of landside bridge opening".
For *"Waiting time navigation"* the most important components are *"Vessels per lock operation"* and *"Lock cycle time"* which together determine the lock capacity. Besides these components, the intensity and composition of navigation have lots of influence on the *"Waiting time navigation"*.

Possible improvements have to be within the current infrastructural situation therefore the improvements have to be searched within the processes to pass the lock complex and the supply of navigation and road traffic. Analysis of the processes to pass the Lorentz lock complex are used to gain further insight in the components influencing the waiting times for navigation and road traffic. For this analysis flowcharts and time-progress diagrams are used to clarify the behavior of vessels at the lock complex and the actions needed to pass the Lorentz lock complex.
There are two possible improvements to reduce the congestion of navigation resulting from the process analysis:

- Improving the behavior of recreational navigation.
- Upgrading the small, eastern, navigation lock at Kornwerderzand.

The supply of navigation at the Lorentz lock complex also influences the moment and amount of congestion. The supply of navigation is unequally distributed over the year and over the day. The unequal distribution over the year is caused by the huge share, over ninety-five percent, of recreational navigation which only uses the locks during navigation season. And the unequal distribution over the day is mainly caused by the Waddenzee tide and resulting tidal flows and water levels.
Based on this information and by analyzing the navigation the distributions of the navigation at the Lorentz locks can be predicted. These predictions of the distribution of the navigation at the Lorentz locks can be used to inform skippers. This can be done in two ways; first the distribution of navigation over the year, month and week can be made public. This distribution presents the busy periods, days and skippers can decide to avoid those days and periods. Secondly the distribution over the day can be presented to the skippers and yachtsmen so they can choose to avoid congestion.

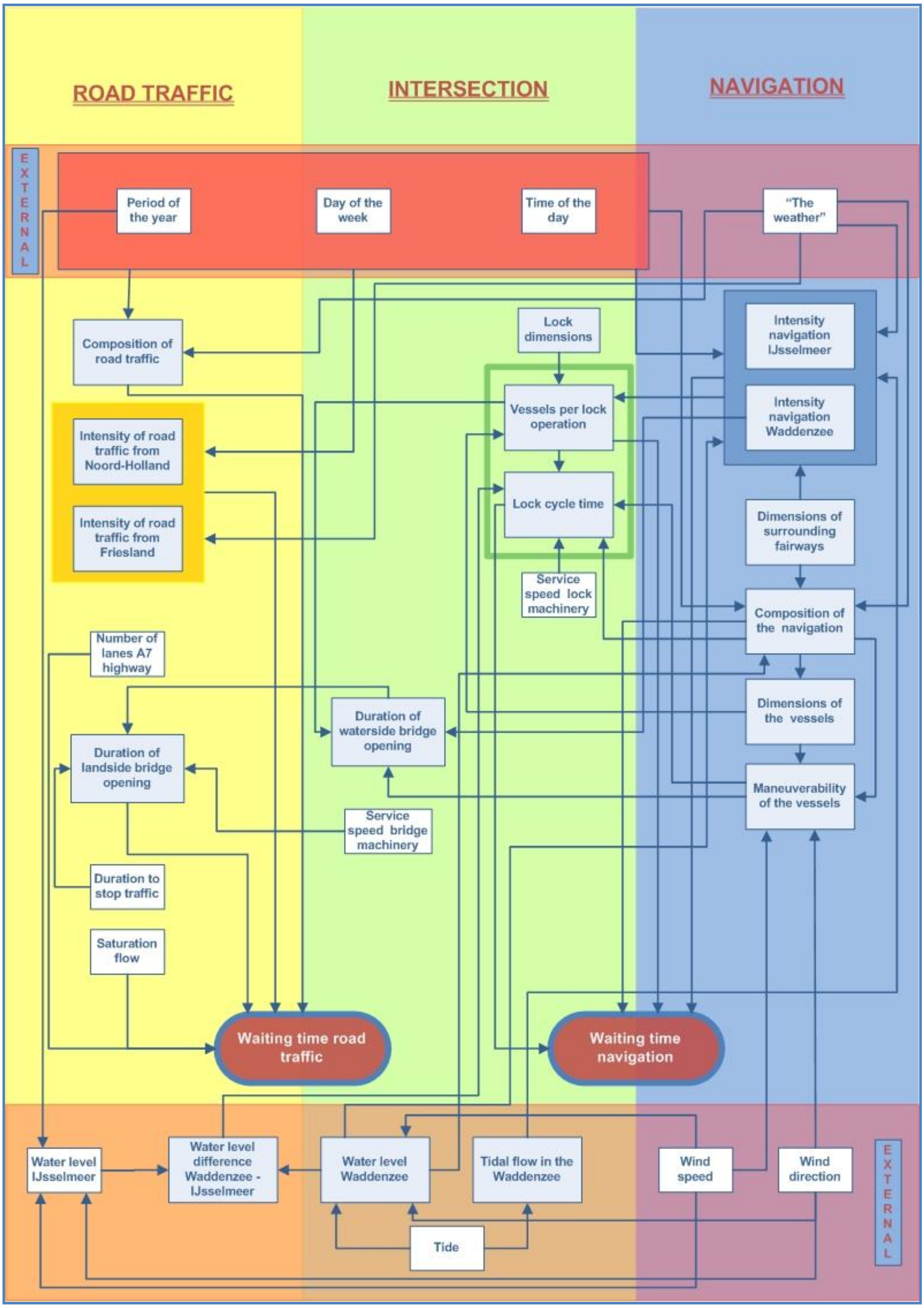


Figure 3: All components influencing the waiting time for navigation and road traffic at the lock complexes at the Afsluitdijk; and their interaction.

When sufficient navigation tries to avoid the busy periods, a more equal distribution of navigation will be the result which again results in less waiting time at the Lorentz navigation locks. Therefore another possible improvement to reduce congestion of navigation at the Lorentz lock complex is:

- Creating a more equal distribution of navigation at the Lorentz lock complex.

To create an objective judgment about the amount of congestion of navigation at the Lorentz Lock complex, the waiting times are investigated with the usage of micro-simulation software. With this software a simulation model of the Lorentz navigation locks is developed and this model is used to determine the current amount of congestion and the effects of possible improvements on the waiting time for navigation.
According the guideline for recreational navigation the maximum total waiting time must be one hour on the 10^{th} busiest day of the season. In the year 2005 the waiting time is over three and a half hours, in 2006 over three hours and in 2007 the maximum waiting time is one hour and fifteen minutes. Therefore it can be concluded that the Lorentz navigation locks do not meet the guidelines with regard to the total waiting times.
Previously three possibilities to reduce the congestion for navigation are presented. These possible improvements are; improving the behavior of recreational navigation, upgrading the small navigation lock at Kornwerderzand and creating a more equal distribution of navigation at the Lorentz lock complex.
The effect of improved behavior of recreational navigation is a ten percent reduction of the maximum waiting time. The most effect has upgrading the eastern navigation lock with a reduction of the maximum waiting times up to 50 percent. And finally a more equal distribution of the navigation supply at the navigation lock can reduce the maximum waiting time up to fifteen percent, but in general has less effect.

Besides the waiting time for navigation at the Lorentz lock complex, there is also the waiting time for road traffic at the lock complex and the possibility of summated congestion when there is waiting time at both lock complexes. The requirement to prevent summated congestion is that all traffic queued up at a lock complex travels to the other side of the Afsluitdijk and the swing-swivel bridges at that other, receiving, side have to be closed when they arrive.

There are three methods to prevent delays for road traffic as a result of bridge openings at both sides of the Afsluitdijk:

- Give a bridge priority based on the navigation supply. If a vessel approaches one of the bridges, the bridge opens, and the bridge on the other side has to be closed when all vehicles pass that have been waiting in front of the bridge with priority.

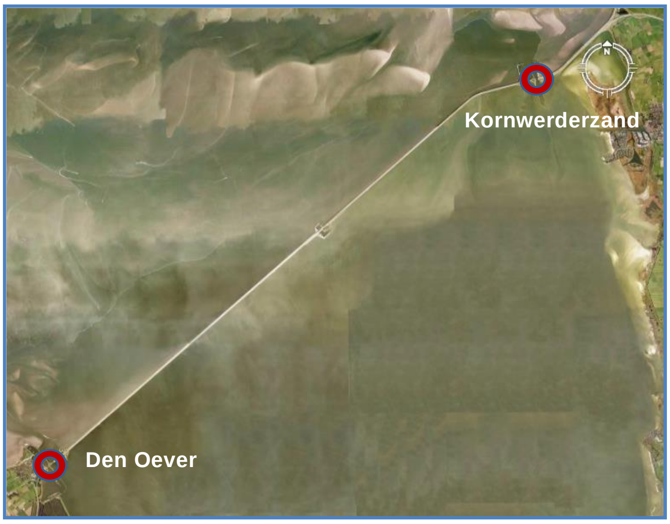
- The second option is “simultaneous bridge openings”. In this type of interaction between the bridges navigation is not determinative and the starting time of bridge openings is fixed, so a service schedule for navigation has to be created.

- The third way is by implementation of a dynamic traffic management system. This system automatically determines the arrival times at the receiving side of the first and last vehicle of the queue and the maximal time difference between these arrival times. Following bridge operations can be adapted based on this information and no, or little, time is lost because all times are determined more accurate which creates maximum time to freely operate the bridges at the Afsluitdijk

Recapitulating; the congestion at the Afsluitdijk and its lock complexes is unacceptable according the guidelines defined in this research. Within the current infrastructural situation the congestion for navigation at the Lorentz navigation locks at the Afsluitdijk can be reduced, but it cannot meet the guidelines. Opposite congestion for road traffic can become acceptable by implementing presented improvements.

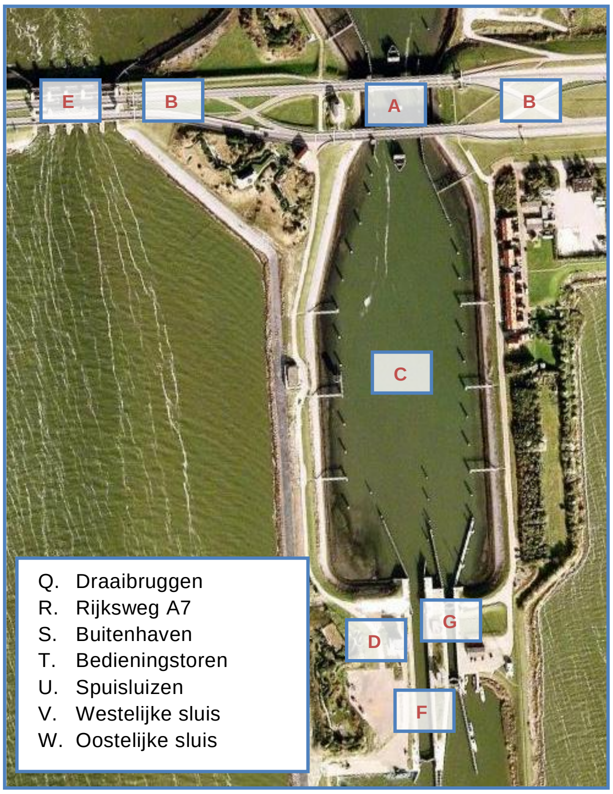
Samenvatting

Dit onderzoek richt zich op de congestie voor scheepvaart en wegverkeer op de Afsluitdijk en de aangelegen sluiscomplexen. Meestal richt onderzoek zich slechts op een modaliteit, maar in dit onderzoek wordt aandacht besteed aan de congestie voor zowel scheepvaart als wegverkeer.



Figuur 1: Situering van de sluiscomplexen bij Den Oever en Kornwerderzand (Google Earth, 2008)

Zoals Figuur 1 aangeeft, zijn er twee sluiscomplexen in de Afsluitdijk. Een is er gelegen bij Den Oever en de tweede in Kornwerderzand.
Met betrekking tot de congestie bij de Afsluitdijk, wordt er onderscheid gemaakt tussen twee soorten. Ten eerste is er lokale congestie voor wegverkeer en scheepvaart bij de sluiscomplexen en ten tweede is er de mogelijkheid dat wegverkeer vertraging ondervindt bij beide complexen.
De indeling en problematiek van beide complexen zijn vergelijkbaar alleen is er meer hinder en verkeer bij het sluiscomplex in Kornwerderzand. Daarom staat dit sluiscomplex met de haar verkeersstromen centraal met betrekking tot de lokale congestie bij de sluiscomplexen. Figuur 2 toont de indeling van het Lorentz sluiscomplex met de buitenhaven die de twee sluizen en draaibruggen van elkaar scheidt.



Figuur 2: Indeling van Lorentz sluiscomplex bij Kornwerderzand (Google Earth, 2008)

In de meeste gevallen is de wachttijd voor wegverkeer bij een sluiscomplex acceptabel. Het is alleen niet acceptabel om voor de bruggen bij beide sluiscomplexen te wachten. Hedendaags is er weinig afstemming betreffende de bediening van de bruggen bij Den Oever en Kornwerderzand waardoor het mogelijk is dat automobilisten twee keer moeten wachten

De congestie en resulterende wachttijden hinderen beide modaliteiten, maar daarnaast is er ook economische schade door vertragingen voor zowel recreatie als werkverkeer. Een derde aanleiding voor dit onderzoek is het gebrek van een duidelijk, eenduidig, standpunt met betrekking tot de hoeveelheid hinder en economische schade.

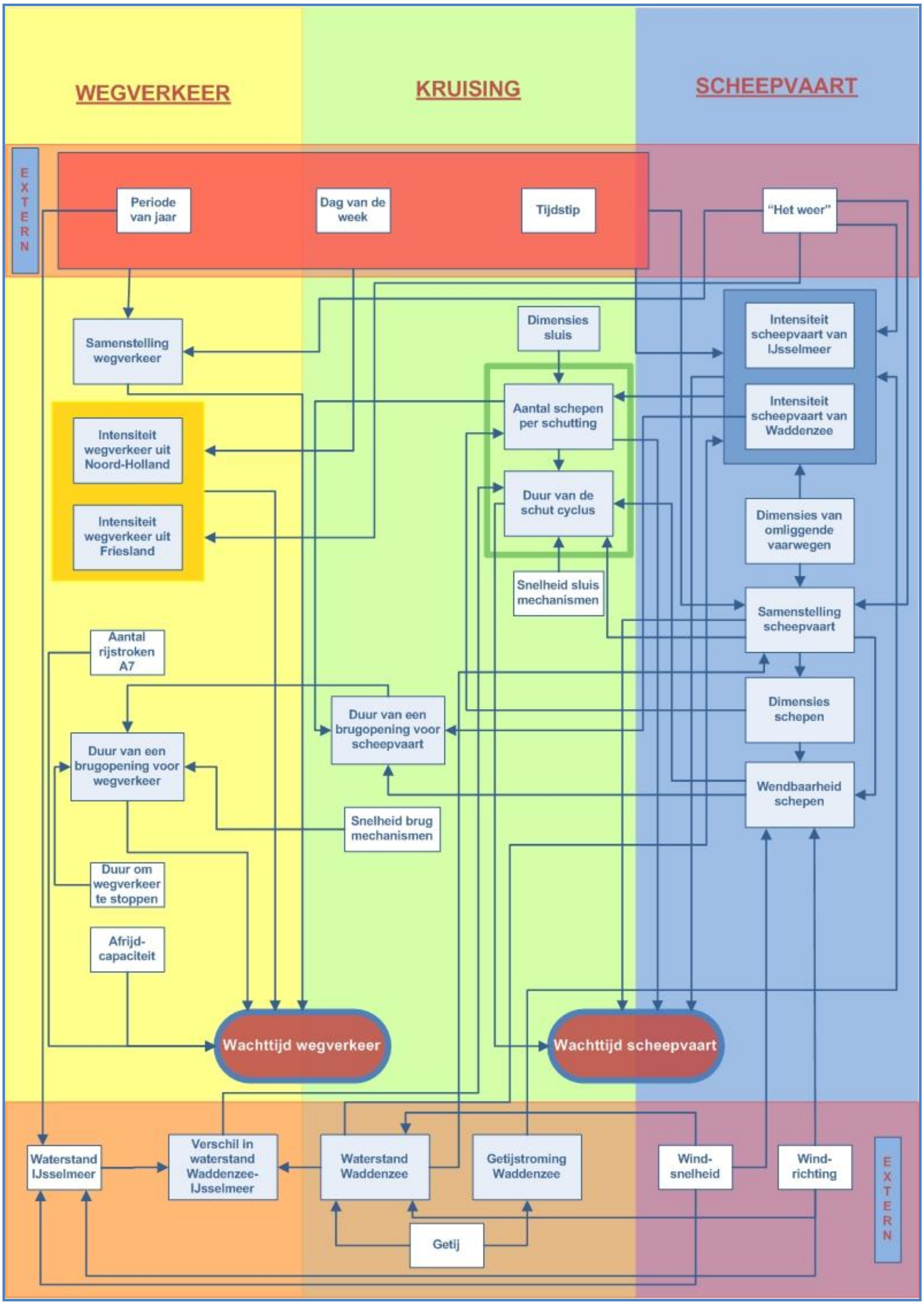
Het doel van dit onderzoek is om de centrale onderzoeksvraag te beantwoorden.
Is de hoeveelheid congestie op de Afsluitdijk en bij de sluiscomplexen acceptabel, door welke factoren wordt de congestie beïnvloed en welke van deze factoren kunnen binnen de huidige infrastructurele situatie worden beïnvloed om de congestie te verminderen?

Om deze vraag te beantwoorden is er informatie verzameld over de Afsluitdijk, de infrastructuur en het verkeer bij de Afsluitdijk. Vervolgens zijn alle factoren die invloed hebben op de congestie geïnventariseerd en is de samenhang tussen deze componenten bepaald. Alle componenten, en hun interactie zijn vervolgens geschematiseerd. Deze schematisering is weergegeven in Figuur 3. Het schema is verdeeld in drie kolommen; *"Wegverkeer"*, *"Kruising"* en *"Scheepvaart"*. Binnen deze hoofdbestanddelen van het schema zijn er veel factoren die invloed uitoefen op de hoofdonderwerpen van dit onderzoek; *"Wachttijd voor wegverkeer"* en *"Wachttijd voor scheepvaart"*. Belangrijke factoren die de *"Wachttijd voor wegverkeer"* beïnvloeden zijn de intensiteit en samenstelling van het wegverkeer en de *"Duur van een brugopening voor wegverkeer"*.
De belangrijkste factoren voor de *"Wachttijd voor scheepvaart"* zijn *"Aantal schepen per schutting"* en de *"Duur van de schutcyclus"* die samen de schutcapaciteit bepalen. Naast deze factoren hebben de intensiteit en samenstelling van de scheepvaart veel invloed op de *"Wachttijd voor scheepvaart"*.

Mogelijke verbeteringen van de bereikbaarheid moeten binnen de huidige infrastructurele situatie worden gezocht, daarom wordt er gezocht naar oplossingen binnen de processen om het sluiscomplex te passeren en de verkeersstromen van en naar het sluiscomplex. Passages van het Lorentz sluiscomplex zijn geanalyseerd om meer inzicht te krijgen in de factoren die invloed hebben op de wachttijd voor scheepvaart en wegverkeer. Voor de analyses zijn stroomschema's en tijd-afstand diagrammen gebruikt om te verduidelijken hoe scheepvaart zich gedraagt bij het complex en welke acties nodig zijn voor een passage. Uit deze analyses vloeien twee mogelijke verbeteringen voort:

- Het verbeteren van het gedrag van recreatievaart.
- Het verbeteren van de kleine, oostelijke, schutsluis.

De aanvoer van scheepvaart bij het Lorentz sluiscomplex beïnvloedt ook het moment en de hoeveelheid congestie. De aanvoer van scheepvaart is ongelijk verdeeld over het jaar en over de dag. De ongelijke verdeling over het jaar wordt veroorzaakt door het grote aandeel, boven de 95%, van recreatievaarders die het sluiscomplex alleen gebruiken in het recreatievaartseizoen. De ongelijke verdeling over de dag wordt vooral beïnvloed door het getij van de Waddenzee en de getijstromen en waterstanden hieruit volgend.
Op basis van deze informatie en analyses van de scheepvaart intensiteiten kunnen de toekomstige scheepvaart intensiteiten bij het Lorentz sluiscomplex worden voorspeld. Vervolgens kunnen deze voorspellingen door schippers en recreanten worden gebruikt. Dit kan op twee manieren worden gedaan; ten eerste kunnen de verdelingen van scheepvaart over het jaar, een maand of een week publiek worden gemaakt. Deze verdeling geeft dan informatie over drukke periodes, dagen en schippers kunnen besluiten om deze dagen en periodes te mijden. Ten tweede kan de verwachte verdeling van scheepvaart over de dag worden gepresenteerd aan schippers en recreatievaarders zodat ze de congestie op de dag kunnen vermijden.



Figuur 3: Alle factoren die de wachttijd voor scheepvaart en wegverkeer bij het sluiscomplex beïnvloeden inclusief de interactie.

Wanneer voldoende recreatie –en beroepsvaarders de congestie proberen te mijden dan ontstaat een gelijkmatigere verdeling van de scheepvaartintensiteiten en dat resulteert weer in minder wachttijd bij de Lorentz sluizen. Een volgende manier om de congestie bij de Lorentz sluiscomplex te verminderen is:

- Het creëren van een gelijkmatigere verdeling van de scheepvaartintensiteiten.

Om een objectief oordeel te kunnen vellen over de hoeveelheid congestie bij het Lorentz sluiscomplex zijn de wachttijden bepaald middels het gebruik van microsimulatie software. Met deze software is een model van de Lorentz sluizen ontwikkeld waarmee de huidige hoeveelheid congestie en de invloed van mogelijke verbeteringen kan worden bepalen.
Volgens de richtlijnen voor recreatievaart mag de maximale totale wachttijd één uur zijn op de 10^{de} drukste dag van het seizoen. In het jaar 2005 was de wachttijd meer dan drie en een half uur, in 2006 meer dan drie uur en in 2007 was de wachttijd één uur en vijftien minuten. Hieruit kan worden geconcludeerd dat de Lorentz sluizen niet aan de richtlijnen voldoen met betrekking tot de wachttijden.
Eerder in deze samenvatting zijn drie mogelijkheden aangedragen om de congestie voor scheepvaart te reduceren. Deze mogelijke verbeteringen zijn; het verbeteren van het gedrag van recreatievaart, het verbeteren van de kleine oostelijke sluis en het creëren van een gelijkmatigere verdeling van de scheepvaartintensiteiten.
Het verbeteren van het gedrag van de recreatievaart reduceert de maximale wachttijd met tien procent. Het meeste effect heeft het verbeteren van de kleine, oostelijke, schutsluis met een reductie van de maximale wachttijd tot 50 procent. En tenslotte is er de gelijkmatigere verdeling van de scheepvaartintensiteiten die resulteert in reducties to vijftien procent, maar in het algemeen een minder positief effect heeft op de maximale wachttijd.

Naast de wachttijden voor scheepvaart is er ook de wachttijd voor wegverkeer bij het sluiscomplex en de gesommeerde congestie als er wachttijd is bij beide sluiscomplexen. De voorwaarde om gesommeerde congestie te voorkomen is; dat al het verkeer uit een wachtrij naar de andere kant van de Afsluitdijk rijdt en dat de draaibruggen aan die ontvangende zijde gesloten zijn als het verkeer aankomt.

Er zijn drie manieren om te voorkomen dat wegverkeer congestie aan beide zijden van de Afsluitdijk ondervindt:

- Een van de bruggen dominant maken op basis van de aanvoer van scheepvaart. Als een schip een van de bruggen nadert, dan gaat de brug open. Vervolgens moet er worden gezorgd dat de brug aan de andere zijde gesloten is wanneer alle voertuigen passeren die hebben moeten wachten voor de dominante brug.

- De tweede optie is om de bruggen gelijktijdig te openen. In dit geval heeft scheepvaart geen voorrang en staan de openingstijden van de brug vast.

- De derde manier is het implementeren van een dynamisch verkeersmanagement systeem. Dit systeem kan automatisch de aankomsttijden aan de ontvangen zijde bepalen van het eerste en laatste voertuigen dat in de wachtrij heeft gestaan. Hierop kan de bediening van de brug worden afgestemd en zo kan de afstemming tussen de bruggen worden geoptimaliseerd.

Samengevat is de hoeveelheid congestie onacceptabel op basis van de richtlijnen die in dit onderzoek zijn gesteld. Binnen de huidige infrastructurele situatie kan de congestie voor scheepvaart bij de Lorentz sluis worden gereduceerd, maar kan er niet worden voldaan aan de richtlijnen. Hiertegenover kan de congestie voor wegverkeer wel acceptabel worden middels het implementeren van de aangedragen verbeteringen.

Table of Contents

1 Introduction

The goal of this chapter is to create insight in the report structure and its contents. It starts with an introduction of the central subject(s) within the research followed by theory concerning infrastructure problems. Next the research motives are presented and subsequently the specification of the research is explained. This specification contains the problem definition, the research objective and research questions.
Finally a representation of the report structure is presented in the second paragraph which shows the separate parts (chapters, paragraphs) of this report and its connections.

1.1 The accessibility problems

This research focuses on one of the deficiencies of the Afsluitdijk, namely the accessibility problems for navigation and road traffic at the Afsluitdijk and its lock complexes. Most of the time research focuses on only one modality, but in the research the accessibility problems for navigation as well as road traffic are taken into account.
Concerning the accessibility of the Afsluitdijk there are two situations distinguished. First of all there is the local congestion for road traffic and navigation at the lock complexes, but for road traffic it's also possible to have delay at both lock complexes. Therefore congestion for road traffic is also investigated for the Afsluitdijk in total.

1.1.1 The local congestion of road traffic and navigation at the lock complexes

There are two lock complexes in the Afsluitdijk. One is the Stevin and the other is the Lorentz lock complex. The first one is situated at the western, North-Holland, side of the Afsluitdijk and the second is located in the east at Kornwerderzand in the province of Friesland.
Both complexes have the same layout and accessibility problems only there is more nuisance and traffic at the Lorentz complex at the Friesland side. Therefore, this lock complex and its traffic flows are the central subjects concerning the local congestion.
The Lorentz lock complex is a level intersection between the A7 national highway and fairways connecting the IJsselmeer and the Waddenzee. Therefore, there are two swing-swivel bridges at the lock complex which have to be opened to let the vessels pass. As a result vehicles cannot pass when the bridge is open so there are conflicting interests of both modalities and compromises between waiting queues and time for navigation and road traffic are made.

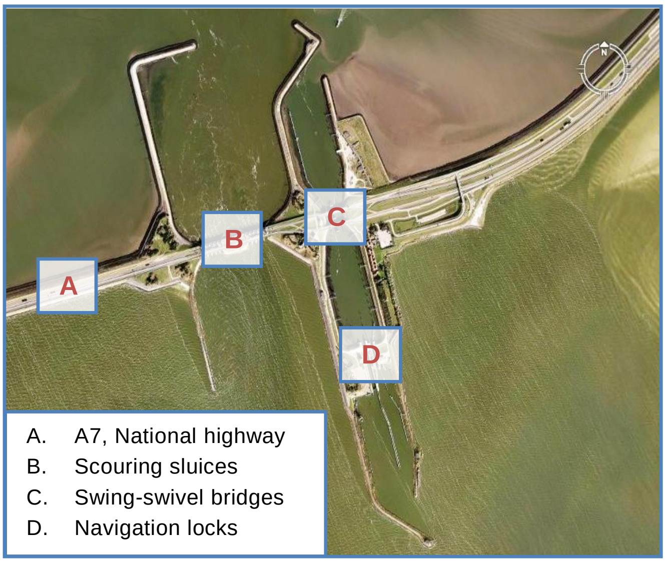


Figure 1-1: The surroundings of the Lock-sluice complex at Kornwerderzand with its main components (Google Earth, 2008)

Under most circumstances the capacity of the lock complex is sufficient so the waiting time for road traffic and navigation is acceptable.

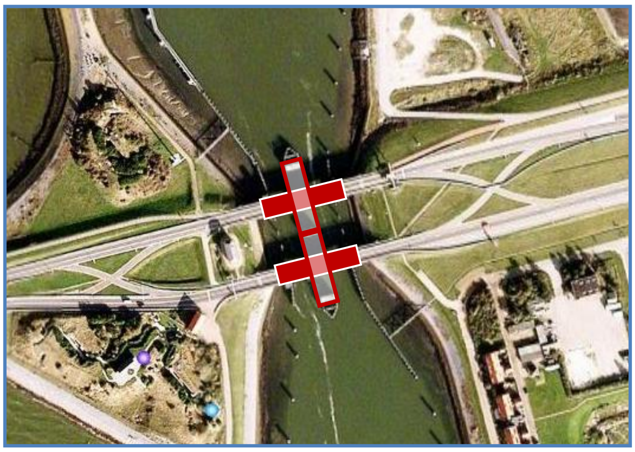


Figure 1-2: Swing-swivel bridges in the A7, at the lock complex at Kornwerderzand (Google Earth, 2008)

Unfortunately this is totally different during summer days, weekends, in the navigation season. During these periods, the intensity of navigation increases by an enormous amount of recreational navigation.
These increased intensities combined with a possible shortage of capacity at the navigation locks and longer bridge openings, results in waiting times of several tens of minutes for road traffic and over three hours for navigation.

1.1.2 The congestion of road traffic at the Afsluitdijk

Besides the independent congestion at the Lock complexes in the Afsluitdijk there is also the possibility of summated congestion for road traffic. As mentioned before, the Afsluitdijk has lock complexes at both ends, Den Oever and Kornwerderzand, so there is also the possibility of summated congestion for road traffic.
In most cases the waiting times at the individual lock complexes are acceptable for road traffic. It is not however, acceptable to wait for *both* lock complexes at the Afsluitdijk. Nowadays there is little tuning between the service of the swing-swivel bridges at Den Oever and Kornwerderzand, therefore it's possible that drivers have to wait twice. In that case drivers are sometimes waiting over twenty minutes on a 26 kilometers trip on a straight highway which would normally take about 15 minutes to cover.

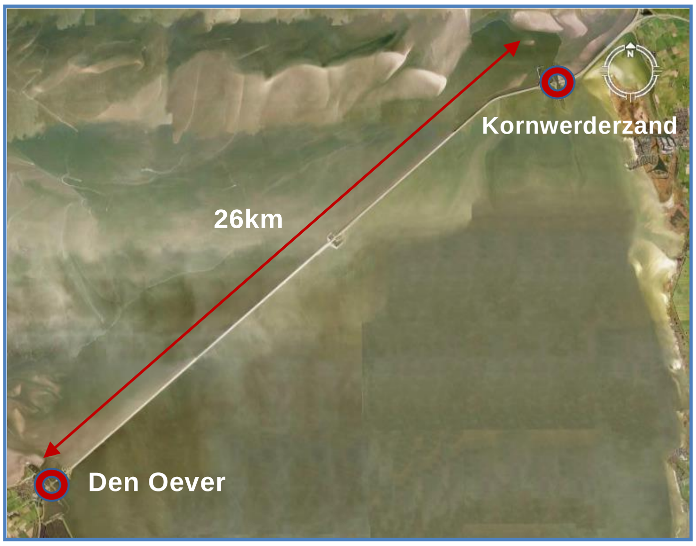


Figure 1-3: Locations of the swing-swivel bridges at Den Oever and Kornwerderzand (Google Earth, 2008)

1.2 Infrastructure problems

In general there are five types of infrastructure problems. These types of problems are technical deficiencies, lack of capacity, insufficient usability, insufficient safety and insufficient environmental quality.

- Technical deficiencies
  The infrastructure does not meet technical specifications. Therefore there is a constant need for maintenance, renovation, and replacements.

- Lack of capacity
  The infrastructure cannot guide the process because the capacity demand exceeds the supply. Either the capacity needs to be increased or the demand needs to be reduced.

- Insufficient usability
  The process, which is accommodated by the infrastructure, happens irregularly, unpredictably, slowly and with insufficient comfort. This is a reason to modernize or offer new infrastructure systems.

- Insufficient safety
  There is a (high) risk of accidents with casualties at or surrounding the infrastructure. After calamities, this sometimes leads to major adjustments.

- Insufficient environmental quality
  The infrastructure causes an inconvenience to its surroundings. In the last decades, this is the reason for the development of a more critical perspective on infrastructure and improvements of the implementation of infrastructure.
  The surroundings, including the natural environment, can cause problems which can be solved by implementation of infrastructure.
  (De Boer, 2001)

The accessibility problems at the Afsluitdijk combine four of the five types presented above. The four types are the technical deficiencies, lack of capacity, insufficient usability and insufficient safety. Two of the types are not included in this research and the remaining two, lack of capacity and insufficient usability, are included.
Technical deficiencies cause occasional congestion which gives no value judgment about the functionality of the system under "normal circumstances" and therefore this type of problem is not addressed in this research. Insufficient safety is also becoming a problem at the Afsluitdijk and mainly at its lock complexes. For every infrastructural system which operates at the limits of its capacity, the risk of accidents increases. During navigation season there are periods when the navigation locks are operating at the limits or at capacity which results in safety being reduced. Also this type of problem is not included in the research because it has no direct impact on the congestion.
The remaining two types of problems are lack of capacity and insufficient usability which will be thoroughly investigated within this research.

1.3 Research motives

The 75th anniversary of the Afsluitdijk was the motive to initiate research on this historical structure. The anniversary was celebrated in May 2007 and received lots of media attention. Besides the media attention, it was the moment to discuss future developments concerning the Afsluitdijk. The subjects of these discussions were mainly water related because the most important functions of the Afsluitdijk are in the fields of hydraulic engineering and water management. Nevertheless the Afsluitdijk has other functions like connecting the provinces of North-Holland and Friesland by road as well as connecting, and separating, the IJsselmeer and Waddenzee.
According previous research on this subject, this important connection, the Afsluitdijk, appears to have deficiencies with regard to the accessibility for navigation and road traffic. Until recently these deficiencies have not been solved and there are no plans to solve them in the short term. The nuisance and economical damage caused by accessibility problems and the lack of an unambiguous attitude towards this subject are the motives for this research and are presented in the next sub-paragraphs 1.3.1 and 1.3.2.

1.3.1 Nuisance and economical damage

Of course the congestion and resulting waiting times result in annoyance for both modalities. Besides this nuisance there is also economical damage caused by delays for navigation, professional, recreational, and road traffic.
Usually the value of time is an important factor to quantify the amount of damage caused by congestion. For road traffic and professional navigation this is already clear. The economical damage for recreational navigation however, has been previously underestimated. Fortunately it is clear nowadays that this group is a big spender in the recreation sector. Recreational navigation gives an important impulse to the economy in aquatic sports areas. It contributes considerably to employment and turnover in these aquatic sports areas. For example, the total employment in the Netherlands caused by recreational navigation in the year 2000 was about 20.000 human years, the total production about 1,8 billion Euro's and the added value was 0.8 billion Euro's. (Stichting Recreatietoervaart Nederland, 2000)
The nuisance and economical damage for both modalities and the surrounding (aquatic sports) areas are one of the two motives behind this research.

1.3.2 The lack of an unambiguous stand on the congestion at the Afsluitdijk

Despite the fact that there is nuisance and economical damage for both modalities at the Lorentz lock complex, previous research has no unambiguous stand on the level of nuisance. Several stands concerning the congestion are summarized to prove this statement:

- *During summer there has been on average ten days with waiting times over three hours. It is expected that waiting times at the Lorentz locks will increase in the future as a result of the growth of navigation in numbers as well as dimensions, navigation on tide windows and a 40% growth of road traffic until 2020.*
  Because of the lack of numerical data, it is impossible in this survey to estimate if, and if so, on which term the problems for navigation will be unacceptable.

When the high tide of the Waddenzee (with lots of navigation) is during the morning or evening peak hour on the A7 national highway, there is congestion in both directions at the swing-swivel bridges at the Lorentz lock complex. In that case waiting times can increase until several tens of minutes. This results in lots of annoyance for the road traffic especially when the bridges at both lock complexes in the Afsluitdijk are open.
The road traffic increases until 2020 with 40% and combined with a growing number of lock passages results in increasing waiting time for road traffic in frequency as well as duration. (Ministerie Verkeer & Waterstaat, 2001)

- *The long waiting times at the Lorentz locks are linked to the Waddenzee tide. An important improvement is increasing the number of berths on the Waddenzee side, so navigation doesn't have to wait on the IJsselmeer side for the right Waddenzee tide. In the future, an aqueduct at Kornwerderzand will be necessary. (Stichting Recreatietoervaart Nederland, 2000)*

- *Increased navigation combined with increased vessel dimensions could cause an increase in waiting time for navigation. In addition increasing road traffic can cause a further increase in the waiting time for navigation.*
  Nevertheless there are no bottlenecks expected at the navigation locks in the Afsluitdijk, but it is recommended to follow the developments in the field of navigation to be able to anticipate in an early phase on these developments.
  The passage of the swing-swivel bridges by navigation from both directions is going smoothly. In the future the increasing road traffic can (further) obstruct the lock process. The combination with the charter navigation can cause problems in the future.

  According the guidelines for fairways of the CVB, the minimal lock (like the Stevin and Lorentz lock in the Afsluitdijk for vessel class Va) comes up to the requirements for a maximum of 10.000 passages for professional navigation per year.

  At the busiest Lorentz lock, only 2500 professional vessels pass each year, so even with a future growth of 50% until 2020, the number of passages will still be quite small.
  Of course there is also recreational navigation, but because of the small number of professional passage there is relatively a lot of the capacity remaining for recreational navigation. This is true despite the fact that the navigation is concentrated at high tide in the Waddenzee.
  *Interviews at the locks tell that at the recreational peak during summer, navigation is sometimes 2 to 3 times on demurrage. But because of the low frequency, this is acceptable. It should also be taken in account that the Lorentz navigation locks already have two chambers, one for professional navigation (138*14) and one recreational, yacht, lock of 67 by 9 meters. (Adviesdienst Verkeer en Vervoer, 2001)*

This enumeration shows different perspectives concerning the congestion at Kornwerderzand, but they have one thing in common. All perspectives are based on global descriptions of the amount of the congestion, but no thorough research has been initiated (yet) to create clarity about these amounts congestions. This lack of clarity is the second motivation behind this research.

1.4 Specification of the research

Previous (sub) paragraphs have described the accessibility problems at the Afsluitdijk and the motives for this research. In this paragraph the research is specified which includes the Problem definition, the Objective and the Research questions.

1.4.1 Problem definition

As presented in paragraph 1.1, the accessibility problem within this research is twofold. On one hand there is the local congestion for navigation and road traffic at the lock complexes in the Afsluitdijk which is specified to the congestion at the Lorentz lock complex at Kornwerderzand.
On the other hand there is the summated congestion for road traffic on the Afsluitdijk. This deviation is made because it is possible for road traffic to experience congestion at both lock complexes which cannot be investigated by focusing on one (Lorentz) lock complex. Consequently this problem gets separate attention within this research concerning the accessibility problem.

The definition of the accessibility problem at the Afsluitdijk is:

There is congestion for road traffic as well as navigation at the Afsluitdijk and its lock complexes and there is no clear insight in the characteristics and the amount of congestion. Therefore there is no unambiguous stand of the Dutch Directorate for Public Works and Water Management whether this congestion is acceptable, or not and thereby there is little initiative to reduce this congestion.

1.4.2 Objective

Resulting from the problem definition, the objective within this research is:

To determine the amount of congestion at the Afsluitdijk, whether this is acceptable, which aspects influence the congestion and which of these aspects can best be influenced within the current infrastructural situation to reduce the congestion.

In order to determine whether or not the congestion is acceptable, a definition of "acceptable" is needed. In this research the acceptability of the congestion for navigation results from the Guidelines Fairways which are drawn up by the Division of Traffic and Navigation of the Dutch Directorate for Public Works and Water Management.
The standard, guidelines, for the total waiting time of navigation at navigation locks on the main fairways are:

The average total waiting time for professional navigation in the defining month has a maximum of 30 minutes.
The total waiting time for recreational navigation is at most one hour on the 10th busiest day of the season. (Ministerie Verkeer & Waterstaat, 2006)

For road traffic there are no exact guidelines, but there is the ambition to reach an average speed of 80 kilometers per hour on the national highways. (Ministerie Verkeer en Waterstaat, 2008) Fortunately the duration of the waiting time at a lock complex is normally not the problem for motorists, but it becomes a problem when road traffic has to wait for both lock complexes at each side of the Afsluitdijk. Therefore, it is assumed that:

Congestion for road traffic is acceptable when there is only waiting time at one of the two lock complexes.

The part of the problem definition *"within the current infrastructural situation"* clarifies that improvements, alterations, concerning new structures and infrastructure are not in the scope of this research. This demarcation is made because the lack of an unambiguous stand concerning the accessibility problems also indicates a lack of support of expensive infrastructural changes.

1.4.3 Research questions

Despite the nuisance and economical damage by congestion at the Afsluitdijk and its lock complexes the exact characteristics, like the amount, frequency and moment, of the congestion are still unclear. In addition little possible adaptations to reduce the congestion have been investigated. The answers to the following sub-questions clarify most of these characteristics, including possible adjustments to reduce congestion and thereby support to answer the main research question.

- *When does the congestion occur?*
- *What is the amount of congestion expressed in time and is this acceptable?*
- *Which aspects influence the moment, frequency and amount of congestion?*
- *Which aspect can best be influenced within the current situation to reduce the congestion?*
- *Can the congestion become acceptable with improvements within the current infrastructural situation?*

The sub-questions support to answer the central question within this research:

Is the amount of congestion at the Afsluitdijk and its Lorentz lock complex acceptable, by which aspects is the congestion influenced and which of these aspects can best be influenced within the current infrastructural situation to reduce congestion?

1.5 Report map

To clarify the setup of this report, a report map is presented in
Figure 1-4. This map connects the contents of the report and thereby creates insight in the interrelationships of all different chapters.

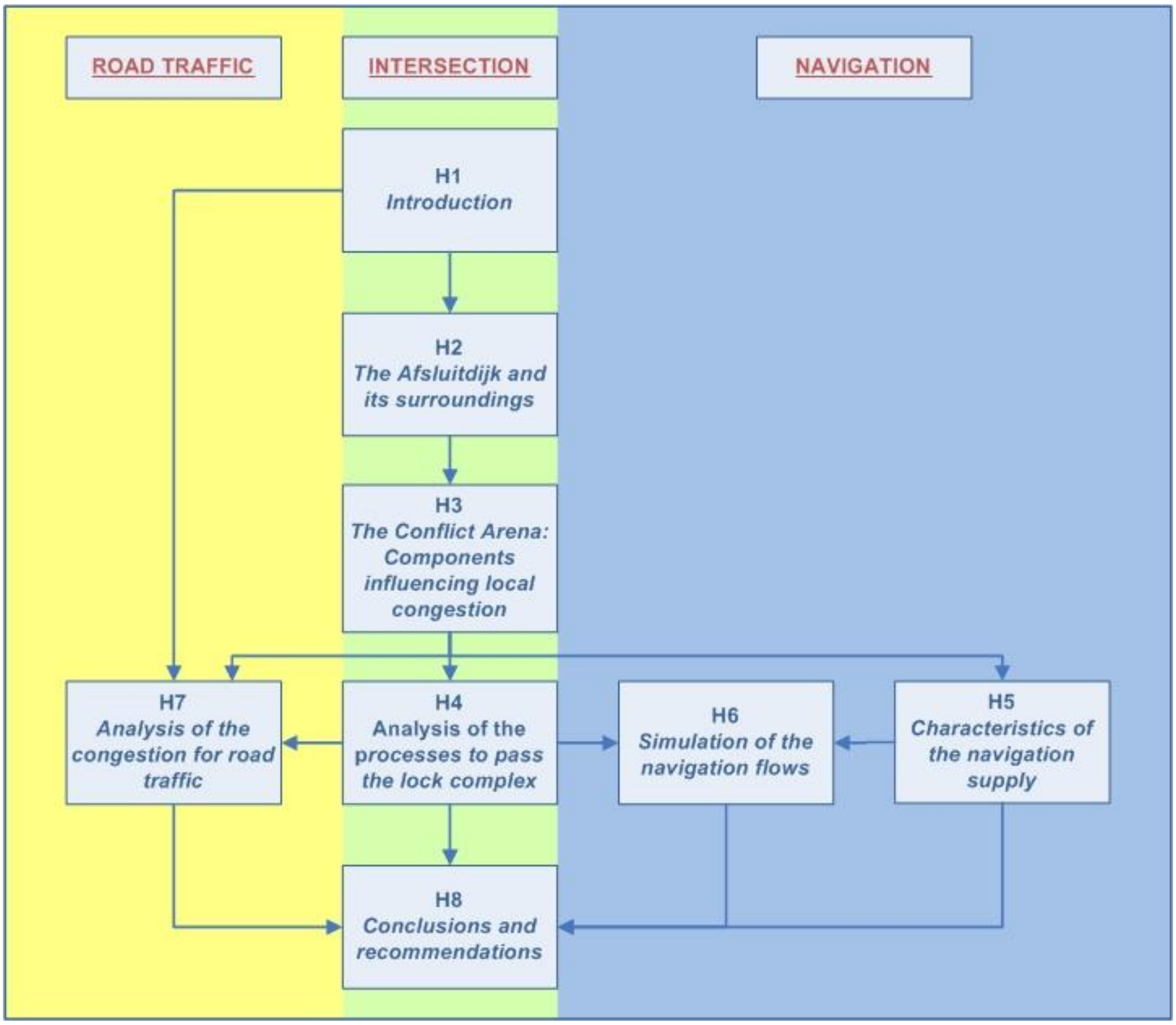


Figure 1-4: Report map

This chapter, Chapter 1, introduces the central subjects within this research, the motives for the research and the specification containing the problem definition, the objective and research questions.
In the next chapter background information about the Afsluitdijk is presented to create more insight in the surroundings, the characteristics and traffic at the Afsluitdijk and its lock complexes.
The following chapter, 0, contains a Conflict Arena with all components influencing the local congestion and the interaction between those components.
Chapter 0 gives an analysis of the processes to pass the Lorentz lock complex. First the processes are analyzed and finally possible savings of time within the passage processes are presented.
After the analysis of the processes to pass the lock complex, chapter 5 focuses on the supply of navigation at the navigation locks. This chapter describes the characteristics of the navigation

supply and gives a comparison between the theoretical and actual distribution of navigation. Subsequently travel advises for navigation are given to avoid congestion and thereby create a more equal distribution at the Lorentz navigation locks.
The next chapter, 6, combines the information of previous chapters for the development of a simulation model of the Lorentz navigation locks. This model is used to determine the actual amount of congestion and the effects of improvements concerning the passage process and the navigation supply.
In chapter 7 the focus shifts to the summated congestion for road traffic before the swing-swivel bridges at the lock complexes on both sides of the Afsluitdijk. This chapter starts with calculations to determine the amount of local congestion at one lock complex followed by the presentation of conditions and possibilities to prevent the summated congestion caused by congestion at both lock complexes.

Finally chapter 8 contains the conclusions and recommendations resulting from the analyses presented in chapters 3 through 7. Based on these analyses the research questions presented in the beginning of this chapter will be answered.

2 The Afsluitdijk and its surroundings

Within the framework of this research, it is necessary as well as interesting, to have some background information about the Afsluitdijk, its infrastructure and the traffic using this infrastructure. Therefore, this chapter contains a concise description of the history, construction, location and functions of the Afsluitdijk. Subsequently the infrastructure and surroundings of the Lorentz lock complex is presented in paragraph 2.5. Finally, paragraph 2.6 presents the characteristics of the traffic, road and water, and its networks.

2.1 History

In 1670 the first plan including an Afsluitdijk appeared. Hendric Stevin, son of the famous mathematician and engineer Simon Stevin, had the idea to connect Noord-Holland with the Frisian Islands and finally the coast of Friesland.
After Stevin, no new "Zuiderzee plans" were published until 1848, but plans kept coming in the second half of the 19th century. The name "Zuiderzee plans" came from the fact that the Zuiderzee would be closed by construction of an Afsluitdijk. The Zuiderzee was an inland sea, but should have become a lake, The IJsselmeer, after closure by the Afsluitdijk.
The year 1886 was a memorable year for the reclaiming and closure of the Zuiderzee. This year the Zuiderzeevereniging was founded. This association wanted to start technical and financial research about closure of the Waddenzee for future gradual reclaiming of the Zuiderzee, the Wadden and the Lauwerszee.
Cornelis Lely soon became in charge of the technical investigation and would later become minister of the Dutch Directorate for Public Works and Water Management. He was the main force behind implementation of the Zuiderzeewerken as a planner and a politician.

In 1888 the famous, current, design occurred for the first time including the four polders south of the Afsluitdijk. It took a long time before the government got interested and to create enough (financial) bases. The flood disaster of 13, 14 January 1916 and the lack of fertile ground for food production during World War I resulted in a feeling of necessity. On July the 5th 1918 "the Zuiderzee law" was published which included the construction of the Afsluitdijk as the first step.
Construction started on 29 June 1920 between Noord-Holland and Wieringen. These two and a half kilometers were finished in 1924. The second 32 kilometer, section was between Wieringen and the coast of Friesland. This started in 1927 and was completed on May 18th, 1932, when the final opening was closed.
At the start of construction, there was little knowledge about soil and fluid mechanics but with common sense, bottom samples, experiments, and research commissions the knowledge was developed along the way.

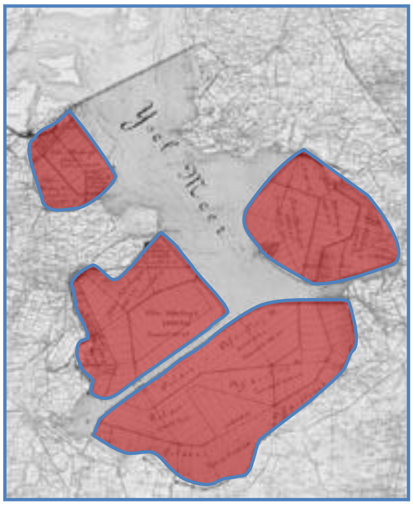


Figure 2-1: Initial design Zuiderzeewerken (Nieuw Land Erfgoedcentrum, 2008)

As a consequence, sometimes changes in the design had to be made. Even professor doctor H.A. Lorentz, winner of Nobel prize, was chairman of a commission and took care of the higher water levels and wave runup during storms. (Fuchs & Simons, 1972)

Since 1932 there have been no major changes or alterations to the Afsluitdijk and it still functions until this day. It is very impressive that engineers created a structure, with a shortage of information and knowledge, which has functioned for over 75 years. Engineers like Stevin, Lorentz and Lely have created history and thereby deserved a spot in the Dutch engineering hall of fame.
Despite the effort of these great engineers, the Afsluitdijk won't function sufficiently for another 75 years. This is the result of changed requirements for water management, water-retaining structures and infrastructure which make adaptations necessary.

2.2 Construction

The inner part of the dam consists of sand, but on the Waddenzee side a boulder clay dam gives resistance against water flows against and over the dam. This gives protection against seepage and dikebreaches. Most of the boulder clay dam is directly founded on the sea bed.
The sand-dam is covered by a layer of boulder clay topped by a small layer of clay. Underneath the water surface the sand-dam was protected by twig and cane mattresses covered with stone loads and above the water the cover was bricks and grass. (Fuchs & Simons 1972)

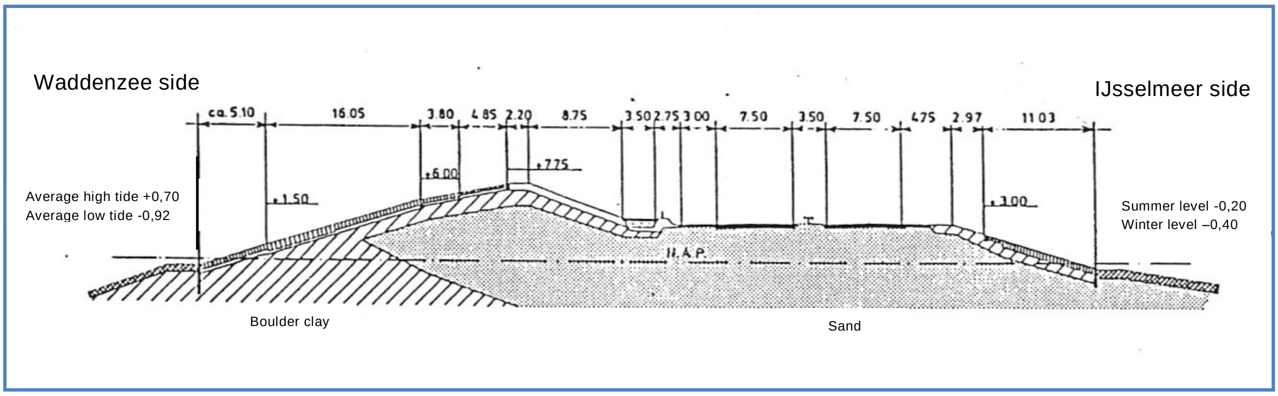


Figure 2-2: Average cross section Afsluitdijk (Fuchs & Simons 1972)

2.3 Location

The Afsluitdijk is surrounded by the province of Noord-Holland, municipality Wieringen, in the west, the Waddenzee in the north, the province of Friesland, municipality Wûnseradiel, in the east and the IJsselmeer in the south. The entire Afsluitdijk is controlled by the Dutch Directorate for Public Works and Water Management, IJsselmeer-area.

The Waddenzee and IJsselmeer are of such importance for the Netherlands that they have their own part in the national government's' spatial policy.

<u>The Waddenzee</u>

The Waddenzee takes up the sea area between Den Helder and the national frontier with Germany. The Waddenzee is the largest nature reserve of Western-Europe and the largest tidal region in the world. It is a coherent area and the main characteristics are: (geo) morphology, ecology and landscape. This unity and coherence stretches over the surrounding areas which form the Wadden-area together with the Waddenzee. The identity of this area is based on a number of qualities which are rare and irreplaceable. These qualities are: natural resources, (open) horizon and coherence.

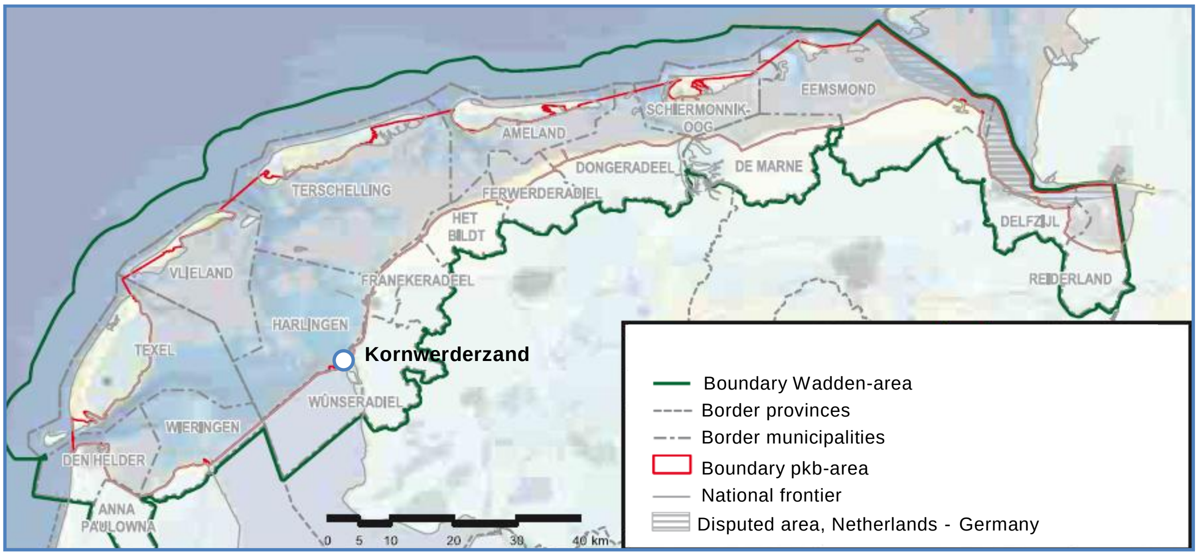


Figure 2-3: Wadden-area (Ministerie VROM, 2007)

The main goal of the national spatial policy for the Wadden-area is the sustainable conservation and development of the Waddenzee as a nature reserve and the preservation of the unique open landscape.

This main goal has consequences for new human activities which influence the Wadden-area in a negative way. The permissibility of new, or alteration, or adaption of existing human activities is based on the European Bird –and Habitat directives and the Nature conservation law. (Ministerie VROM, et. al., 2006)

[1] pkb, "planologische kernbeslissing", is the Dutch national guide-line for spatial planning.

<u>The IJsselmeer</u>

The IJsselmeer is part of the IJsselmeer-area together with the Markermeer, Ijmeer, the (smaller) edge lakes surrounding the Flevopolder and the Flevopolder itself. The main qualities of this area are; nature, culture and the "open horizon". The area also has the very important function of protecting the hinterland against flooding, water management, and supplying fresh water. Next to these functions the area also is important for water sports and other recreational activities.

The main goal for the IJsselmeer-area is to consolidate the functions of the IJsselmeer and to maintain and develop the area as a large-scale open area with special international nature, landscape and cultural values.

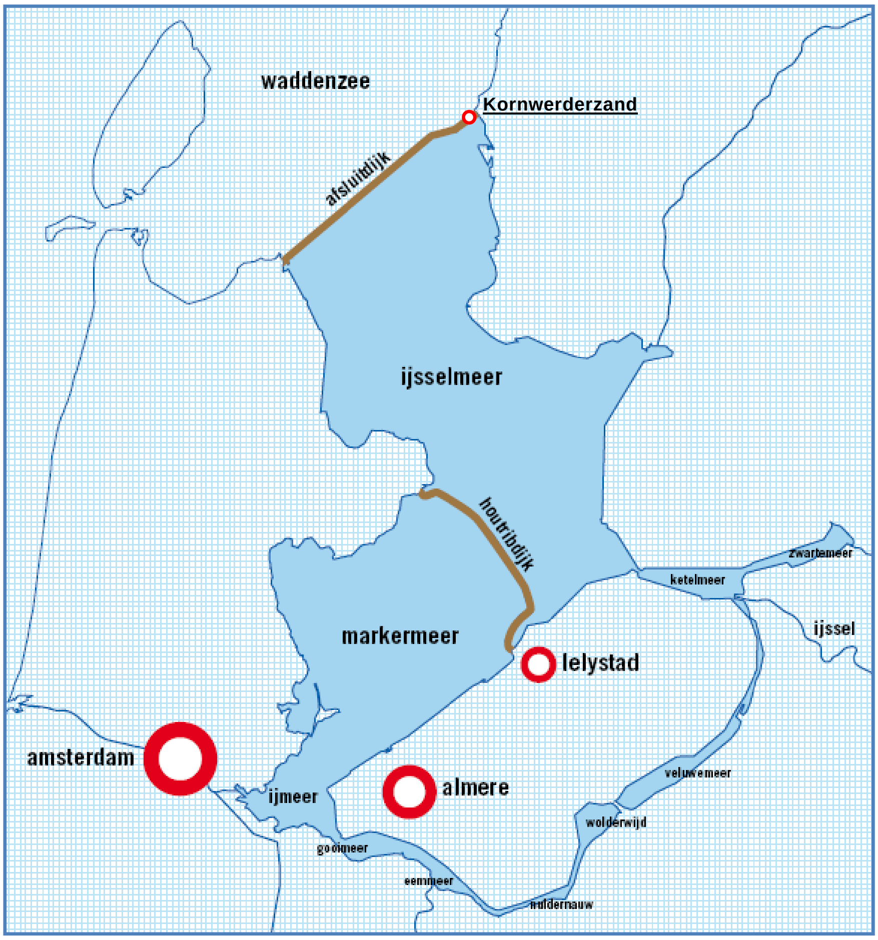


Figure 2-4: The IJsselmeer-area (Projectgroep Een ander IJsselmeer, 2007)

To maintain the qualities of the IJsselmeer-area, a separation is made between dynamic more intensive spatial usage in the south and less development, more tranquility and space in the north.

New water related functions outside the dike (or development of existing functions) like water recreation and business grounds won't be developed, unless they contribute to the nature, cultural historic and water policy focused on water management and water transport. (Ministerie VROM, et. al., 2006)

2.4 Functions Afsluitdijk

The primary reasons to start the "Zuiderzee works", with construction of the Afsluitdijk, were to protect the surrounding provinces of the Zuiderzee against flooding, increase the land surface of the Netherlands and lasting growth of employment (Dr. J.M. Fuchs & W.J. Simons, 1972)

Figure 2-6: Lock-sluice complex Den Oever, Noord-Holland (Google Earth, 2008)

Figure 2-5: Lock-sluice complex Kornwerderzand, Friesland (Google Earth, 2008)

Focused on the functions of the Afsluitdijk nowadays, the Afsluitdijk should be divided into two components. First of all there is the dam itself and secondly the lock-sluice complexes. Both components have their own qualities which allow the Afsluitdijk as a whole to perform its functions and thereby maintain the current situation in the Netherlands.

Table 2-1: Qualities of the Afsluitdijk components

	Dam	Lock-sluice complex
Retain	X	X
Separate	X	X
Flush		X
Connect[2]	X	X

- *Retain*
  The Afsluitdijk stalls the Waddenzee water.

- *Separate*
  The Afsluitdijk separates the salt Waddenzee water from the fresh IJsselmeer water.

[2] The dam and lock complexes both connect in a different way.

- *Flush*
  To maintain the right water levels in the IJsselmeer, the scouring sluices can flush water from the IJsselmeer to the Waddenzee.

- *Connect*
  The Afsluitdijk connects the provinces Noord-Holland and Friesland.
  The locks enable a fairway between the IJsselmeer and Waddenzee, and vice versa.

Through the years and decades, the amount of functions of the Afsluitdijk have changed, but the reasons for construction more or less apply until this day.

Next to the reasons for construction; protection against flooding, increasing land surface and growth of employment, there are lots of other functions for the Afsluitdijk nowadays. Underneath all functions of the Afsluitdijk are described:

<u>Protection</u>

The Afsluitdijk protects the provinces surrounding the IJsselmeer, Markermeer, Ijmeer, Gooimeer, Veluwemeer and Ketelmeer against the rough and salty Waddenzee's water by retaining it.

<u>Fresh water supply</u>

The Afsluitdijk separates the salt Waddenzee water from the fresh IJsselmeer water which enables the surrounding provinces to use the IJsselmeer as a fresh water reservoir.

<u>Water management tool</u>

The scouring sluices in the Afsluitdijk enable water management based on clear (summer/winter) watermarks for the IJsselmeer in the surrounding areas of the IJsselmeer.

<u>Economical</u>

By connecting the provinces of Noord-Holland and Friesland with the Afsluitdijk and the A7 national highway on top of it, the travel times and distances are reduced. These reductions stimulate economical development in the northern part of the Netherlands.
Secondly the lock-sluice complexes at Den Oever and Kornwerderzand are part of important fairways for professional and recreational navigation.
Finally, the Afsluitdijk attracts many tourists and recreationist during the year which generates income for many entrepreneurs.

Cultural-historical

The Afsluitdijk has become a symbol for the Dutch battle against water and the Netherlands in its current existents, which attracts visitors from all over the world.

Ecological

The construction of the Afsluitdijk caused salt water disappearance from the IJsselmeer and made streams and tide changes in the Waddenzee as well as the IJsselmeer. All these changes had ecological consequences in the Waddenzee and the hinterland of the Afsluitdijk. Since construction finished in 1932, a new ecological situation in the surroundings of the Afsluitdijk has developed.

Connection

The Afsluitdijk connects the provinces Noord-Holland and Friesland which reduces travel distances and times.

Unfortunately previous research has proven that lots of functions do not meet today's requirements. One of these is the accessibility problem which is the central subject in this report. Besides this problem, there are deficiencies in the field of hydraulic engineering, water management and infrastructure. Appendix 1; Deficiencies of the Afsluitdijk presents a complete enumeration and description of the deficiencies of the Afsluitdijk.

2.5 The infrastructure at the Lorentz lock complex

The situation at Kornwerderzand is an unique situation because the locks and bridges are separate, connected by an inner harbor, and the nearby presence of scouring sluices, housing and even cultural/historical heritage represented by the casemates.

Underneath the specific objects are described:

A. At Kornwerderzand there are two swing-swivel bridges in the A7 national highway to cross the fairway, number 301, from Urk to Kornwerderzand. The bridges have a span of two times 15,74 meters with a support pillar in the middle, which means there are two bridge passages with a width of 15,74 meters. When the bridges are closed the headroom for the vessels is 5,15 meters. (Rijkswaterstaat, 2007) There are two lanes on each bridge. The northern, Waddenzee, bridge enables road traffic from Kornwerderzand to Den Oever and the southern one visa versa. On both bridges a maximum speed of 70 km/h is allowed.
It takes about three minutes to open the bridges which are built up in two minutes to stop road traffic and one minute to technically open the bridges. The bridges will always be opened less than 15 minutes with the exception of technical failures and again, it takes one minute to close the swing-swivel bridges (Lockkeepers, 2008).

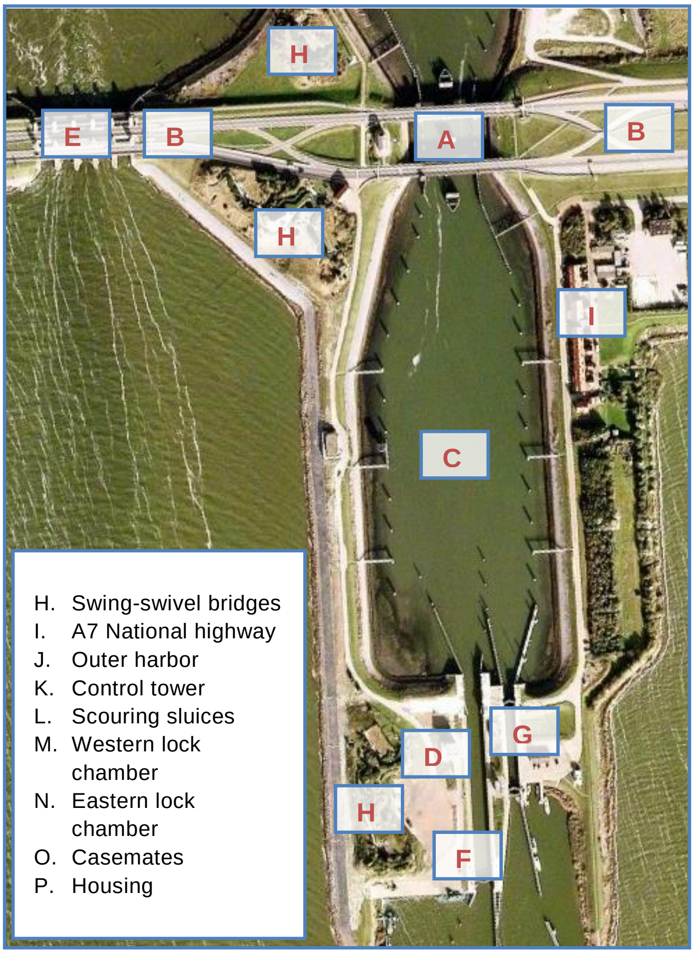


Figure 2-7: The Lorentz lock complex at Kornwerderzand with adjacent objects (Google Earth, 2008)

B. The road infrastructure, A7 national highway, on the Afsluitdijk including extra, spare, lanes between the lanes in different directions to keep the traffic flowing when one of the swing-swivel bridges is out of service. Because of a lack of space on the Afsluitdijk, the road infrastructure does not always meet the Dutch guidelines for road design. Therefore the maximum speed is reduced to 70 km/h for some sections.

C. At Kornwerderzand (and Den Oever) there is the unique situation that bridges are not placed on top of the navigation lock-heads. Therefore there is a outer harbor between the locks and the bridges. This lock approach at Kornwerderzand has a width of 120, length of 350 and depth of circa 3,80 meters. The depth of the harbor is under discussion because there is reasonable doubt if it has sufficient depth. There are dredging maintenance activities, but these only have temporary effect and are usually poorly executed. (Lockkeepers, 2008)

D. In this control tower, the lock keepers control the entire lock complex, operate the navigation locks, swing-swivel bridges, and scouring sluices, detect incoming vessels, communicate with them and guide them through the locks and swing-swivel bridges.

E. The scouring sluices are built in the period 1927-1932 and consist of 2 groups of 5 flushing tubes (Witteveen+Bos, 2006). The scouring sluices are over 75 years old and after construction two lanes ran through them.
After doubling up the number of lanes to two times two, space is limited on top of the scouring sluices. As a result of the limited space, there is a reduction of the maximum speed from 120 km/h to 70 km/h on this stretch of the Afsluitdijk to (partially) meet the guidelines for road design (ARCADIS, 1999).

F. On the IJsselmeerside of the complex there are two navigation locks. The width and length of the western, big, lock chamber are 14 and 137,8 meters respectively. The depth of the lock sill is NAP -4.4 meters at the IJsselmeerside and NAP -4 meters at the Waddenzee side.
Total locking time (without entering, leaving time vessels) is about 4 to 5 minutes from which half the time is needed for leveling. A large difference in water levels, about 1,3 meters, takes 2 to 3 minutes, but there is little difference in leveling times for other water level differences.
The maximum water level difference is about 2,6 meters which takes about 5 minutes to level (Lockkeepers, 2008).

G. The smaller, eastern, lock chamber has a width of 9 and a length of 67,12 meters. The depth of the lock sill is NAP -4.4 meters at the IJsselmeerside and NAP -4 meters at the Waddenzee side.
Total locking time (without entering, leaving time vessels) is about 8 to 10 minutes. The small lock chamber has small shutters and old mechanics which results in slower leveling and opening/closing of the lock gates.

The maximum water level difference of about 2,6 meters (+2,1 meters to -0,5 meters NAP) takes this chamber about 9 minutes to level, because of the small shutters (Lockkeepers, 2008).

Both locks can only lock until a maximum water level of NAP +2,15 meters at the Waddenzee, because the stability, and thereby safety, of the construction is not guaranteed at higher water levels (Rijkswaterstaat, 2007).

H. From 1931-1934 there were casemates built at Kornwerderzand to protect the Netherlands, especially the provinces of Holland, from a threat from the east.
Germany was still feared as a result of the First World War and the construction of the Afsluitdijk made a direct connection to the provinces of Holland. Therefore, it was thought to be vital to protect this connection from any (foreign) threats. In May 1940 these ideas appeared to be right when the German army entered the Netherlands and took the casemates with severe force. Nowadays there is the Casemates museum where visitors can take a walk along a few casemates which are still intact.

I. The village of Kornwerderzand exists with only a few houses and about 20 inhabitants. In the past, there only lived people who were working at the locks, but nowadays there only live a few lockkeepers. The design of the houses reflects the hierarchy of the lock employees which used to be in the past. The lockkeepers lived in the "normal attached houses", and the lockmaster had the bigger detached house.
The village of Kornwerderzand is part of the municipality of Wûnseradiel in the province of Friesland.

2.5.1 Capacity Lorentz Locks

During the peak intensities of the navigation season the Lorentz locks are used fulltime at maximum capacity. During these moments, the lock chambers are used in parallel which means both chambers lock at the same time in the same direction.
Because of this parallel usage, there is only one bridge opening necessary per lock cycle and thereby the amount of openings of the swing-swivel bridges is minimized.

During these busy periods, about 30 minutes are needed to fill, level, and empty both lock chambers. This includes opening the lock gates, entering and mooring of all vessels, closing the lock gates, leveling, opening lock gates and leaving of all vessels.

The western (big) chamber can accommodate a maximum of 30-35 yachts and the eastern, smaller, chamber can accommodate 10-12 yachts. The reason that both lock chambers take 30 minutes is the differences in size and mechanism.
The big chamber needs more time to fill with vessels because it accommodates almost 3 times as many vessels than the small lock chamber. On the other hand, the mechanism of the big lock chamber is better since it is newer and faster, so it takes less time to open, close the gates and level. Therefore, both lock chambers need about the same amount of time and furthermore they will wait to allow exit if one of them is not ready yet (Lockkeepers, 2008).

A total cycle at the Lorentz lock complex takes about one hour, two times 30 minutes, and the amount of vessels during that hour, per direction, is a maximum of 47 recreational vessels. Based on previous information, the capacity of the Lorentz lock complex is 47 yachts/hour/per directions.

Unfortunately this is the maximum capacity expressed in number of vessels per time unit. In reality there are also larger vessels than yachts using the Lorentz navigation locks. This decreases the amount of vessels per lock chamber and the time needed to fill and empty the lock chamber with vessels. Nevertheless, the decreased amount of vessels has more impact, so the lock capacity is lower in reality than based on the information of the lock keepers. The theoretical formula for the lock capacity (Cs) in the case of two-way traffic is:

$$Cs = (2 \cdot Nmax/Tc) \qquad [1]$$

In this case N_{max} is the <u>average</u> number of vessels over a large number of maximum capacity locking operations and T_c is the corresponding <u>average</u> cycle time. (Groenveld, et. al., 2006)

2.6 The traffic at the Afsluitdijk

The main issues in this research are the two intersecting modalities respectively navigation and road traffic. This paragraph describes the characteristics of these modalities at the lock complexes in the Afsluitdijk.
First, the characteristics of the road traffic will be described, followed by a description of the navigations' characteristics.

2.6.1 Road traffic

Road network
The map of the road network in the Netherlands makes clear that the A7 national highway on the Afsluitdijk has an important role in the accessibility within the Netherlands. The existence of this connection enormously reduces travel distance and time between the Northern provinces and the western part of the Netherlands and there is no comparable alternative route as shown in Figure 2-8.

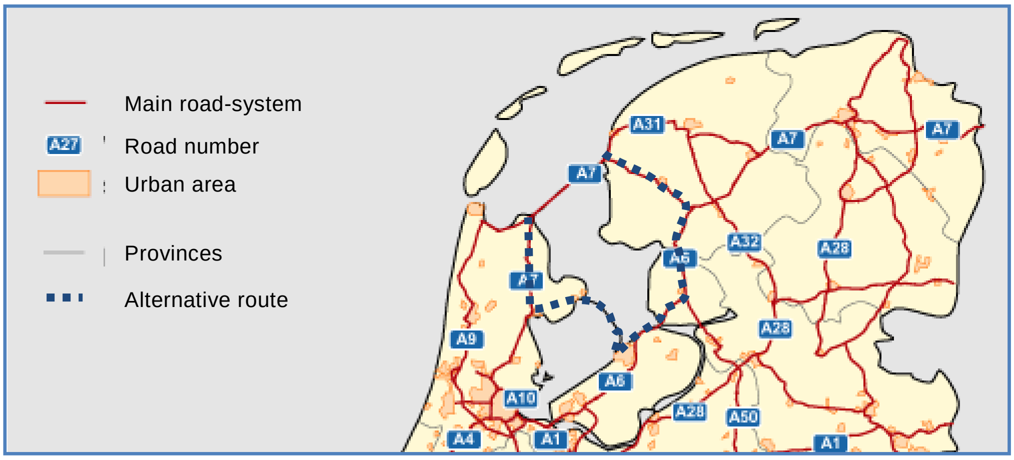


Figure 2-8: Main road-system with alternative route for the A7 on the Afsluitdijk (RIVM, 2002)

Infrastructure
The A7 is a 2 x 2 lane national highway with a design speed of 120 km/h. When the highway was upgraded, from two to four lanes, there was not sufficient space to meet all guidelines for the design of highways. Especially the space on top of the scouring sluices was/is limited therefore the maximum speed on these parts of the Afsluitdijk is reduced to 70 km/h to maintain safety.

Intensities
Despite the import role of the direct connection between the provinces of Friesland and Noord-Holland, the intensities are relatively low. Especially when you take into account that it is a national highway, average intensities of about 17.000-18.000 vehicles each 24 hours including both directions are not high. Figure 2-9 shows the intensity will increase to over 23.000 vehicles in 2020.

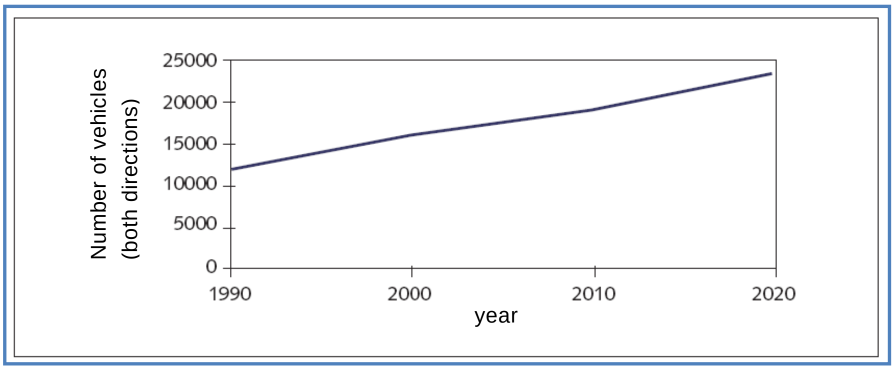


Figure 2-9: Development and prognosis of the number of vehicles per 24 hours in both directions on the Afsluitdijk (Ministerie Verkeer & Waterstaat, 2001)

Most traffic is on Fridays and Sundays is caused by recreational traffic which is also responsible for increasing intensities during the summer months. On Fridays the average intensity reaches over 10.000 vehicles per direction per twenty-four hours. The averages shares of freight traffic vary between 10 and 20 percent during the day and 30 to 40 percent during the night. (Grontmij Nederland bv., 2008)

2.6.2 Navigation

Fairway network

The entire fairway network of the Wadden and IJsselmeer-area with navigability class II and higher is included in Figure 2-10. The CEMT classes are presented in *Appendix 3; CEMT vessel* . Figure 2-10 also makes clear that the lock complexes at Den Oever and Kornwerderzand are the connections between the IJsselmeer and Waddenzee.

The usage of the fairways differs between recreational and professional navigation because both have different origins and destinations. An example is the recreational navigation with a destination within the Waddenzee-area. Most of them bound for the North Sea, Den Helder, the Frisian Islands (Texel, Vlieland and Schiermonnikoog) and Harlingen, but most professional navigations will not visit the Frisian Islands. In other words, the shares of recreational and professional navigation differ for each fairway. The next paragraph contains figures that substantiate the differences in traffic shares.

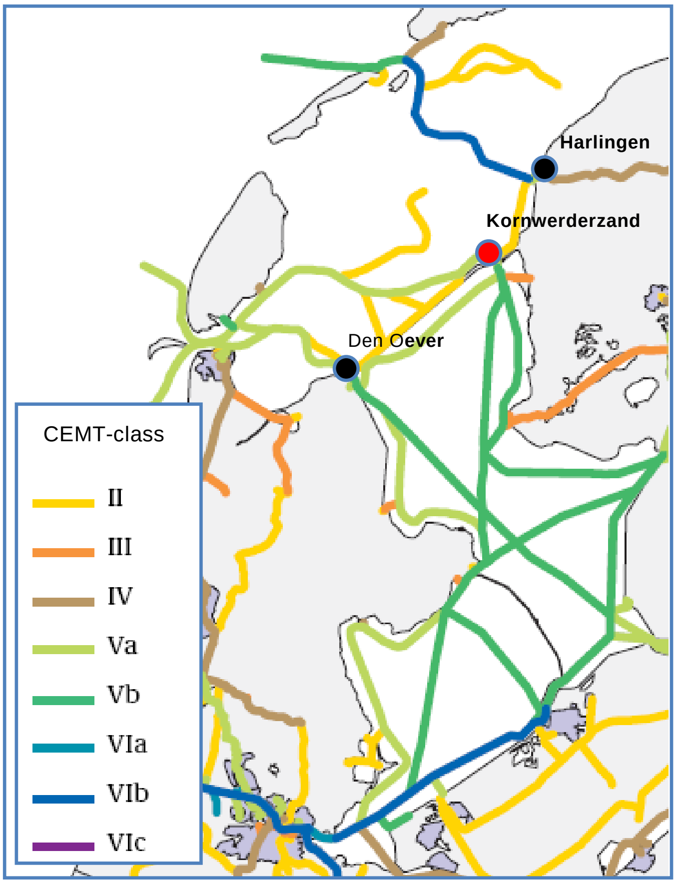


Figure 2-10: Fairway network IJsselmeer and Wadden-area with navigability class II and higher.

Infrastructure
The water infrastructure in the surroundings of the Afsluitdijk consists of the fairways and the navigation locks at Den Oever and Kornwerderzand.
Figure 2-10 shows the fairways in the surroundings of the Afsluitdijk and its locks. South of the Afsluitdijk, most fairways are CEMT-class *Va* or higher, which is sufficient for most vessels. In the north on the other hand, there are lots of fairways with CEMT-class *II*. For most recreational vessels, this is no problem, but especially for professional navigation the space is limited. The depth of the fairways is especially important for professional navigation because they need the biggest draught. To prevent getting stranded most professional vessels only enter the Waddenzee at high tide.

Passages
Every year over eighty thousand vessels cross the Afsluitdijk. In 2006 there were about 38.000 passages at Den Oever and the Afsluitdijk was crossed 48.000 times at Kornwerderzand (Dienst Verkeer en Scheepvaart, 2008). Approximately 90 percent of the passages at Kornwerderzand as well as Den Oever are recreational navigation, so the majority of the passages results from recreational traffic (Ministerie Verkeer en Waterstaat & Centraal Bureau voor de Statistiek, 2003). This large share of recreational navigation also results in an unequal spread of the passages over the year. Figure 2-11 shows the spread of the passages per month over the year in 2006 with the peak during the spring and summer months.

Navigation is separated over five different classes respectively;

- Professional navigation
- Motor ships < 20 meters (recreational)
- Sailing ships < 20 meter (recreational)
- Motor/sailing ships >20 meters (recreational)
- Remaining vessels (recreational)

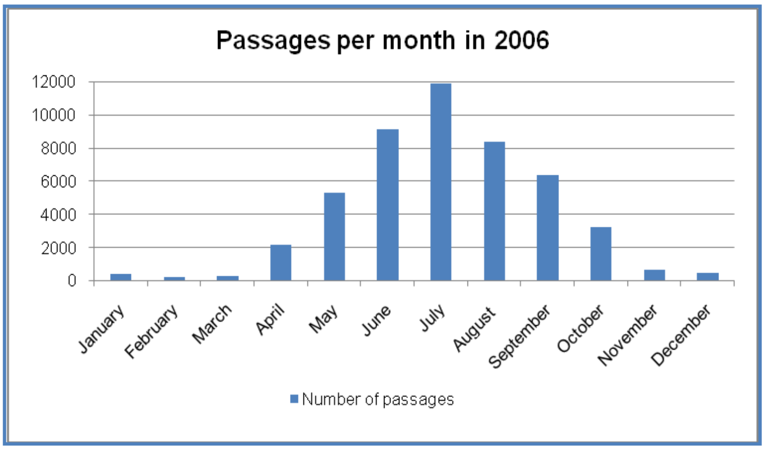


Figure 2-11: Number of passages per month in 2006 at the Lorentz locks in the Afsluitdijk (Dienst Verkeer en Scheepvaart, 2008)

On average the share of the class groups in 2002 were 10, 6, 69, 14 and 1 percent of the total passages at the Lorentz lock complex at Kornwerderzand (Ministerie Verkeer en Waterstaat & Centraal Bureau voor de Statistiek, 2003). During summer, navigation season, these shares differ because all recreation navigation is concentrated in these months and professional navigation is more equally spread over the year. As a result the share of professional navigation is small(er) during this period. During the navigation season the shares of the five classes shift to 5, 6, 73, 15 and 1 percent.
In the future all navigation will increase in numbers as well as vessel sizes. At the lock complexes in the Afsluitdijk most navigation is recreational and especially this type of navigation will increase a lot in the amount of vessels, number of trips and vessel size. In the year 2025 a 40% growth in the number of vessels in the IJsselmeer-area, compared to 1999, is estimated (Ministerie Verkeer en Waterstaat, 2001).

3 The Conflict Arena; components influencing local congestion

Previous chapters have already presented the accessibility problems and background information to create further insight on the problems and their characteristics.
In this chapter all components influencing the (local) congestion, and their interaction, will be presented in “the Conflict Arena”. For the presentation of “the Conflict Arena” a diagram of connections is used. Figure 3-1 shows the conflict arena including the components which influence or even determine the amount of congestion, expressed in time, for road traffic and navigation at the Kornwerderzand lock complex.

3.1 The diagram of connections of the Conflict Arena

The diagram of connections in Figure 3-1 is divided in three columns to structure the arena and its components. These columns are named “road traffic”, “the intersection” and “navigation”. Horizontally there are two reddish rows at the top and bottom of the diagram overlapping the columns. These rows contain external components which express a point of time and natural conditions belonging to this point of time. All these components have one thing in common. They cannot be manipulated by human interference.
To simplify the diagram, the intensities for road traffic and navigation in both directions are joined by a box in the same color as the column. The yellow road traffic intensity box on the left and the blue navigation intensity box on the right.
Another point of attention is the green box in the (green) intersection column. This quadrangle boxes the components *Vessels per lock operation* and *Lock cycle time* which combined result in the capacity of the navigation lock which is presented in sub-paragraph 2.5.1.

On the border between the road traffic and intersection column is the *Waiting time for road traffic* component in a red oval box at the bottom of the diagram. On the border between the intersection and navigation column, an identical red box can be found with the *Waiting time for navigation* component.

In Figure 3-1, all components influencing the congestion and their interaction are presented in a diagram of connections. This presentation brings up additional information about the complexity of the congestion problem at Kornwerderzand and all aspects involved.

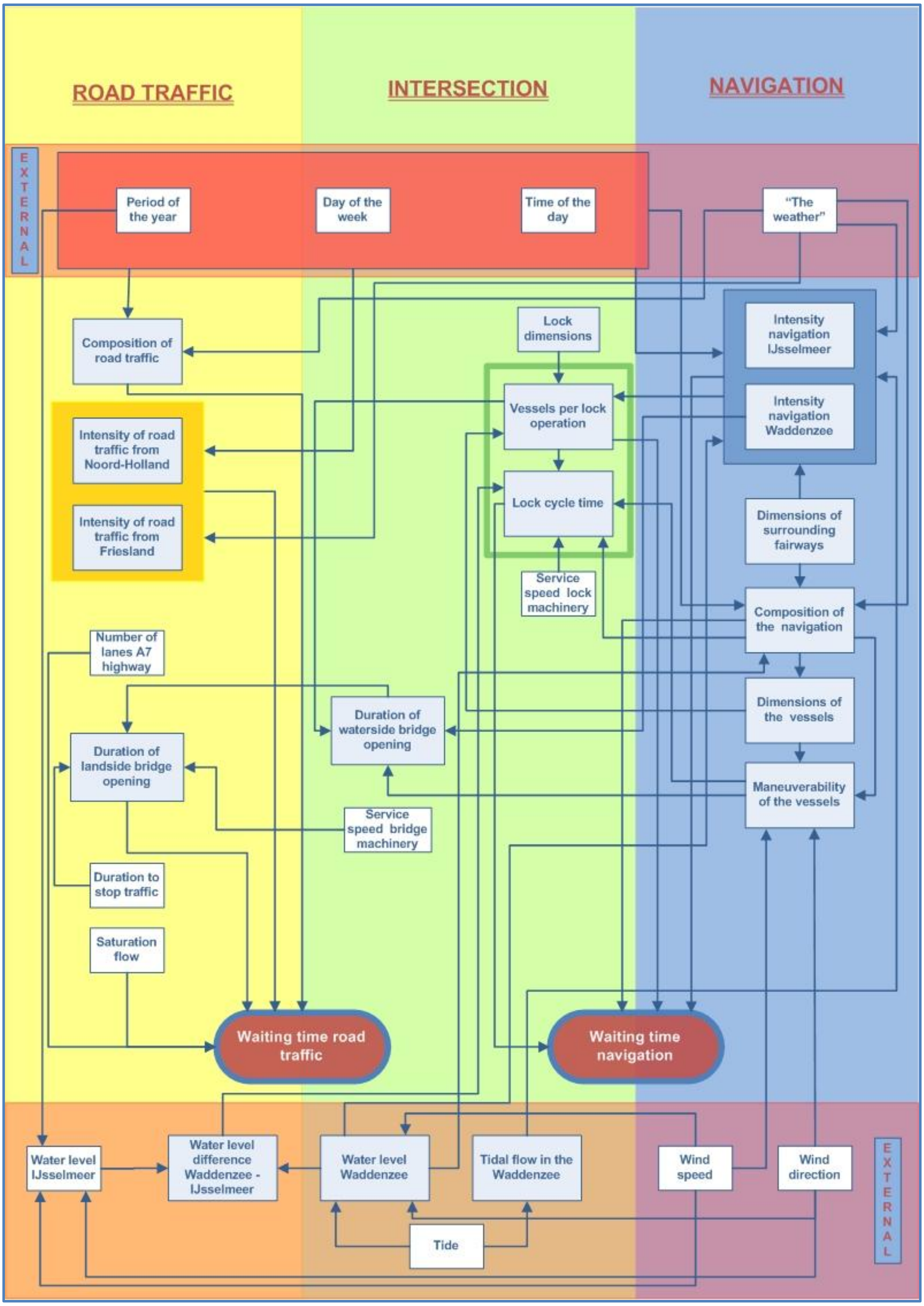


Figure 3-1: Diagram of connections of the conflict arena at the Lorentz lock complex

3.1.1 The components of the Conflict Arena

Lots of aspects influence the congestion for road traffic as well as navigation at the Lorentz lock complex at Kornwerderzand. These aspects determine the waiting time for both modalities directly or indirectly and are placed as components within the diagram. In this paragraph all components are further explained.

- *Period of the Year*

Includes the four seasons spring, summer, autumn, winter and holiday periods. In fact, the various periods in the year, which have specific characteristics, that can influence peoples travel behavior.

- *Day of the week*

Monday, Tuesday, Wednesday, Thursday, Friday, Saturday and Sunday with the focus on the difference between weekdays and weekends.

- *Time of the day*

Any point of time from 00.00 until 23.59.

- *"The Weather"*

With "the weather" the temperature, the amount of cloud cover / sunshine and amount of precipitation are included. In fact, the weather has great influence on people's decision to travel. The weather often dictates the type of activities people will take part in thus affecting their travel decisions.

- *Composition of road traffic*

The share of (slow) freight traffic, trucks, on the total traffic volume.

- *Intensity of road from traffic Noord-Holland*

The amount of vehicles per time unit heading from the province of Friesland to the province of Noord-Holland using the A7 national highway on the Afsluitdijk.

- *Intensity of road traffic from Friesland*

The amount of vehicles per time unit heading from the province of Noord-Holland to the province of Friesland using the A7 national highway on the Afsluitdijk.

- *Number of lanes on highway*

The number of lanes (per direction) on the A7 national highway on the Afsluitdijk

- *Duration of landside bridge opening*

The amount of time necessary to stop road traffic, open swing-swivel bridge, let navigation pass, stop navigation, close swing-swivel bridge and allow road traffic.

- *Duration to stop traffic*

Time needed to stop road traffic by using traffic lights and barriers.

- *Saturation flow*

Characteristic of the road which determines how fast waiting queues solve.

- *Lock dimensions*

The length, width and depth of the navigation lock chamber(s) at Kornwerderzand.

- *Vessels per lock operation*

The number of vessels that are locked during one lock operation from IJsselmeer to Waddenzee or vice versa.

- *Lock cycle time*

The time needed for a lock operation from one side to another and back. The time vessels need to enter the lock chamber, operation of the lock and exiting of the vessels followed by the entrance of vessels from the other side, operation of the lock and exiting of those vessels.

- *Service speed lock machinery*

The speed of the machinery that open, close the lock gates and equalize the water levels. This speed determines the time needed for these actions and thereby the operating time.

- *Duration of waterside bridge opening*

The time, after the physical opening of the swing-swivel bridges, vessels are allowed to pass the swing-swivel bridges and thereby the Afsluitdijk.

- *Service speed bridge machinery*

The speed of the machinery that open, close the swing-swivel bridges in the A7 national highway on the Afsluitdijk. This speed determines the time needed for opening and closure and thereby the operating time of the swing-swivel bridges.

- *Water level IJsselmeer*

The water level in the IJsselmeer at the IJsselmeer (inner) side of the Lorentz navigation locks at Kornwerderzand.

- *Water level difference Waddenzee-IJsselmeer*

The difference between the water levels of the (dynamic) Waddenzee and the IJsselmeer at the Lorentz lock gates in Kornwerderzand.

- *Water level Waddenzee*

The water level of the Waddenzee at the Waddenzee (outer) side of the Lorentz navigation locks at Kornwerderzand.

- *Tidal flow Waddenzee*

The Waddenzee follows the astronomic tide which results in tidal flows in the Waddenzee.

- *Tide*

The astronomic tide as a result from the gravitation of the moon and, in less extent, the sun.

- *Intensity navigation IJsselmeer*

Is the amount of vessels per time unit heading south, from the Waddenzee to the IJsselmeer, entering at the north, Waddenzee, side of the Lorentz lock complex at Kornwerderzand.

- *Intensity navigation Waddenzee*

Is the amount of vessels per time period heading north, from the IJsselmeer to the Waddenzee, entering at the south, IJsselmeer, side of the Lorentz lock complex at Kornwerderzand.

- *Dimensions surrounding fairways*

The width and depth of the fairways surrounding the Lorentz lock complex which influence the supply of vessels to the Lorentz lock complex.

- *Composition navigation*

The composition of the navigation regarding trip motives (recreational, professional) and belonging types of vessels.

- *Dimensions vessels*

The length, width and draught of the vessels passing the Afsluitdijk at Kornwerderzand.

- *Maneuverability vessels*

The maneuverability of the vessels that are using the Lorentz navigation lock.

- *Wind speed*

The speed, force, of the wind in the Wadden and IJsselmeer-area.

- *Wind direction*

The direction, in the Wadden and IJsselmeer-area, where the wind is coming from.

- *Waiting time road traffic*

Is the difference in travel time between a free passage of the swing-swivel bridges and a passage including delay caused by a bridge opening as a result of passing vessels.

- *Waiting time navigation*

The time between point of time of arrival at the Lorentz locks and the point of time when the lock gates at the entrance side of the navigation lock chamber start to close after the vessel has entered the chamber.

3.1.2 The interaction between the components

After the presentation of the Conflict Arena in paragraph 3.1 and the explanation of the components in sub-paragraph 3.1.1, this sup-paragraph describes the interaction between all components within the Conflict Arena. The description is divided in six parts of the Conflict Arena.

The distinguished parts of the Conflict Arena are:

- External factors
- Waiting time road traffic
- Navigation
- Capacity Lorentz navigation locks
- Waiting time navigation
- Waterside and landside bridge openings

External factors

The Lorentz lock complex is, among others, an intersection between road traffic and navigation. All people using the infrastructure at this intersection have a motive to be there and they all travel with a certain trip motive.
In this setting, the biggest share of travelers has a professional or recreational motive, but the distribution between professional and recreational and the amount of travelers depends on the point of time and conditions.
In the scheme the *Period of the year, Day of the week* and *Time of the day* determine a point of time and *Water level IJsselmeer, Water level Waddenzee, Tidal flow Waddenzee, "The weather", Wind speed* and *Wind direction* are the conditions at this point of time. The combination of this point of time with its conditions influences the amount and composition of the traffic on the road as well as on the water.

Waiting time road traffic

The waiting time for road traffic and navigation are important subjects within this research. In the scheme, the waiting time for road traffic is influenced by several components.
The reason for waiting times for road traffic is the opening of the swing-swivel bridges to let the vessels pass. The *Duration of the landside bridge opening* combined with the *Intensity and Composition of the road traffic*, the *Number of lanes of the A7 highway* and the *Saturation flow* of those lanes determine the *Waiting time for road traffic*.
The *Duration of the landside bridge opening* derives from other components, but this is described underneath the heading "Waterside and landside bridge openings".

Navigation

As mentioned before, every point of time with its conditions influences the amount and composition of traffic, but for navigation, there are several more components influencing the amount and composition. For navigation it is important to have sufficient draught for their vessels.
The components *Dimensions of surrounding fairways* together with *Water level Waddenzee* determine the available draught and width of the surrounding fairways on the Waddenzee side and thereby also the capacity of the fairways. This means those components have influence on how much and which vessels can use the fairway and can/will use the Lorentz lock complex.

Another component influencing the *Intensity of navigation* is the *Tidal flow in the Waddenzee.* As a result of the tide, the water level in the Waddenzee will shift from ebb to flood with belonging flows. These tidal flows are used especially by recreational, navigation to gain speed and thereby reduce their travel time. Therefore the *Tidal flow in the Waddenzee* also influences the amount and composition of the navigation at the Lorentz lock complex.

<u>Capacity Lorentz navigation locks</u>
The capacity of the Lorentz navigation locks is determined by the components *Vessels per lock operation* and the *Lock cycle time*.

The amount of *Vessels per lock operation* follows from the *Lock dimensions,* the available vessels by the component *Intensity navigation* and *Dimensions of the vessels*. The *Dimensions of the vessels* is again related to the *Composition of the navigation* because each type of navigation has its own type of vessels with belonging dimensions.

The *Lock cycle time* has the most complex interaction with other components within the scheme. These components are the *Water level difference Waddenzee-IJsselmeer, Service speed lock machinery, Vessels per lock operation, Composition navigation*, and the *Maneuverability of the vessels*.
The *Water level difference Waddenzee-IJsselmeer* determines, together with the *Service speed of the lock machinery,* how much time it takes for the pumps to equalize the water levels. The Service speed of the lock machinery also includes the speed of the lock gates and thereby the time needed for opening and closure. These times summed up are the operation time for the locks.
The *Vessels per lock operation, Composition navigation* and the *Maneuverability of the vessels* all influence the entering and exiting times of the vessels. When there are more vessels, it is more difficult, and time consuming, to fill and empty the lock chamber by entering and exiting of the vessels. The *Composition of the navigation* is important because the crew experience and skills differ over the different types of navigation which influences the time needed to enter and/or exit the navigation locks. Finally the *Maneuverability of the vessels* is not equal so this component also influences the entering and exiting times of the lock chambers and thereby the *Lock cycle time.*

<u>Waiting time navigation</u>
The lock process can be simplified by dividing it into two parts. The supply of vessels and the capacity of the navigation lock to transit. The supply derives from the components *Intensity navigation* and *Composition of the navigation* and the capacity from the amount of *Vessels per lock operation* and the *Lock cycle time.*
When the supply of vessels exceeds the capacity of the navigation lock *Waiting time for navigation* is the results. The amount of waiting time derives from the components *Intensity navigation, Composition of the navigation, Vessels per lock operation* and the *Lock cycle time.*

Waterside and landside bridge openings
The *Duration of a waterside bridge opening* depends on the amount of vessels approaching from the IJsselmeer side, *Vessels per lock operation*, and/or the amount of vessels approaching from the Waddenzee side, *Intensity of navigation Waddenzee*. The *Maneuverability of the vessels* also has influence because it determines how much time is needed for vessels to pass the swing-swivel bridges.
The *Duration of a landside bridge opening* is longer than the *Duration of a waterside bridge opening* because it's the *Duration of a waterside bridge opening* plus the time needed to open and close the bridge, *Service speed bridge machinery*, plus the *Duration to stop and allow road traffic*.

3.1.3 Recapitulation

This chapter has presented all components influencing the waiting times for navigation and road traffic with the usage of a diagram of connections. This diagram of connections is presented in Figure 3-1 and also represents the interaction between all components.

The diagram of connections is divided in three main parts; "Road Traffic", "Intersection" and "Navigation". Within the main parts of the diagram of connections there are lots of components influencing the main subjects of this research "Waiting time road traffic" and "Waiting time navigation".
Important components influencing the "Waiting time road traffic" are the intensity and composition of road traffic and "the duration of landside bridge opening".
For "Waiting time navigation" the most important components are "Vessels per lock operation" and "Lock cycle time" which together determine the lock capacity. Besides these components, the intensity and composition of navigation have lots of influence on the "Waiting time navigation".

The next chapter, chapter 0, unravels the processes to pass the Lorentz lock complex from the IJsselmeer as well as the Waddenzee side. This will be done from the perspective of the navigation and the lockkeepers; eventually technical and operational savings of time within the processes will be presented.

4 Analysis of the processes to pass the Lorentz lock complex

This chapter introduces the general process to pass a lock complex that is operated at the spot. First, the focus is on the passage for vessels approaching the Lorentz lock complex from the IJsselmeer and secondly there is a description in paragraph 4.3 of the passage for vessels with the Waddenzee as their origin.
Finally paragraph 4.5 points out possible savings of time within the processes to pass the Lorentz navigation locks with the difference between technical, operational savings and savings of time concerning vessel behavior.

4.1 General process

The operation of the navigation locks at Kornwerderzand happens at the spot from a central control tower where there are screens with video images to check all vessels in the surroundings of the complex, communication tools to communicate with the vessels and the control panel to operate the locks, scouring sluices, and swing-swivel bridges located at Kornwerderzand.

Figure 4-1: Old (left) and new (right) control towers at Kornwerderzand.

In this chapter the processes to pass the Lorentz lock-complex are described. These processes derive from the "Richtlijnen Vaarwegen: RVW 2005", drawn up by the Dutch ministry of Traffic and Public Works which are placed in Appendix 4 and 5. The processes are based on central controlled locks and bridges for professional navigation.
At the Lorentz lock complex, the process of passage depends from which side a vessel approaches the lock complex because there are swing-swivel bridges on the Waddenzee side and on the IJsselmeer side vessels first reach the navigation locks before they pass the bridges.

Therefore the processes of both, IJsselmeer and Waddenzee, sides are described in the following paragraphs.

Underneath the main components of the processes are described. The actions within the processes can be divided into five types:

- Announcement (A)
- Exchanging information (B)
- Giving instructions (C)
- Operating locks and bridges (D)
- Shipping-movements (E)

These five parts each consist of a number of process steps which will also be described chronologically in the following paragraphs.

4.2 The process to pass from the IJsselmeer side

The description of this process starts with a description and presentation of a flowchart including the actions necessary to pass the Lorentz lock complex from the IJsselmeer side. The presentation of the flowchart is followed by a time-progress diagram which links the distance covered by a vessel to the time needed for this coverage. This is a way to create insight in the relative amount of time each action takes.

4.2.1 Chronological order of actions to pass from the IJsselmeer side

When vessels approach the Kornwerderzand lock complex, they first reach the navigation locks. The (theoretical) process to pass a navigation lock, according the guidelines for fairways of the Dutch Directorate for Public Works and Water Management, is described in Appendix 4.

Figure 4-2 presents the flowchart of the passage for vessels approaching the Lorentz lock complex at Kornwerderzand from the IJsselmeer side. This flowchart is based on Appendix 4 and Appendix 5 but adjusted to the situation at Kornwerderzand. The content of Figure 4-2 is described underneath.

<u>Approach, arrival and waiting</u>

Vessels approach the Lorentz locks from the IJsselmeer and announce themselves to the lockkeepers. After that, the lockkeepers gather information about the characteristics of the vessels and determine if the vessels have to wait. Next the lockkeepers make a lockplan and finally give information to the vessels on when and how to enter the navigation locks.

<u>Entering and locking</u>
When the vessels are ready to enter, the lock gates are opened. Most of the time, vessels from the other, Waddenzee, side have to leave the chamber first and subsequently vessels are allowed to enter the lock chamber. During the entrance and mooring in the chamber, the lockkeepers give directions. Eventually entrance is prohibited, the lock gates close, and the water levels are leveled.

<u>Leaving</u>
After leveling, the lockkeepers determine if the lock gates can be opened. During busy periods the lock chambers are used parallel in the same direction to reduce the amount of bridge openings.
Therefore it is sometimes necessary for vessels in the lock chamber to wait until the other lock chamber is finished leveling.
When both chambers are ready, the vessels are allowed to leave the chamber. Then vessels start to cross the outer harbor and when the lock keepers determine that all vessels are ready to pass the bridges, the road traffic is stopped.

<u>Bridge passage</u>
Subsequently, the swing-swivel bridges are opened and passage of the bridges is allowed. After the passage of the vessels, (remaining) navigation is stopped and the bridges are closed. Finally road traffic is allowed again.

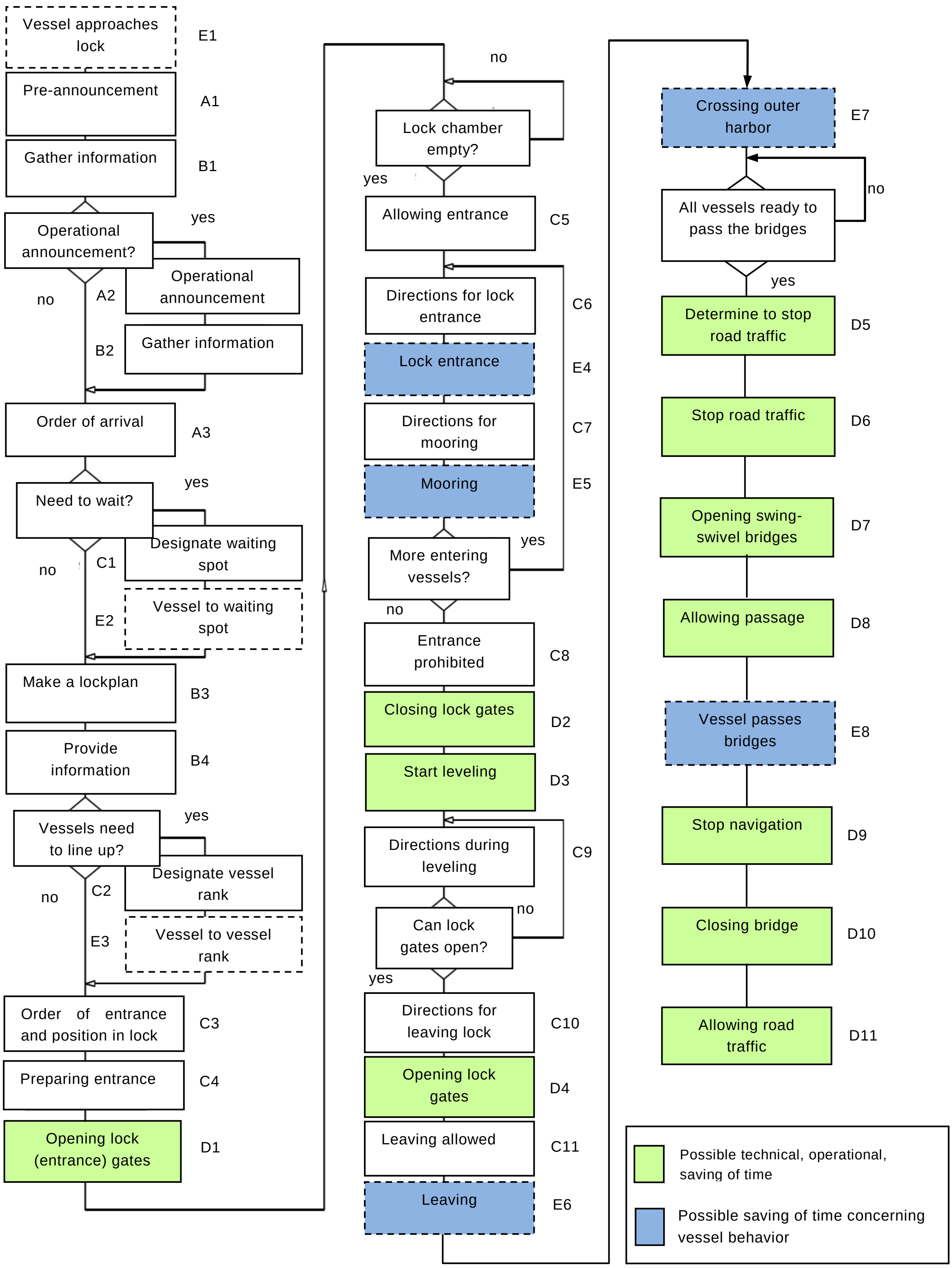


Figure 4-2: Flowchart of the passage of the Lorentz lock-complex from the IJsselmeer side including indicated improvement possibilities (Ministerie Verkeer en Waterstaat, 2006)

4.2.2 The relation between time-and progress at a passage from the IJsselmeer

This subparagraph describes the process to pass the Lorentz lock complex from the vessel's perspective. Underneath the processes of a passage from the IJsselmeer are visualized by the usage of a time-progress diagram.

Two types of passages are distinguished in Figure 4-3. The first type of passage, A, is with direct availability of a lock chamber and in the second situation, B, the vessel has to wait before a lock chamber is available.

Exact times needed for the actions are not used, because those differ a lot with regard to the vessel type, vessel load, competencies of the skipper, weather conditions and the behavior of other vessels. Nevertheless the times needed for actions/movements are rather comparatively.

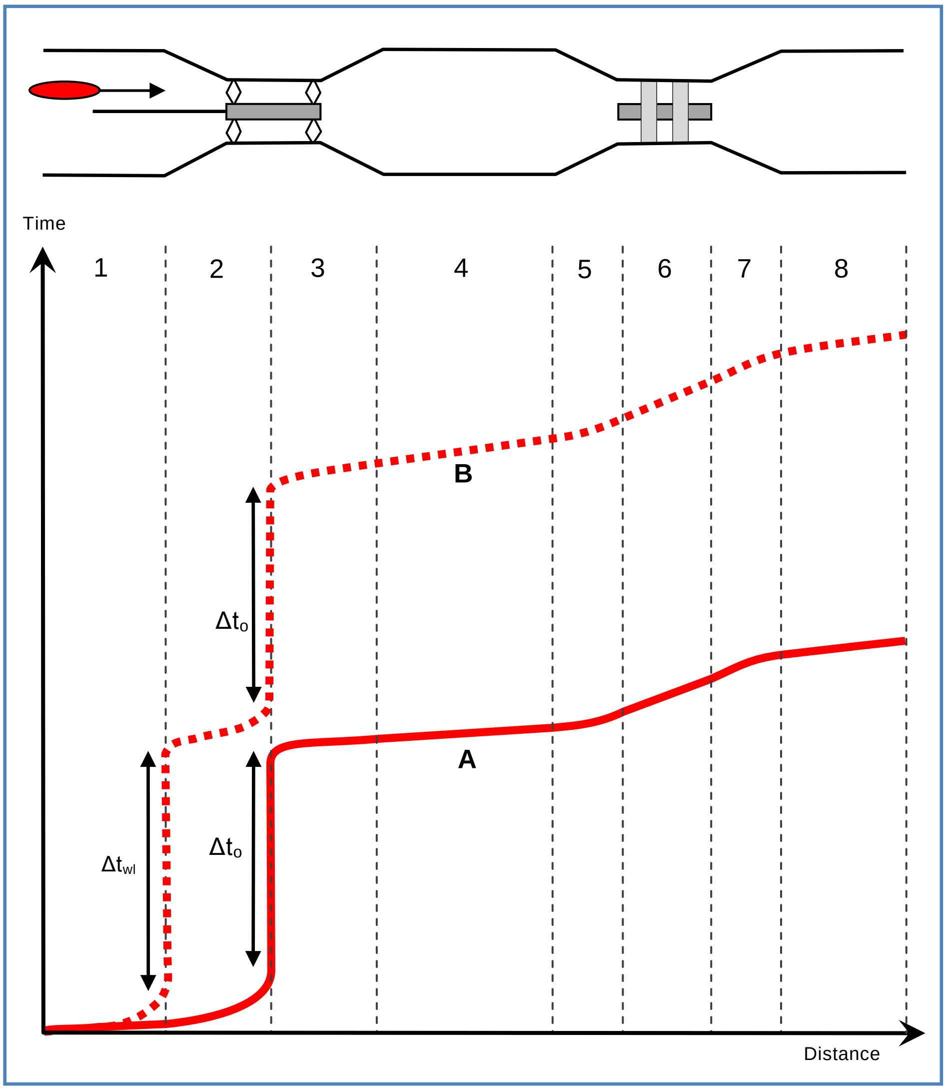


Figure 4-3: The time-progress diagram for passages from the IJsselmeer with (in)direct lock chamber availability (Groenveld, et al., 2006)

The time-progress diagram describes the actions of the vessel over time related to the distance covered in that time.
The total trajectory is separated in eight parts which are described underneath for both types of passages.

Passage A:
As mentioned before, passage A is a passage of the lock-complex with direct lock chamber availability. When a vessel approaches the Lorentz locks, it first crosses the inner harbor on the IJsselmeer side before decreasing speed and entering the lock chamber. Next the vessel comes to a halt and moors in the lock chamber.
Δt_o is the time between mooring in, and leaving of, the lock chamber. This operating time includes the time needed to fill the lock chamber with other vessels, the closing of the lock entrance gates, leveling and opening the lock exit gates. During busy periods, when the lock chambers are operated parallel, also the time waiting for the other lock chamber is included.
After this time the vessel starts to cross the outer harbor between the locks and the bridges, increases speed and crosses the outer harbor. When the vessel nears the swing-swivel bridges, the speed decreases and the vessel passes the bridges. After this passage, the vessel increases speed, crosses the outer harbor and heads for the Waddenzee.

After this description, the passage without direct lock availability, passage B, will be described underneath.

Passage B:
A vessel crosses the inner harbor again, but comes to a halt before the Lorentz locks.
Δt_{wl} is the waiting time between stopping before the lock gates and increasing speed to enter the available lock chamber.
After this waiting time, the vessel enters the lock chamber, decreases navigation speed again, comes to a halt and moors in the lock chamber.
Δt_o is the time between mooring in, and leaving of, the lock chamber. This operating time includes the time needed to open the lock exit gates, leveling the water level, fill the lock chamber with other vessels and to close the lock entrance gates. Also in this situation, the time waiting for the other chamber is included during busy periods.
After this time needed to lock through, the vessel increases speed to go across the outer harbor between locks and bridges, approach the swing-swivel bridges, decreases speed and passes both bridges. Following the bridge passage, the speed increases, outer Waddenzee harbor is crossed and the vessel heads for the Waddenzee.

The main differences between both passages are the approach of, and waiting time in front of the, the navigation locks. This might seem a small difference, but Figure 4-3 shows that the waiting time before lock chamber availability consumes a lot of the total time to pass the Lorentz lock complex from the IJsselmeer side.

4.3 The process to pass from the Waddenzee side

This paragraph explains the process to pass the Lorentz lock complex for navigation arriving from the Waddenzee. It starts with a chronological description of the actions needed for a passage, followed by a presentation of the relation between the time and progress during a passage from the northern, Waddenzee, side in sub-paragraph 4.3.2.

4.3.1 Chronological order of actions to pass from the Waddenzee side

As mentioned in paragraph 4.1, the process to pass the lock complex depends on which side a vessel approaches the lock complex. This paragraph describes the process when vessels approach the Lorentz lock complex at Kornwerderzand from the Waddenzee side. When a vessel approaches from the Waddenzee, they first have to pass the swing-swivel bridges. The guidelines to pass a bridge are described in *Appendix 5; Process to pass a bridge* and Figure 4-4 shows the flowchart of the process to pass the complex from the Waddenzee side.

<u>Approach, arrival and waiting</u>

Vessels approach the Lorentz locks from the Waddenzee and announce themselves to the lockkeepers. Following the lockkeepers gather information about the characteristics of the vessels and determine if the vessel has to wait. This mainly depends on the availability of the locks on that side. If there is, or becomes, a navigation lock available the lockkeepers stop road traffic and start to open the swing-swivel bridges.

<u>Bridge passage</u>
Subsequently the swing-swivel bridges are opened and passage of the bridges is allowed. After the passage of sufficient vessels to fill the lock, (remaining) navigation is stopped and the bridges are closed. Finally road traffic is allowed again.
Next the vessels cross the outer harbor and the lockkeepers determine if the vessels have to wait before entering. After that the lockkeepers make a lockplan and finally give information to the vessels on when and how to enter the navigation locks.

<u>Entering and locking</u>
When the vessels are ready to enter, the lock gates are opened. Most of the time vessels from the other, Ijsselmeer, side have just left the chamber so the gates are already open and vessels are allowed to enter the lock chamber. During the entrance and mooring in the chamber, the lockkeepers give directions. Eventually entrance is prohibited; the lock gates close and the water levels are leveled.

<u>Leaving</u>
After leveling the lock gates are opened and vessels are allowed to leave the chamber. Then vessels start to cross the inner harbor and head for the IJsselmeer.

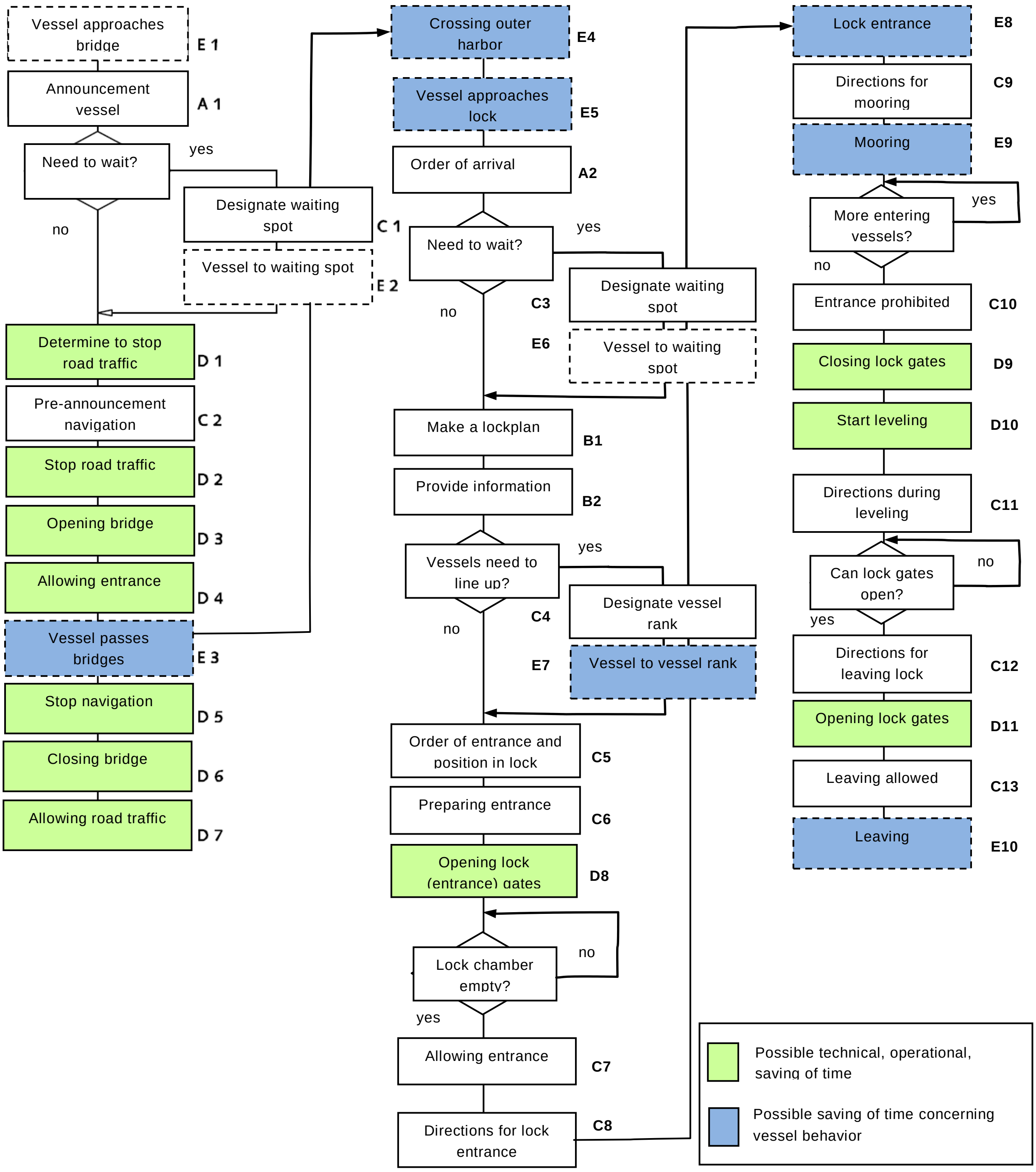


Figure 4-4: Flowchart of the passage of the Lorentz lock-complex from the Waddenzee side including indicated improvement possibilities (Ministerie Verkeer en Waterstaat, 2006)

4.3.2 The relation between time and-progress for a passage from the Waddenzee

The process to pass the Lorentz lock complex from the Waddenzee side, related to time and distance, is described in Figure 4-5. A distinction is made between arrival of a vessel when the bridges are open and a passage with waiting time before the bridges open. When the swing-swivel bridges are open, this goes together with direct lock chamber availability because the navigation locks and bridges are operated parallel.

Eight vessel actions/movements, waiting time for swing-swivel bridges and the time inside the navigation lock chamber are distinguished.

The time and distance scales are not the actual figures, but especially the time needed for the different actions are rather proportionately drawn.

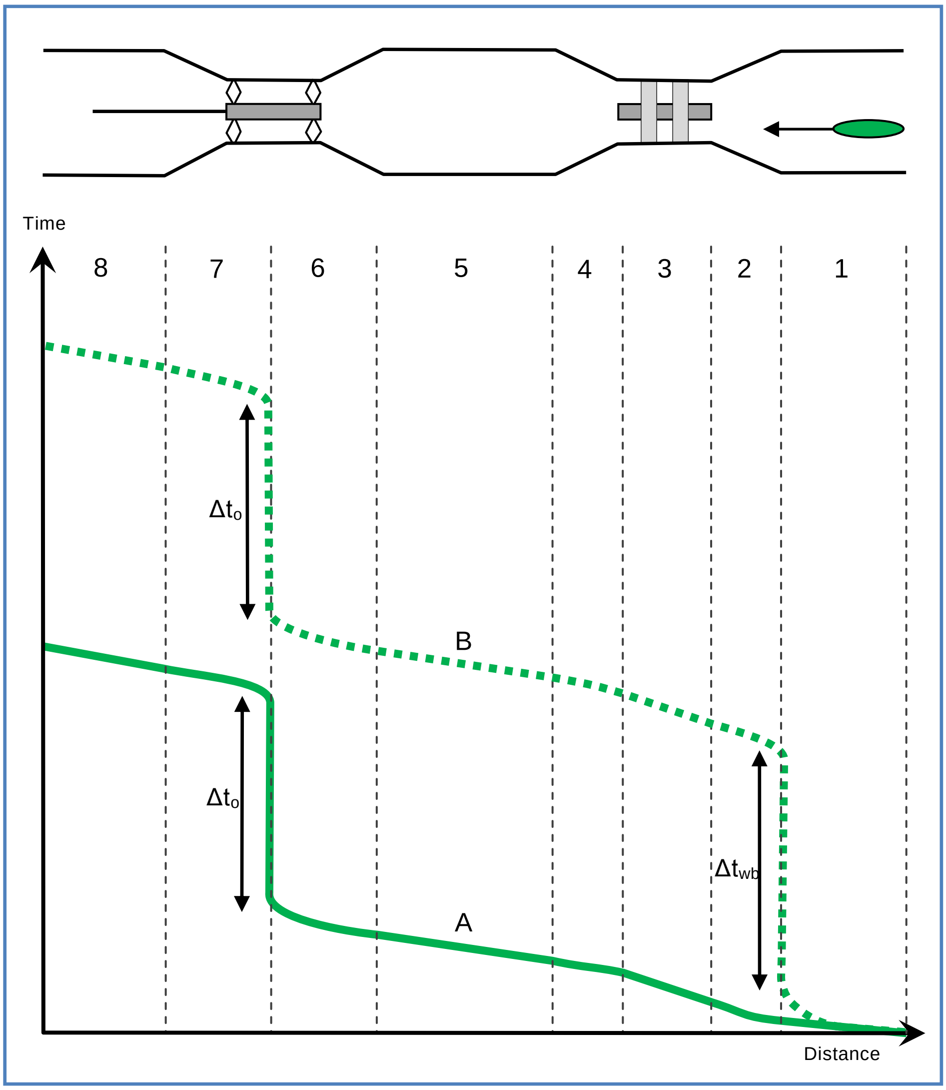


Figure 4-5: The time-progress diagram for passages from the Waddenzee with (in)direct passage of the swing-swivel bridges (Groenveld, et al., 2006)

The time-progress diagram of the passage from the Waddenzee side describes the actions of the vessel over time related to the distance covered in that time.
The total trajectory is separated in eight parts which are described underneath for both types of passages.

Passage A:
The passage of the Waddenzee side is also divided in a passage with direct passage and a passage included waiting time. This description starts with passage A, which includes direct passage of the swing-swivel bridges.
The vessel approaches the lock-complex from the Waddenzee side and crossed the outer Waddenzee harbor, nears the (opening) bridges, decreases speed and passes both swing-swivel bridges before increasing speed again and crossing the outer harbor between the bridges and the locks.
When the vessel comes close to the locks, it decreases speed, enters the lock chamber and comes to a halt before mooring in the lock chamber.
Δt_o is the time between mooring in, and leaving of, the lock chamber. This operating time includes in this case the time needed to fill the lock chamber with other vessels, the closing of the lock entrance gates, the leveling of the water level and opening the lock exit gates.
Following this "operation" time, the vessel increases speed to leave the lock chamber, cross the inner IJsselmeer harbor and head for the IJsselmeer.

Complementary to the definition of the direct passage, the indirect bridge passage (B) is described underneath.

Passage B:
The vessel starts again by crossing the outer Waddenzee harbor, but has to decrease speed and come to a halt because the swing-swivel bridges are closed.
Δt_{wb} is the waiting time from coming to a halt in front of the closed bridges until the swing-swivel bridges are open and passage is allowed.
After the bridge opening the vessel increases speed and continues to approach the bridges, passes the bridges, further increases speed and crosses the outer harbor between the bridges and the navigation locks.
These actions are followed by decreasing the navigation speed, entering the lock chamber, coming to a halt and mooring in the lock chamber.
Δt_o is still the time between mooring in, and leaving of, the lock chamber. This operating time includes the time needed to close the lock entrance gates, the leveling of the water level, the time needed to open the lock exit gates and (in this case) the time needed to fill the lock chamber with other vessels.
After this time is passed, the vessel continues the passage by increasing speed, leaving the lock chamber, further increasing speed and finally crossing the inner IJsselmeer harbor before entering the IJsselmeer.

In paragraph 4.4 remarks on the descriptions in this chapter are expounded. These remarks are points of attention on how to interpret the information, text and figures, presented.

4.4 Remarks on the descriptions of processes to pass the Lorentz lock complex

This chapter describes the processes to pass the Lorentz lock complex at Kornwerderzand from the IJsselmeer as well as the Waddenzee side with the usage of two different types of tools respectively flowcharts and time-progress diagrams.

Unfortunately the process to pass the lock complex is influenced by lots of aspects. This starts with the type of vessel and belonging properties, the vessel load and the competencies of the skipper. Furthermore the behavior of surrounding vessels has lots of impact and finally there are external factors like weather conditions and water levels.

The descriptions of the processes in this chapter are based on a professional vessel which is not small enough to pass the underneath the swing-swivel bridges.
A professional vessel is far more predictable than recreational navigation. Professional navigation can reasonably be described as a group in contrast to recreational navigation which has much more variance in behavior. Besides, most of the scientific literature is based on professional navigation.

Despite the fact that the descriptions are based on a specific type of navigation, all process descriptions remain very useful, but it has to be taken into account that they could differ a bit in respect to other types of vessels. Possible differences resulting from the remarks are described underneath.

- **Point of attention flowcharts**

    - *Professional – Recreational*

    The theoretical lock and bridge process are focused on professional navigation, but at the Lorentz lock complex at Kornwerderzand the biggest share is recreational navigation. This doesn't change the process a lot, but the main difference is the way of communication. Lots of the recreational vessels do not have a marine telephone therefore other tools are used more intensively to exchange information. Examples are sight, speakers and/or traffic signals.

    Another difference is the fact that some recreational vessels can pass the bridge when it is closed, so they can skip some steps in the bridge process when the bridge (/lock) keeper gives them permission to pass underneath the bridge.

- **Point of attention time-progress diagrams**

  - *Times Δt_{wl}, Δt_{wb} and Δt_o*

  The times included in the diagrams, Δt_{wl}, Δt_{wb} and Δt_{o}, are influenced by the amount and behavior of surrounding vessels, water level difference, maneuverability vessel, competencies of the skipper, weather conditions, but they clearly consume most of the time to pass the lock complex. Recreational navigation is more a subject to these aspects than professional navigation, because professional navigation usually gets priority.

  Of course there is also the fact that some vessels can pass the bridge when it is closed, so they can skip some steps in the bridge process when the bridge (/lock) keeper gives them permission to pass underneath the bridge.

4.5 Conclusions

The elaborate descriptions of the process to pass the Lorentz lock complex from the Ijsselmeer side makes clear that saving of time is possible in three ways:

- Technical, operational improvements to reduce the time needed to control the locks and bridges. Hereby the cycle time is reduced and the capacity of the navigation locks increases.
  These improvements include faster lock gate and bridge mechanics for shorter opening and closing times of these objects and bigger shutters to quicken the leveling.

- Secondly the behavior of recreational navigation can be improved to reduce the time needed for entering, leaving lock chambers, for mooring and to pass the swing-swivel bridges.
  Lots of time gets lost because of the inexperience of recreational skippers to pass the Lorentz lock complex and their lack of control of their vessels. Therefore it takes more time than necessary to fill, empty the locks and pass the bridges. (Lockkeepers, 2007)

- The third possibility is to alter the operation process of the navigation locks. At the moment the locks are operated parallel during periods with lots of navigation. As a result time is lost because the locks sometimes have to wait on each other. Stopping the parallel operation of the navigation locks prevents this loss of time.

The technical, operational improvements can be implemented easily by modernizing the mechanics of the locks and bridges. For the smaller, old, lock chamber this can reduce opening, closing times up to 50%, but for the newer, big, lock chamber reduction will be little. Nevertheless the slowest lock chamber is normative because of the parallel usage of the locks to minimize the number of bridge openings, so it's useless to speed up the small, old, lock when it has to wait on the big lock.
Besides all previous reasons, the technical, operational times take a relatively small share, approximately 15%-20%, of the total cycle time.
If the small lock should be improved, modernization to the level of the big lock is a possibility. If it is an exact copy from the big lock it has the same characteristics, including cycle times, so parallel operation is applicable and the capacity of the complex increases.

This improvement is barely within the scope of this research, because this research focuses on improvements within the current situation. Nevertheless the effect of this improvement will be determined in chapter 6.

Improving the behavior of recreational navigation is more difficult to implement, but the time needed for vessel movements and actions takes the remaining 80-85% of the cycle time and time can be gained. The lockkeepers think there are possibilities to improve the behavior if the aquatic sports associations instruct their members "How to behave at the (Lorentz) lock complex". In an interview lockkeepers have estimated that the time needed for vessel actions can be reduced with circa ten percent.
The effect of this reduction on the waiting times will also be determined in chapter 6 with the use of a simulation model.

Unfortunately stopping the parallel operation of the navigation locks has some negative consequences. At the moment it is unwanted to have navigation waiting in the outer harbor between the locks and the swing-swivel bridges. If this has to remain this way in the future, up to two times as much bridge openings are needed to let the same amount of vessels pass.
If navigation waiting in between the locks and the bridges is accepted, the amount of bridge openings can be reduced again by using the harbor as a buffer. Unfortunately this has another negative side effect. The outer harbor between the bridges and navigation locks is relatively small and soon unsafe traffic situations will occur. These unsafe situations are a result of the harbor becoming crowded and vessels entering, exiting the locks. The entering and exiting vessels mingle, space gets limited and the maneuverability of lots of recreational vessels is little.
Recapitulating, both an increase of the amount of bridge openings as well as reduced safety in the outer harbor between locks and bridges are undesirable. Therefore this alteration is not further included as an improvement to reduce congestion.

The effects of upgrading the small, dated eastern lock chamber and improving the behavior of navigation at the lock complex are determined in chapter 6 with the usage of a simulation model.
In the following chapter, five, the characteristics of the navigation supply at the Lorentz lock complex will be investigated. Subsequently there will be determined if, and how, the supply of navigation can become more equally distributed over the day and consequently reduce the congestion for navigation.

5 Characteristics of the navigation supply at the Lorentz locks

The unequal distribution of the navigation passages over the year and over the day has a huge impact on the congestion at the Lorentz lock complex. Therefore research is necessary to determine why the navigation is concentrated at these specific times and periods and to find out if navigation can be influenced to alter their travel behavior and thereby create a more equal traffic load for the Lorentz lock complex.

5.1 Factors influencing navigation intensities

Lots of factors influence the intensities of the navigation at the Lorentz lock complex and thereby also the congestion for navigation. Most of these factors are external and the amount of influence depends on the type of navigation. The external factors are:

- Season of the year
- Holidays, weekends: *spring break, summer holidays, autumn half term*
- Time of the day: *morning, afternoon, evening, night*
- “The weather”: *temperature, cloudiness*
    - Wind: *direction and force*
- Tide; *water level and currents of the Waddenzee*.

The amount of influence of these factors on the intensities at the Lorentz lock complex depends on the trip motive. Recreational navigation is influenced by all factors, but professional navigation mainly depends on the tide in respect to the water level of the Waddenzee and the required draught for their vessels.

Recreational navigation has an average share of about 90% of the total navigation. During the busy summer periods this share even increases, so all factors presented above have impact on the navigation intensities.

5.2 Distribution of the navigation over a year

As mentioned in previous paragraph, recreational navigation has a huge share, over 90%, of the total navigation flow. The spread of the navigation shows this by a concentration in the (recreational) navigation season. This is mainly because of the weather and partly by the scheduled holiday periods. In this period there is usually less cloudiness and the temperature is higher which makes it more attractive for aquatic sports.
Over 95 % of the total yearly passages at Kornwerderzand in 2006 were during the months April till November. Figure 5-1 shows the monthly passages for the year 2006.

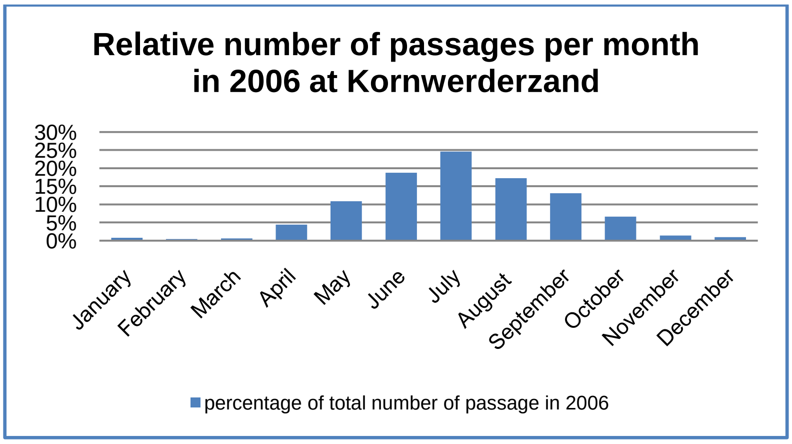


Figure 5-1: Relative number of passages per month in 2006 at the Lorentz locks

5.3 Theoretical distribution of the navigation over a day

The spread of the navigation intensities over the day is influenced by the Waddenzee's tide and this paragraph describes the (theoretical) relation between the Waddenzee's tide and the intensities is described followed by the actual data of the tide and intensities at the Lorentz locks in the Afsluitdijk.
The intensities over the day are separated for professional and recreational navigation, because both groups have different trip motives and therefore different trip characteristics.

5.3.1 Theoretical interrelationship between navigation behavior and Waddenzee's tide

From the interview(s) with the Lorentz lockkeepers presented in *Appendix 2; Interview with the lockkeepers of the Lorentz lock complex at Kornwerderzand* and literature derived the information that the navigation intensities over the day are, for both recreational as well as professional navigation, influenced by the tide on the Waddenzee. This influence of the tide works two-sided;

- One, the tide determines the water level on the Waddenzee and combined with the dimensions of the fairways the maximum draught of vessels.
- Secondly, the tide creates tidal flows to and from the mainland which can be used to increase speed and reduce travel time.

For professional navigation the maximal draught is more important than the tidal flows, because they normally need more draught and have more engine power to cope with possible opposite tidal flows.
Recreational navigation has more interest in the tidal flows because they generally have not got sufficient power to deal with the tidal flows which are up to three knots (5,6 km/hour) in opposite direction (Dienst der Hydrografie van de Koninklijke Marine, 1992).

The next subparagraphs describe the main routes on the Waddenzee per navigation group, professional and recreational. The description of these routes is followed by an exposition of the (theoretical) optimal departure and arrival times from and to the Lorentz lock complex per route and in respect to the tide on the Waddenzee. As mentioned before these optimal departure and arrival times are based on the tide of the Waddenzee with its resulting water levels and flows.

- **The Waddenzee's tidal flows**

The analysis of the tidal flows in the Waddenzee is based on Waddenzee, west, flow maps of the Hydrographical service of the Royal Dutch Navy. These maps describe the flows in the western part of the Waddenzee linked to the tidal motion of the water level at Harlingen.

For the Waddenzee tidal flows three situations can be distinguished.

- The first one is when the water level is rising, because there is water from the North Sea flowing into the Waddenzee. Figure 5-2 shows this situation two hours before high tide at Harlingen is reached.

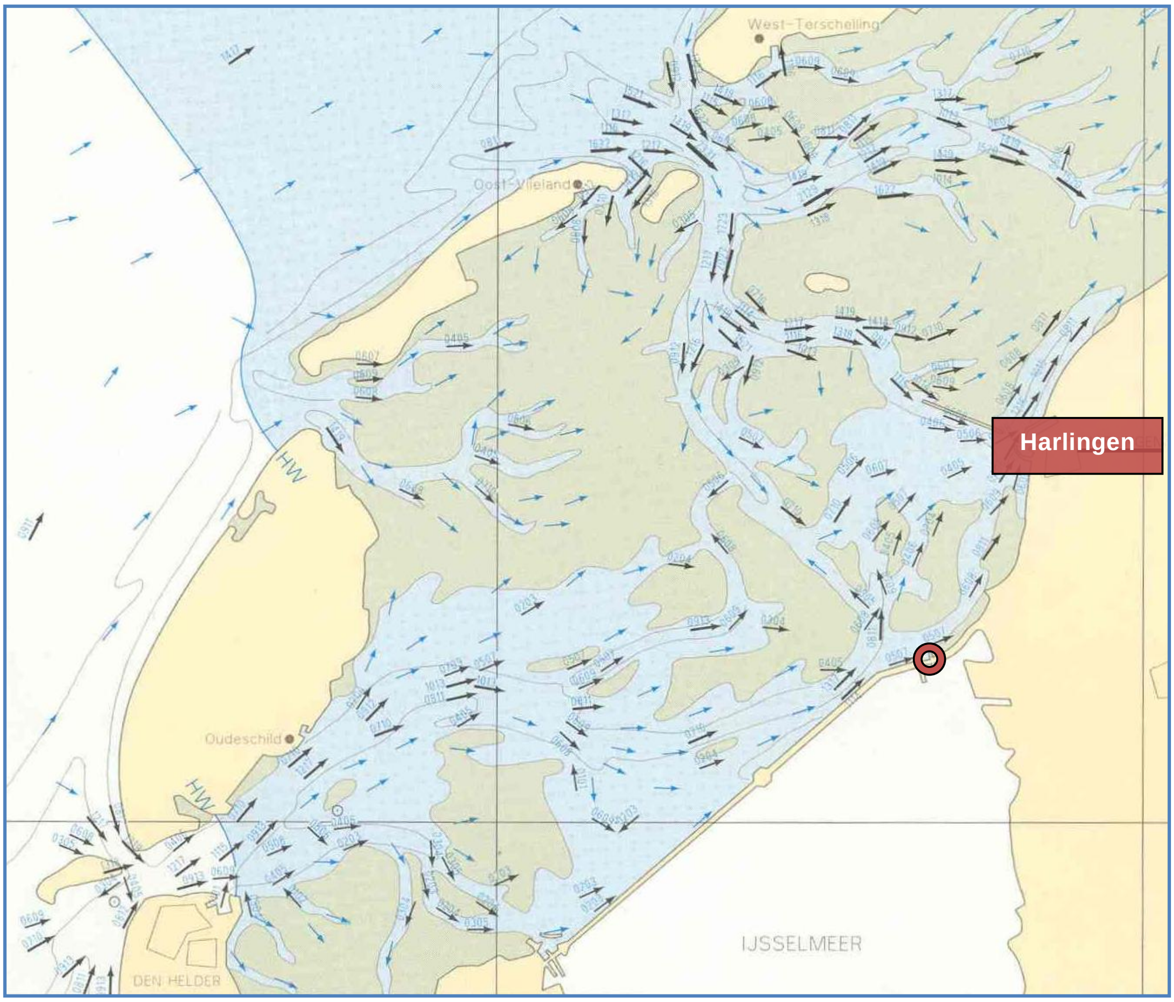


Figure 5-2: Directions of the tidal flows in the Waddenzee two hours before high tide Harlingen (Dienst der Hydrografie van de Koninklijke Marine, 1992)

- The second one is during ebbing water in the Waddenzee. In this situation high tide at Harlingen has passed and the Waddenzee's water is flowing towards the North Sea. The directions of the tidal flows in this situation are shown in Figure 5-3 which shows the tidal flows in the Waddenzee two hours after flood at Harlingen.

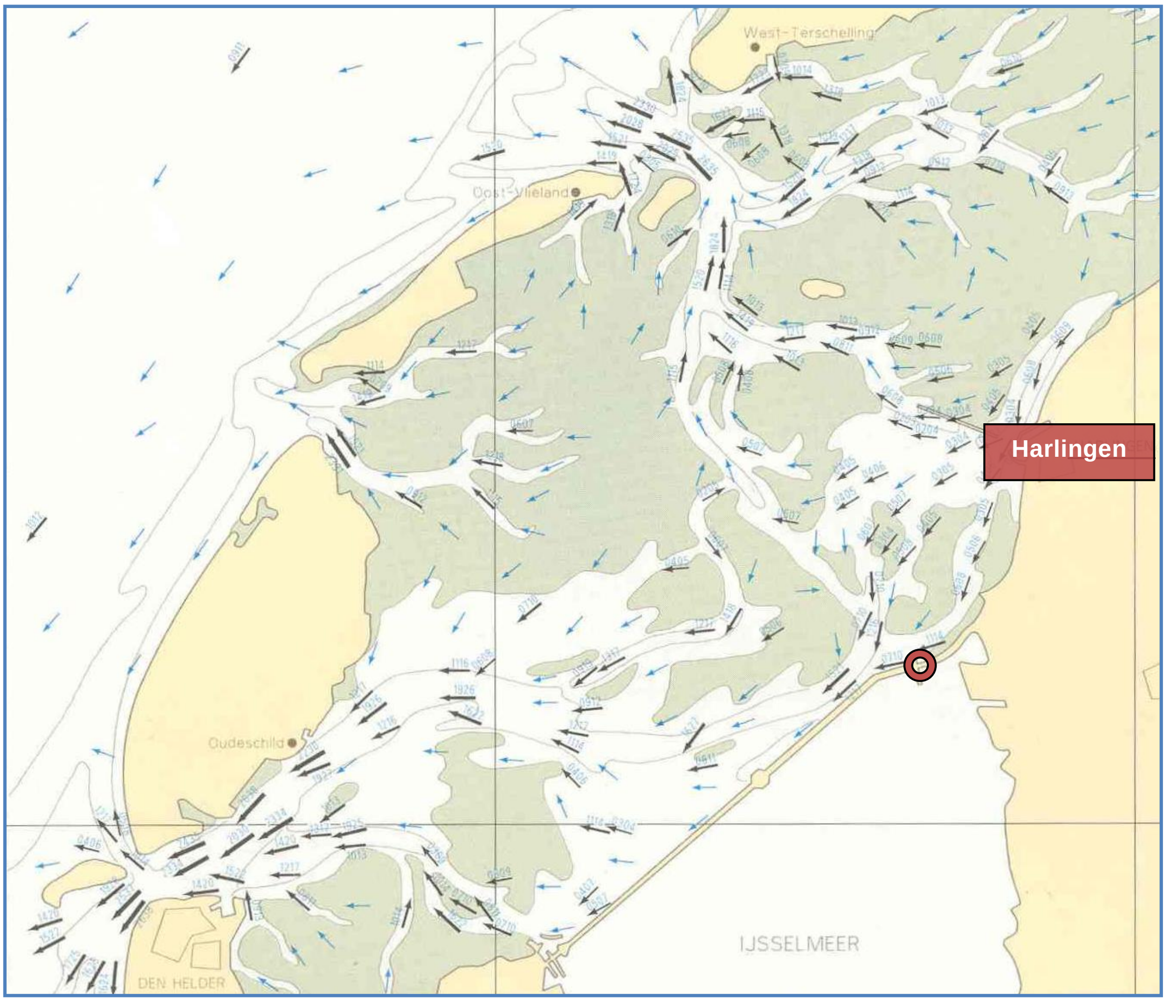


Figure 5-3: Directions of the tidal flows in the Waddenzee two hours after high tide Harlingen (Dienst der Hydrografie van de Koninklijke Marine, 1992)

- The third situation appears when the tide is on the turn, the switch between rising and ebbing water, when the water level has reached high tide or ebb. During this switch the flow velocity of the tidal flows is for a short time around zero. This flow situation only exists for a short period, doesn't benefit navigation and is not prejudicial for navigation. For navigation this situation is frequently used as and estimated time of arrival at their destination or as the optimal departure time to or from the Lorentz navigation locks.

5.3.2 Theoretical distribution of professional navigation

The amount of professional navigation on the Waddenzee is limited. At the Lorentz locks there are only four a five thousand passages each year.
From and to the Lorentz lock complex at Kornwerderzand there is one main fairway for professional navigation. This fairway is presented in Figure 5-4.

There are two connections distinguished respectively Kornwerderzand – Harlingen, eastern Waddenzee and Kornwerderzand – Terschelling, Vlieland and the North Sea. These two connections result in four routes:

- Kornwerderzand – Harlingen, eastern Waddenzee
- Harlingen, eastern Waddenzee – Kornwerderzand
- Kornwerderzand – Terschelling, Vlieland and the North Sea
- Terschelling, Vlieland and the North Sea - Kornwerderzand

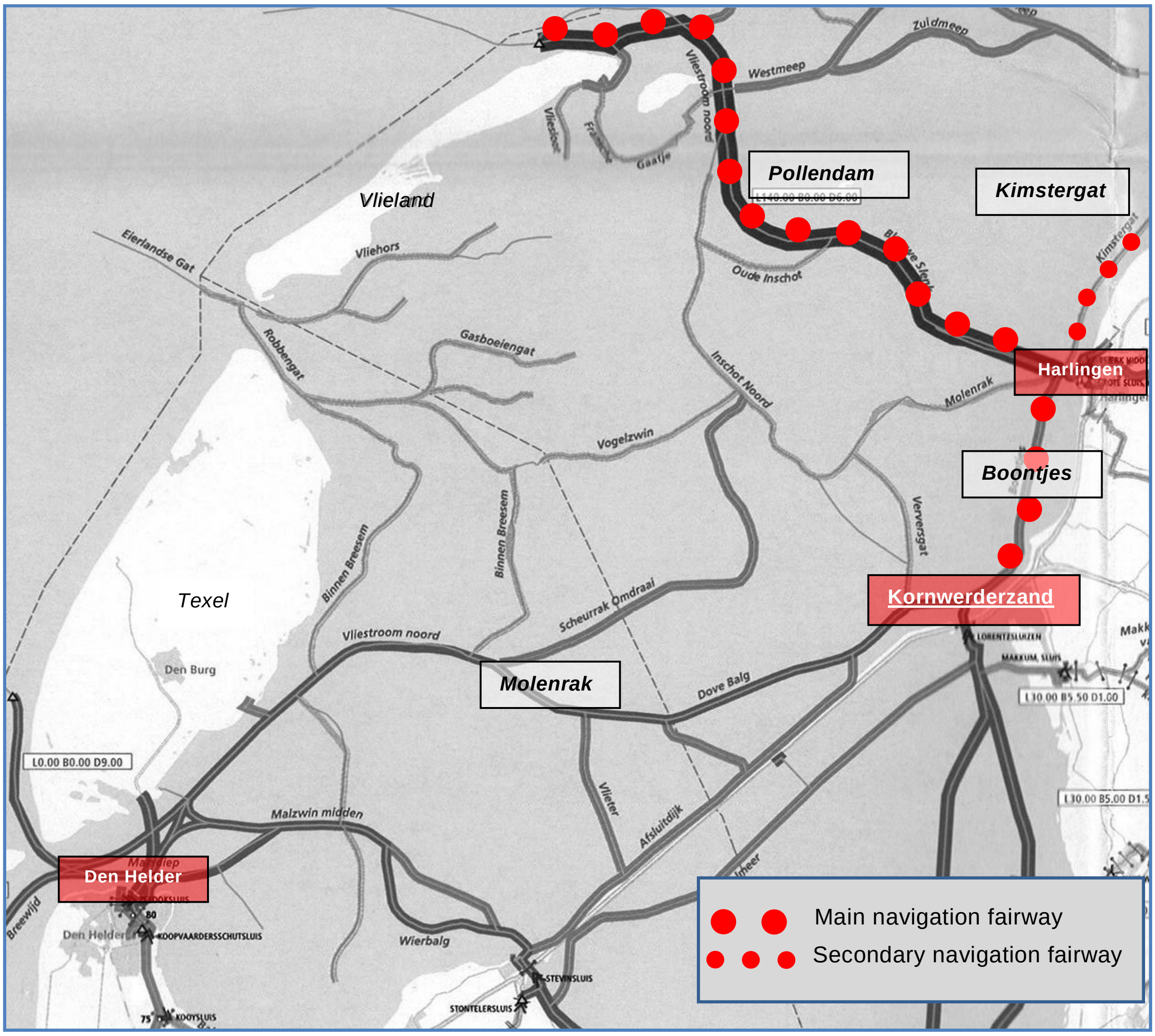


Figure 5-4: Main navigation route for professional navigation on the Waddenzee from and to Kornwerderzand (Ministerie Verkeer en Waterstaat, 2007)

Optimal departure and arrival time at Kornwerderzand

During the trips professional navigation needs sufficient draught and therefore a high water level in the Waddenzee. Besides draught, navigation prefers tidal flows in the same direction as they are heading to reduce the travel time needed to reach their destination. For these analyses an average speed of 15 km/h is used for professional navigation. On base of this assumption, combined with the demands regarding draught and tidal flows, the optimal departure time can be determined.

- Kornwerderzand – Harlingen, eastern Waddenzee

The distance between Kornwerderzand and Harlingen is about 15 km, so with an speed between 15 and 20 km/h (depending on the amount of positive tidal flow) the travel time is between 45 and 60 minutes.
For sufficient draught vessels from the IJsselmeer heading for Harlingen want to enter the Waddenzee close to high tide. To also use the tidal flows directing Harlingen and the eastern Waddenzee, the vessels have to enter the Waddenzee before high tide at Harlingen (Figure 5-2). Another advantage is arrival in Harlingen at high tide with little tidal flows.

The optimal passage and departure time at the Lorentz lock complex is in the final hour(s) before high tide at Harlingen.

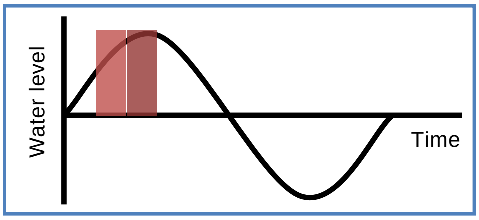


Figure 5-5: Concentration of professional navigation heading to Harlingen, eastern/northern Waddenzee

- Harlingen, eastern Waddenzee – Kornwerderzand

The travel time remains 45 to 60 minutes between Harlingen and Kornwerderzand and sufficient draught is still necessary.
When navigation wants help from tidal flows directing to Kornwerderzand they have to leave Harlingen or the eastern Waddenzee after high tide, so the tidal flows resulting from the ebbing water can be used.

The optimal arrival and passage time at the Lorentz lock complex is in the first hour(s) after high tide at Harlingen.

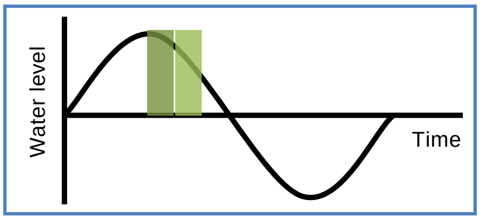


Figure 5-6: Concentration of professional navigation arriving from Harlingen, eastern/northern Waddenzee

- Kornwerderzand – Vlieland, Terschelling and the North Sea

  The concentration of professional navigation is exactly the same as for the route to Harlingen. This is because of the need for sufficient draught and the shift of tidal flows after high tide when the vessel has reached Harlingen. These changed tidal flows can be used to head north to the Frisian Island, Vlieland and Terschelling, and North Sea.
  In this situation navigation can arrive about two hours before low tide with accompanying tidal flows which make it difficult to enter the harbor at Vlieland. In this case navigation waits until low tide, with little tidal flows, to enter the harbor.

- Vlieland, Terschelling and the North Sea – Kornwerderzand

  After departure vessels use the rising water level and corresponding tidal flows to reach Harlingen around high tide. Next the water starts ebbing and corresponding tidal flows, Figure 5-3, are used to reach Kornwerderzand. Therefore navigation reached Kornwerderzand (also) one to two hours after high tide, Figure 5-6.

Distribution of the professional navigation over the routes

Almost all professional navigation passing at the Lorentz lock complex is heading for, or arriving from, Harlingen using the Boontjes fairway. For most navigation Harlingen is their origin or destination. Some of navigation heads through to Terschelling, Vlieland and the North Sea using the Pollendam route while others use the Kimstergat route coming from or heading for the eastern part of the Waddenzee.

Table 5-1: Number of professional passages per fairway on the Waddenzee (Adviesdienst Verkeer en Vervoer, 2006)

Route	Number of professional passages
Pollendam (Harlingen, Vlieland, North Sea)	14.000
Boontjes (Kornwerderzand, Harlingen)	4.000
Kimstergat (Harlingen, eastern part Waddenzee)	500
Molenrak (Den Helder, Harlingen)	0
Total	18.500

Nevertheless all navigation passing the Lorentz lock complex shuttles between Kornwerderzand and Harlingen and there is no navigation to the western part of the Waddenzee. There is no professional navigation to the western part of the Waddenzee, because there is a better alternative. Professional navigation prefers to use the Stevin lock complex at Den Oever and thereby navigate as much as possible on the "easier" IJsselmeer.

5.3.3 Theoretical distribution of recreational navigation

In summer there is lots of recreational navigation on the Waddenzee. During this summer periods the majority of the navigation on the Waddenzee is recreational navigation. At the Lorentz locks there are forty to forty-five thousand recreational passages each year and there are times with over 3500 recreational vessels on the Waddenzee (Stuurgroep Waddenprovincies, 2001).

Distribution of the recreational navigation over the Waddenzee

For recreational navigation on the Waddenzee there are three main destinations.
These destinations are:

- Harlingen (eastern Waddenzee)
- Vlieland, Terschelling and northern Waddenzee
- Den Helder, Texel and western Waddenzee

All vessels using the navigation channels between Kornwerderzand, Harlingen, Texel/Den Helder and Vlieland/Terschelling are evenly spread over these destinations. (Regionaal College Waddengebied, 2007) This means one third heads west and at two thirds are heading for Harlingen. Of these two thirds heading for Harlingen, one third pays a visit to Harlingen and the remaining third heads directly through to the Frisian Islands Vlieland/Terschelling or the North Sea.
Recreational navigation on the Waddenzee is divided in "using the navigation channels" and "not using the channels". The navigation group using the navigation channels consists of 80 percent of the total recreational navigation on the Waddenzee. For this research it’s assumed that this characteristic of the navigation at the Lorentz locks is the same as navigation on the Waddenzee. Therefore also *80 percent of the recreational navigation using the Lorentz lock complex at Kornwerderzand is using the navigation channels*.
The remaining 20 percent does not use the navigation channels and is exploring the Waddenzee outside the fairways. The exact behavior of this group is unknown, therefore it’s assumed that *this group is equally divided over parts of the Waddenzee west and east of Kornwerderzand and has random navigation behavior.*

The total, theoretical, distribution of recreational recreation using the Lorentz lock complex is 36 percent to, or from, the part of the Waddenzee west of Kornwerderzand and 64 percent to, or from, the part east of the Lorentz locks. From the 64 percent east of Kornwerderzand, around half of the skippers have Harlingen as their origin/destination. The other half is through traffic heading to, or coming from, Terschelling and Vlieland.

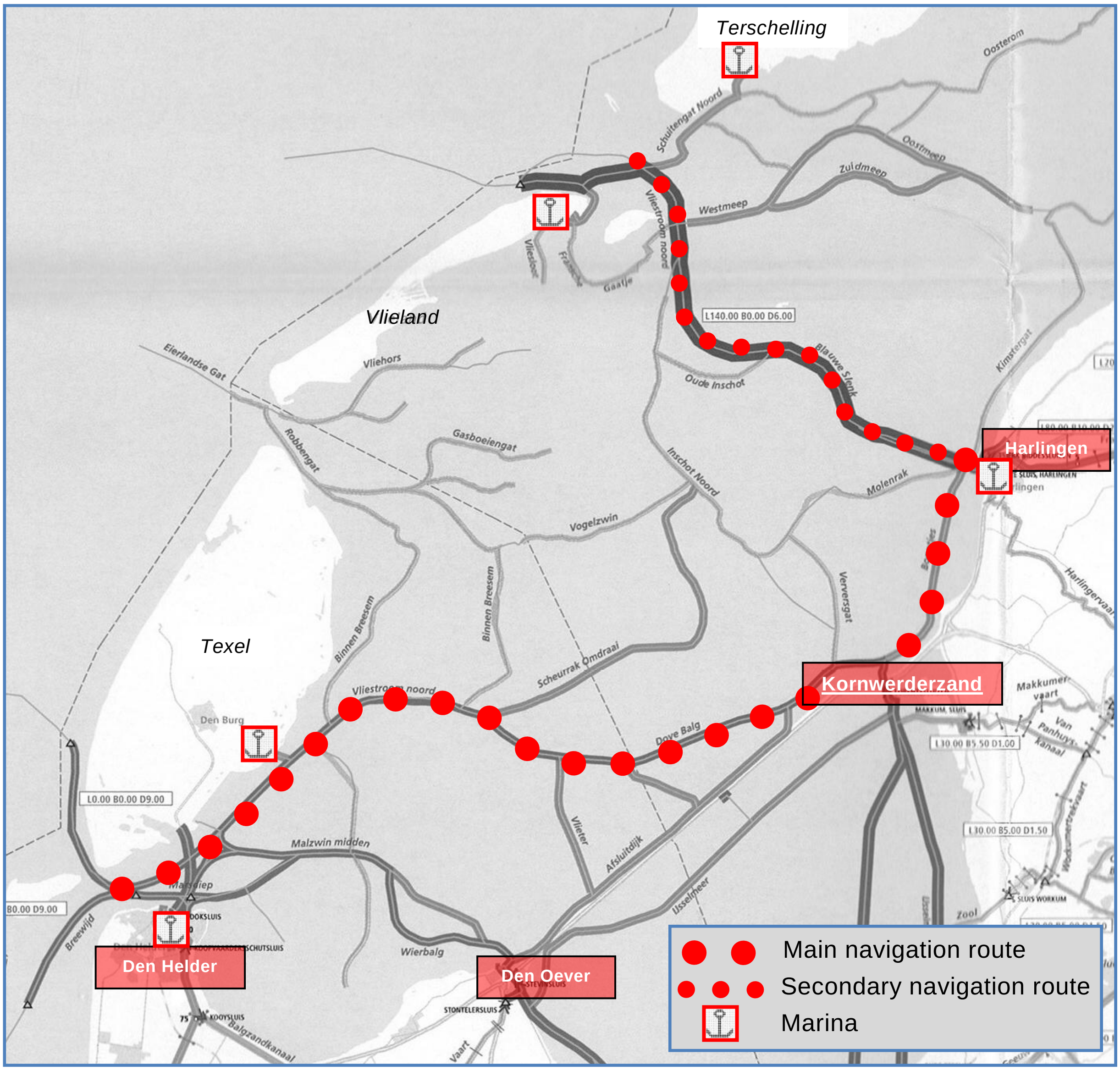


Figure 5-7: Main navigation routes for recreational navigation on the Waddenzee from and to Kornwerderzand (Ministerie Verkeer en Waterstaat, 2007)

The three origins/destinations presented before, result in six different routes between them and the Lorentz lock complex at Kornwerderzand. The first four routes are also used by professional navigation and the routes between Kornwerderzand and Harlingen are most intensively used. The six routes for recreational navigation are:

- Kornwerderzand – Harlingen (eastern Waddenzee)
- Harlingen (eastern Waddenzee) – Kornwerderzand
- Kornwerderzand – Vlieland, Terschelling, northern Waddenzee
- Vlieland, Terschelling, northern Waddenzee – Kornwerderzand
- Kornwerderzand – Den Helder, Texel and western Waddenzee
- Den Helder, Texel and western Waddenzee – Kornwerderzand

Optimal departure and arrival times at Kornwerderzand

For recreational navigation it is important to use the tidal flows, or at least not to head in opposite direction of the tidal flow, because they lack sufficient power to reach an acceptable cruising speed with opposite tidal flows. For these analyses an average speed of 10 km/h is used for recreational navigation.
Besides the tidal flows some recreational navigation takes into account the water level of the Waddenzee because they fear insufficient draught for their vessels. In reality this fear is usually unfounded, but they nevertheless some take it in account.
Based on the demands regarding tidal flows and draught, the navigation speed and the distances to/from Kornwerderzand, the optimal departure and arrival times at the Lorentz lock complex can be determined.

- Kornwerderzand – Harlingen (eastern Waddenzee)

  The distance between Kornwerderzand and Harlingen is about 15 km, so with a speed between 10 and 15 km/h (depending on the amount of positive tidal flow) the travel time is about one or one and a half hour.
  To use the tidal flows directing Harlingen, vessels have to enter the Waddenzee before high tide at Harlingen (Figure 5-2). To also have sufficient draught some vessels from the IJsselmeer heading for Harlingen want to enter the Waddenzee close to high tide.

  The optimal passage and departure time at the Lorentz lock complex is in, or even at, the final hour(s) before high tide at Harlingen, but it is possible during all hours when the water level of the Waddenzee is rising.

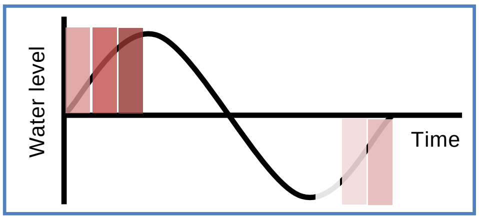


Figure 5-8: Concentration of recreational navigation heading to Harlingen

- Harlingen (eastern Waddenzee) – Kornwerderzand

The travel time remains one or one and a half hour between Harlingen and Kornwerderzand. When navigation wants help from tidal flows directing to Kornwerderzand they have to leave Harlingen after high tide, so the tidal flows resulting from the ebbing water can be used. Besides the sooner they leave after high tide, the higher the water level of the Waddenzee and thereby the more available draught.

The optimal arrival and passage times at the Lorentz lock complex are within the hour(s) after high tide at Harlingen, but it is possible during all hours with ebbing water.

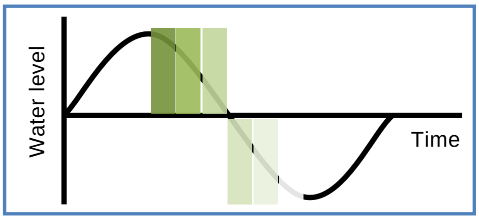


Figure 5-9: Concentration of recreational navigation arriving from Harlingen

- Kornwerderzand – Vlieland, Terschelling, northern Waddenzee

The distance of this route is 35 kilometers which results in travel times from about two and a half up to three and a half hours. On this route it is difficult to use the tidal flows on the entire route, but for optimal usage, and maximum draught, vessels have to depart just before high tide Harlingen. Figure 5-2 shows that the tidal flow directing to the east can be used for the first five kilometers and after reaching Harlingen high tide is passed and the changed tidal flows Figure 5-3 can be used to head north.
In this situation recreational navigation arrives about three hours before low tide when they navigate nonstop. This would mean that accompanying tidal flows make it difficult to enter the harbor at Vlieland. Therefore recreational navigation takes its time by casting the anchor somewhere along the route, visiting Harlingen and in this manner make sure they arrive at Vlieland around low tide.

The optimal passage and departure time at the Lorentz lock complex is just before high tide at Harlingen.

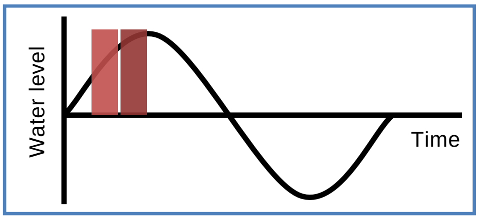


Figure 5-10: Concentration of recreational navigation heading to Vlieland, Terschelling and the northern Waddenzee

- Vlieland, Terschelling, northern Waddenzee – Kornwerderzand

A total distance of thirty-five kilometers has to be covered for this route which takes two and a half to three and a half hours. To use the tidal flows vessels have to leave the about two hours before high tide at Harlingen. This way they reach Harlingen at around high tide, the tide changes, and they use the changed tidal flows to reach Kornwerderzand within an hour after high tide. In addition the maximum available draught is guaranteed with this travel behavior.

The optimal arrival and passage time at the Lorentz lock complex is within the hour after high tide at Harlingen.

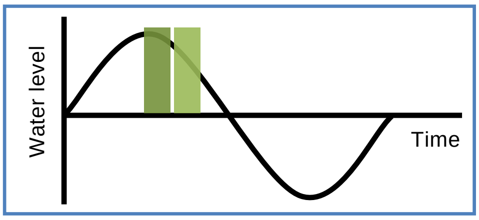


Figure 5-11: Concentration of recreational navigation arriving from Vlieland, Terschelling and the northern Waddenzee

- *Kornwerderzand – Den Helder, Texel and western Waddenzee*

The distance between Kornwerderzand and Den Helder is about 50 kilometers, so with a navigation speed between 10 and 15 km/h (depending on the amount of positive tidal flow) the travel time is between three and a half and five hours.
To use the tidal flows directing Den Helder, vessels have to enter the Waddenzee around high tide at Harlingen. After high tide the tidal flows are six hours directing Den Helder, so Den Helder can be reached within this time period.
On this route the fairways have more depth as between Kornwerderzand and Harlingen, so the draught has little influence on the desirable time of departure.

The optimal passage and departure times at the Lorentz lock complex are within the first hours after high tide at Harlingen.

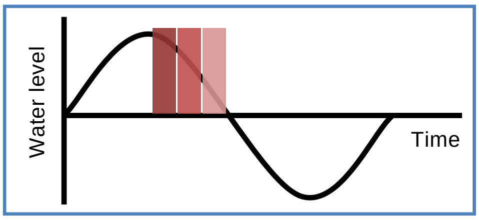


Figure 5-12: Concentration of recreational navigation heading to Den Helder, Texel and the western Waddenzee

- Den Helder, western Waddenzee – Kornwerderzand

  The travel time between Den Helder and Kornwerderzand is determined on 3,5 up to 5 hours. To use the tidal flows navigation departs during rising water three and a half or five hours before high tide at Harlingen. This results in arrivals during the three hours before high tide Harlingen.

  The optimal arrival and passage time at the Lorentz lock complex is within the hours, about three, before high tide at Harlingen.

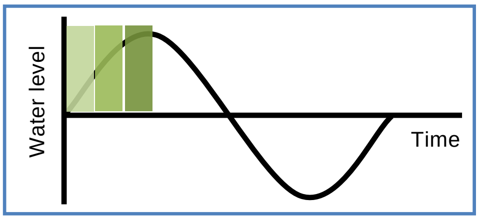


Figure 5-13: Concentration of recreational navigation arriving from Den Helder, Texel and the western Waddenzee

5.3.4 General theoretical distribution all navigation

For each of the six routes from and to the Lorentz lock complex the expected spread of navigation over the day is presented. The directions of the six routes can be divided in north, starting at Kornwerderzand, and south, heading to Kornwerderzand.

Direction NORTH includes all routes starting at Kornwerderzand:
- Kornwerderzand – Harlingen (eastern Waddenzee)
- Kornwerderzand – Den Helder, Texel and western Waddenzee
- Kornwerderzand – Vlieland, Terschelling, northern Waddenzee

Direction SOUTH includes all routes heading to Kornwerderzand, respectively:
- Harlingen (eastern Waddenzee) – Kornwerderzand
- Den Helder, Texel and western Waddenzee – Kornwerderzand
- Vlieland, Terschelling, northern Waddenzee – Kornwerderzand

To create an overall theoretical distribution of the navigation at the Lorentz lock complex, all previous distributions per route are combined. This results in a distribution per main direction at the Lock complex at Kornwerderzand as presented in Figure 5-14.

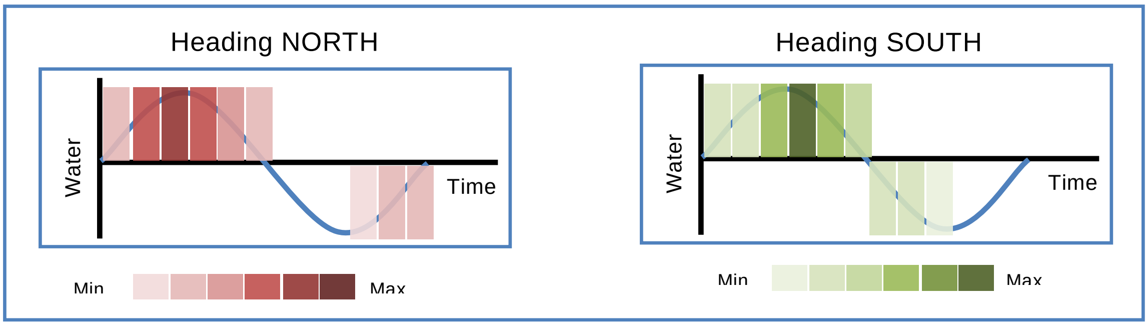


Figure 5-14: Expected distribution of navigation at the Lorentz lock complex per direction and linked to the Waddenzee tide

5.4 Comparison actual data with theoretical distribution

Besides all theoretical reasoning's presented before, there is the influence of daylight on recreational navigation. Recreational navigation mainly travels by daylight for two reasons. First of all most yachtsmen want to enjoy the view and sunlight which makes daylight essential. Secondly it is more difficult to navigate a vessel without direct sight, so most skippers prefer to reach a harbor before sunset.

The influence of daylight is ascendant over all theories based on the Waddenzee tide which makes is necessary to distinguish two situations. The Waddenzee tide shifts over time, so the favorable high tide is at different times during daytime. This shift of the Waddenzee tide is represented in Figure 5-15.

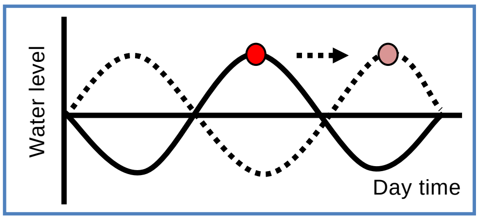
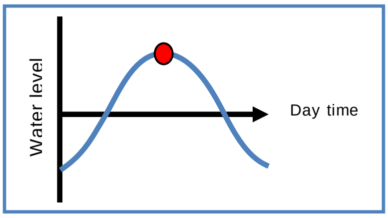


Figure 5-15: The shift of the Waddenzee high tide from midday to evening.

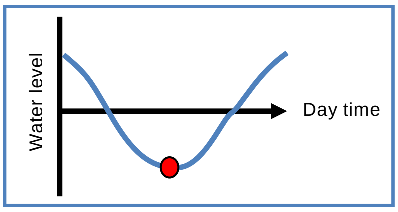
As a result of the shift of the high tide it is sometimes difficult to use it because it is at an uncomfortable moment. Besides the tide and daylight there are also others factors determining the behavior of recreational navigation. These factors are, for example, mealtimes and the fact that tourists don't want to get up (to) early in the morning. Therefore it is assumed that there is a convenient navigation period for recreational navigation which starts at 10.00 and lasts till 17.00. Despite the fact that the shift of the high tide is a progressive cycle, there are two main situations distinguished:

- High tide during convenient navigation period:



In this situation navigation uses the high tide to plan their trips, so all theories mentioned previously in this chapter are applicable.

- High tide in the morning and evening, low tide during convenient navigation period:



The high tides are early in the morning and evening and thereby it is less convenient for (recreational) navigation to use the high tides. In this case the theories based on the Waddenzee tide apply less which shows that the daylight is ascendant to the tidal movement.

After the theoratical spread of the navigation over the day in previous (sub-)paragraphs, this paragraph describes the real spread of navigation over the day. For this analysis data of July 2007 are used. The data includes the number of vessels that are locked per hour and per direction (north and south) at the Lorentz lock complex and the tidal movement of the Waddenzee.

The next two figures, Figure 5-16 and Figure 5-17, are examples of days when the high tide is on a convenient moment and an unconvenient moment. On July 23th high tide was around 14.00 and navigation behaves as expected with a concentration of vessels at the Lorentz lock complex around high tide of the Waddenzee.

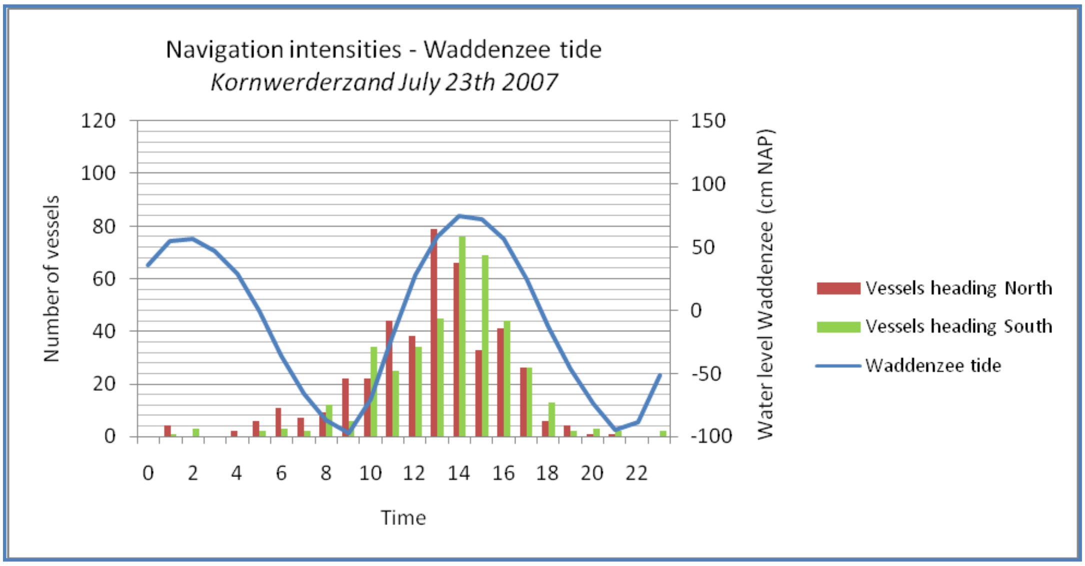


Figure 5-16: Navigation intensities and Waddenzee tide, Kornwerderzand July 23th 2007

On July 13th, the Waddenzee's low tide was around 15.00 and high tides were early in the morning and nine o'clock in the evening. As a result navigation uses high tide less and the passages at the Lorentz lock complex are more equally spread over the day.

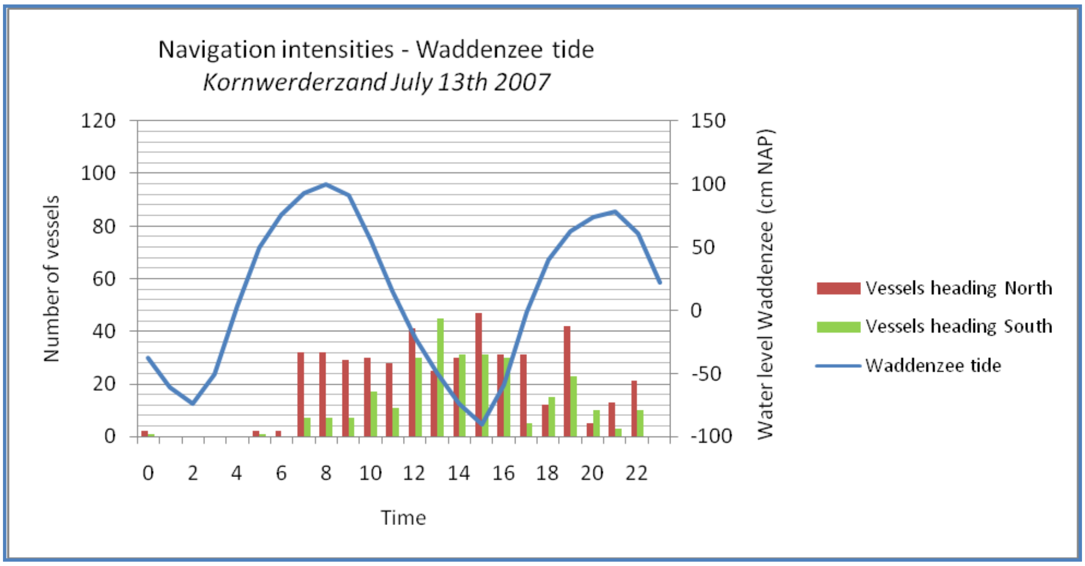


Figure 5-17: Navigation intensities and Waddenzee tide, Kornwerderzand July 13th 2007

The examples in Figure 5-16 and Figure 5-17 follow the theoretical reasonings presented before, but unfortunately there are days when the theory doesn't seem to work. Therefor the entire month of July is investigated and calculations are made to determine what the concentrations of navigation are at which water levels and on which times of the day.

In Figure 5-18 the Date, Navigation directions (North/South), Intensities per hour of the day and Total day-intensities are presented. Appendix 6; Navigation intensities and tidal movement July 2005 gives a more detailed presenation of this figure.
The colors indicate daytime, convenient navigation period, moments of high, and low tide, on the Waddenzee.

- Green: *The period over the day convenient for navigation to use the (high) tide.*
- Yellow: *The time period when there is sufficient daylight for recreational navigation.*
- Brown: *The moments of low tide at Kornwerderzand and adjacent hours.*
- Blue: *The moments of high tide at Kornwerderzand and adjacent hours.*

		00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	Total
1 july	north										23	54	26	16	30	16	10	15		6		2	3		3	204
sun	south									2	6	9	22	20	30	7	4	8	9			12	5		2	136
2 july	north	4	4		2					3	16	50	31	23	32	15	29	7	8	17	4	5	2	3		255
mon	south	2	2		2					1		10	37	37	21	18	10	11	7	9		6	4	6		183
3 july	north	2		2						26		19	38	32	43	15	18	1	3		15	1	4	1	9	229
tue	south	5		5					1	3		25	20	22	37	19	33	4	2		21	2	6	7	4	216
4 july	north	1					2		7	7	16	11	24	35	23	33	13	11	6	6	4	3		4	2	208
wed	south						5	1	2	6	6	9	30	19	28	11	16	24	6	7	4	2	8	4	6	194
5 july	north					1		2		8	16	21	25	42	53	20	32	7	10	16	5	2	2		6	268
thu	south							4		8	19	9	24	18	62	18	37	13	15	14	1	2	3		2	249
6 july	north			2						5	10	4	22	6	5			3		1			13			71
fri	south	2		1						4	6	9	19	2	7		9	1					2			62
7 july	north						2		4	13	17	19	17	51	23	13	8	14	3	8	2	2	1			197
sat	south						2		10	6	9	32	17	22	25	10	7	11	18	9	12		1			191
8 july	north				2	6	10	9	7	9	10	30	39	62	98	79	55	31	23		10	2	2		3	487
sun	south				1		5			7	3	14	28	40	52	43	40	33	31	6	7	8		2	1	321
9 july	north		4		3	7	5			18	14	9	20	27	12	41	38	24	23	17	7	4	2	2		277
mon	south		2			2	4			1	12	13	9	9	10	19	22	23	22	17	21	6			1	193
10 july	north	2				8	5	3	6	21	13	20	39	31	16	26	25	32	14	13	1	4				279
tue	south	1			1	1	3	2		7	13	20	9	40	12	8	28	36	35	4	5	5				230
11 july	north				2		4		23	3	14	10	8	12	23	15	8	8	8	8	6	2	5	4		163
wed	south				2	1	1	2	12	9	7	17	15	8	17	27	25	23	25	39	18		5			253
12 july	north						2	8	7	2	9	16	12	28	13	22	24	20	17	6	9	12	3			210
thu	south	1						8	4	1	8	21	20	21	21	27	40	13	35	21	10	4	2		2	259
13 july	north	2					2	2	32	32	29	30	28	41	25	30	47	31	31	12	42	5	13	21		455
fri	south	1					1		7	7	7	17	11	30	45	31	31	30	5	15	23	10	3	10		284
14 july	north								18	35	44	54	37	20	55	35	22	8	67	8	8	7	2			420
sat	south			11						7	15	26	18	42	60	30	15	34	13	11	5	2	1			290
15 july	north							3	5	26	54	75	32	26	59	24	30	32	13	21	11	13	2	10	3	439
sun	south								2	13	24	39	59	63	39	21	27	45	11	17	42	8	9	3		422
16 july	north		3						4	19	9	44	49	43	18	17	10	18	4	7	15	4	4	3		271
mon	south	1		2				3		3	15	22	23	60	50	13	22	11	2	17	12	10	10	3	2	281
17 july	north								2	4	5	22	32	33	23	21	11	7	4	3	5	9			3	184
tue	south									6	4	10	21	20	25	36	15	8	6	4	9	2		3		169
18 july	north							3		18	11	70	61	66	62	14	10	17	13	11	4	5	4	4	1	374
wed	south							2		4	9	14	47	17	74	29	24	58	22	6	2	10	14	3	2	337
19 july	north	2	2		3	4	3	3	3	15	13	59	72	19	27	42	40	18	27	4	6	2	2	3	2	371
thu	south	7	2		2	1		1	4	5	12	15	38	48	54	58	51	31	19	8	10	3	2	4		375
20 july	north		8				5	2		2	17	22	16	16	13	2	14		9				3			129
fri	south	3	5				2		2	9	3	20	17	3	16	26	15	8	6	2						137
21 july	north				3	6			2	8	24	23	56	75	55	52	36	42	21	19	7	2	3			434
sat	south				1			2	1	2	17	25	47	43	72	47	14	30	23	7	8		4			343
22 july	north		5							3	28	35	41	111	51	39	52	31	5	2	2		3			408
sun	south							1		3	13	50	32	34	95	63	46	24	27		9					397
23 july	north		4			2	6	11	7	9	22	22	44	38	79	66	33	41	26	6	4	1	1			422
mon	south		1	3			2	3	2	12	6	34	25	34	45	76	69	44	26	13	2	3	2		2	404
24 july	north	5					2			3		5	2	5		6	10	7	5	10	19	2			2	83
tue	south			2			2			2		4	9	11	6	8	8	10	2	9	12	6		2		93
25 july	north						5	15	26	7	23	25	42	64	46	42	28	31	11	3	16	6	3		1	394
wed	south					2	1	4	2	26	35	7	46	36	43	78	44	52	52	68	23	1	6			526
26 july	north							22		19	24	8	20	23	31	11	5	12	11	3	1					190
thu	south			2				10	8	15	21	9	27	54	12	8	20	14	15	5	2			2		224
27 july	north						5		3	3	1	15	4	14	9	10	11	11	8	5	4	7	2	3		115
fri	south						3	2	2	3	2	7	11	7	12	14	7	13	15	2	2	7	3	1		113
28 july	north							2	17	26	13	35	45	9	13	7	28	10	12	9	4	2	2	8		242
sat	south							3	2	12	16	39	52	39	10	20	11	24	31	20	35	4	6	4		328
29 july	north								11	25	23	48	38	14	18	18	7	14	6	3	1	4			2	232
sun	south							1		8	19	35	30	64	30	13	28	4	18	8	6		1	1		266
30 july	north									6	5	5	11	13	12	5	9	7	2	5		2	8	5		95
mon	south	3									4	17	14	16	10	12	5	6	3	2	3	1	2	3		101
31 july	north	2						7	2	2	14	52	67	44	51	29	55	24	10	2	10	11	4	3		389
tue	south	1						3	2	4	11	9	43	31	49	28	16	11	18	13	9	9	5			262
Total		47	42	30	24	41	89	144	249	573	839	1499	1818	1949	2087	1583	1457	1191	919	584	535	244	197	132	61	16334

Figure 5-18: Intensities at Lorentz lock complex over the day, per direction, and moments of high and low tide of the Waddenzee.

Table 5-2: Shares of navigation, per direction, linked to tidal periods of the Waddenzee.

Central tide during convenient navigation period	High		Low	
Navigation direction N=north, S=south	N	S	N	S
	% Day total		% Day total	
Navigation 1 hour before through 1 hour after high tide	36	36	29	25
Navigation 1 hour before through 1 hour after low tide	12	12	25	24
Navigation 2 hours before high tide	38	30	24	23
Navigation 2 hours after high tide	31	36	28	22
Navigation 2 hours before low tide	12	11	22	25
Navigation 2 hours after low tide	15	15	24	23
Navigation during rising water	57	48	43	40
Navigation during ebbing water	43	52	57	60

Several relations can be verified with the figures presented in Table 5-2. For the overview two situations are distinguished respectively high tide is the central tide during the convenient navigation period and low tide as the central tide during this period.

<u>High tide is the central tide:</u>

- There is a concentration of navigation around high tide for both directions.
- Navigation heading north is more concentrated before high tide during the rising of the Waddenzee's water level.
- Navigation heading south is reasonably equally spread over the periods of rising and ebbing water, but not equally spread within those periods.

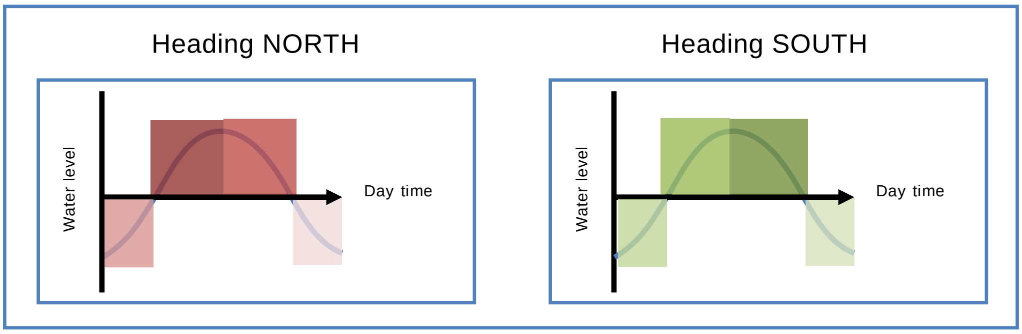


Figure 5-19: Visualisation of the actual navigation distribution during days with the high tide as the central tide.

Underneath the findings of the navigation periods with the low tide as the central tide are presented.

Low tide is the central tide:

- Navigation is more equally spread over the day and the tides for both directions.
- Navigation heading in both directions is a bit more concentrated before low tide, during ebbing water.

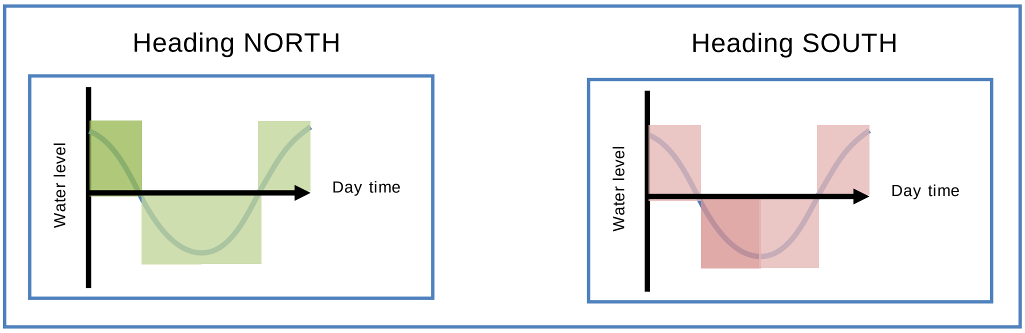


Figure 5-20: Visualisation of the actual navigation distribution during days with the low tide as the central tide.

The more equally spread of navigation is expected as well, or at least that the theoritical spread would not apply.

The concentration of navigation during ebbing water of the Waddenzee becomes clear from the figures presented in Table 5-2 and the visualiziations presented in Figure 5-20. The theoretical spread could explain this for navigation heading south, but for navigation heading north this is less clear.
For this direction it can be explained by the fact that the ebbing water is in the morning and people want to enter the Waddenzee in the morning to spend the day on the Waddenzee.

Recapitelizing most relations suit the expected, theoretical, spread of navigation over the day presented previously in Figure 5-14. The only exception is the concentration of navigation heading north during ebbing water in combination with the low tide as the central tide.
Presumably this can be explained by the fact that the ebbing water is in the morning and yachtsmen want to enter the Waddenzee in the morning to spend the day on the Waddenzee.

5.5 Travel advice for navigation using the Lorentz locks

This paragraph contains travel advice for navigation on the Waddenzee and Ijsselmeer to increase their chance to avoid congestion at the Lorentz lock complex at the Afsluitdijk. To structure this advice distinctions are drawn, again, between situations with high tide as the central tide in the convenient navigation period and low tide as the central tide. Besides this distinction also the navigation directions North and South are distinguished.
Another option is to predict the busyness at the Lorentz navigation locks, present this information to the skippers and let them adjust their travel behavior, or not. This method is used for road traffic by the Royal Dutch Tourists Association (ANWB).

5.5.1 Travel advice for days with high tide as the central tide

Navigation heading North
The concentration of navigation for this direction is in the hours before high tide during rising water. This is mostly recreational navigation heading to Harlingen which particularly needs the tidal flows of the rising water, so it is also possible and advisable to enter the Waddenzee in the earlier stages of the rising water. This way the concentration of navigation at, and just before high tide, gets spread over the entire period of rising water.

Navigation heading South
For this navigation about the same advice can be used. The concentration of navigation for this direction is in the hours after high tide during ebbing water. This is mostly, about two thirds, recreational navigation from the direction of Harlingen which particularly needs the ebbing water, and its tidal flows, to reach Kornwerderzand. Therefore it is possible and advisable to enter the Waddenzee in the later stages of the ebbing water. Consequently the concentration of navigation at, and just after high tide, gets more spread over the entire period of ebbing water.

5.5.2 Travel advice for days with low tide as the central tide

On days with low tide as the central tide navigation is mainly spread over the period of ebbing water. For navigation heading south the ebbing water and resulting tidal flows are useful, but for navigation heading north this argument does not apply.
For navigation heading north the main explanation probably is straightforward. The ebbing period is during the morning and yachtsmen want to spend an entire day on the water, so have to leave in the morning. Besides there is no high tide available to use, so no reasons to alter their schedule.

The advice for navigation heading north is to leave a day earlier in the afternoon. This way they can use the probably more useful rising water and avoid the concentration of navigation during ebbing water. About two thirds of the navigation heading north prefer the rising water and corresponding tidal flows so especially this group can use this advice.

The same advice applies for navigation heading south and don't need to use the ebbing Waddenzee water. This is mainly navigation coming from the western part of the Waddenzee, Texel and Vlieland which is approximately one third of navigation heading south.

The effect of following these advices on the waiting and passage times is determined in the following chapter 6 by the use of a simulation model of the Lorentz navigation locks at Kornwerderzand.

5.5.3 Methods to inform skippers about the expected concentration of navigation.

This option predicts the concentration of navigation at the navigation locks over the day and related to the tidal motion. At first calendars can be presented including all busy days during the navigation season and subsequently predictions of the concentration over the day can be made public.

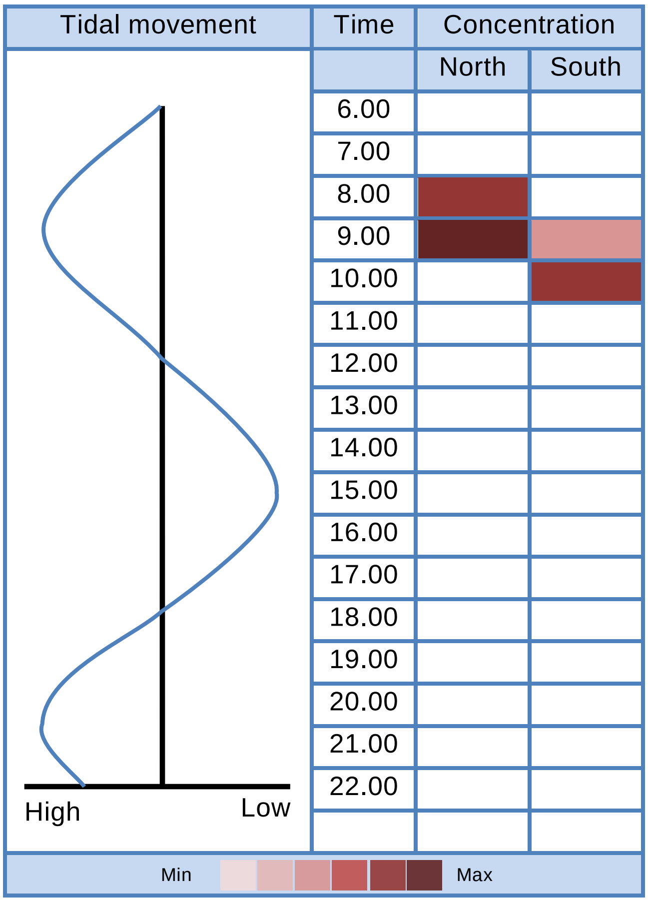


Figure 5-21: Example of a method to inform skippers about the expected concentration of navigation over the day.

With this information skippers can decide to avoid the busy days or avoid the concentration of navigation during the day. Another positive side effect is that professional skippers can avoid the congestion as well. This again reduces the congestion, but nowadays most professional navigation already has the knowledge and experience to avoid the busy days and periods.

5.6 Conclusions

External factors like season of the year, holidays, weekends, time of the day, “the weather” and the Waddenzee tide influence the intensities of the navigation at the Lorentz lock complex. The influence of these factors is more for recreational navigation than professional navigation and the share of recreational navigation is over 90 percent at the lock complex at Kornwerderzand. Therefore the external factors have lots of influence regarding the distribution of navigation over the year and day.

The influence of factors including season of the year, holidays, weekends and “the weather” results in an unequal distribution of navigation over the year. Over 95 % of the yearly passages at Kornwerderzand are during the months April till November with the peak in July. The distribution over the day is mainly influenced by the time of the day and the Waddenzee tide.

There are three main connections used by navigation on the Waddenzee. These connections are:

- Kornwerderzand – Harlingen, eastern Waddenzee
- Kornwerderzand – Terschelling, Vlieland and the North Sea
- Kornwerderzand – Den Helder, Texel and the western Waddenzee

Professional navigation only uses the first two connections and recreational navigation uses all. Recreational navigation is about equally distributed over the three connections and most professional navigation has Harlingen as their origin or destination.

As mentioned previously, the distribution of navigation over the day is mainly influenced by the time of the day and the Waddenzee tide. Of course recreational, and professional navigation, prefers to navigate during the day, but they also want to use the tidal flows resulting from the Waddenzee tide. These tidal flows can increase the navigation speed and therewith decrease travel times. Besides the tidal flows, navigation is also interested in the water level of the Waddenzee, because they need sufficient draught for their vessels. This motive mainly applies for professional navigation. Based on these motives the distribution of navigation at the Lorentz lock complex heading North and South can be predicted.
Two tidal situations are distinguished to predict the distribution of navigation. These situations are; high tide is the central tide during the day and low tide is the central tide during the day. When the high tide is the central tide, the distribution of navigation can reasonably be predicted. If the low tide is the central tide, the theories do not apply and navigation is less concentrated and more equal spread over the day. The conclusions regarding the distributions of navigation in the distinguished situations are presented underneath.

<u>High tide is the central tide:</u>

- There is a concentration of navigation around high tide for both directions.
- Navigation heading north is more concentrated before high tide during the rising of the Waddenzee’s water level.
- Navigation heading south is reasonably equally spread over the periods of rising and ebbing water, but not equally spread within those periods.

Low tide is the central tide:

- Navigation is more equally spread over the day and the tides for both directions.
- Navigation heading in both directions is a bit more concentrated before low tide, during ebbing water.

The predictions of the distribution of navigation at the navigation locks can be used to inform skippers. This can be done in two ways; first the distribution of navigation over the year, month and week can be made public. This distribution presents the busy periods, days and skippers can decide to avoid those days and periods, or not. Secondly the distribution over the day can be presented to the skippers and yachtsmen so they can choose to avoid congestion, or not.
When sufficient navigation tries to avoid the busy periods, a more equal distribution of navigation will be the result which again results in less waiting time at the Lorentz navigation locks.

The effect of a more equal distribution on the waiting times for navigation will be determined in the following chapter. Next chapter, chapter 6, will present the development of a simulation model to predict the current amount of congestion for navigation. Subsequently the model will be used to determine the effect of possible improvements presented in this and previous chapter, chapters 5 and 6.

6 Simulation of the navigation flows at the Lorentz locks

As presented in chapter 1, there is an accessibility problem for navigation and road traffic at the Afsluitdijk, but there are lots of different opinions about the size of this problem. Paragraph 1.3.2 contains an enumeration of different perspectives of the accessibility (problem) at the Lorentz Lock complex and because of the opacity about this subject it's difficult to determine policy for this structure.
To create an objective, founded, judgment about the accessibility at the Lorentz Lock complex and the Afsluitdijk, the accessibility is investigated in this chapter with the usage of micro-simulation software. This chapter focuses on the local congestion for navigation at the Lorentz lock complex at Kornwerderzand.

6.1 Methodology

As mentioned before, there is no data from the past available which exactly determines the frequency and amount of congestion at the navigation locks. Because it is time consuming, difficult and therefore expensive to collect sufficient data in reality, simulations are used to collect data. Another advantage of simulations is the possibility to experiment with the system without disordering the real system.

To determine the most suitable simulation software, an inventory of available software is made. Surprisingly there is only one program available in the Netherlands for the simulation of navigation flows. This program is used by the Division Traffic and Navigation (DVS) of the Dutch government and is called SIVAK[3] II.
The core of SIVAK II is a PROSIM model and therefore it's run in a PROSIM environment. For the user, the PROSIM environment is kept out of sight by the SIVAK user interface which is suitable for the creation and management of the input files and analysis of the output files.
This SIVAK II software is mainly suitable for navigation, but also includes a small road traffic part which will not be used in this analysis.

6.2 Software structure and input possibilities

SIVAK II uses a three layer structure including the layers Blocks, Project and Variant.

Block is for example a navigation lock, a bridge, a water level table, a traffic pattern and so on with all relevant characteristics. The Blocks contain lots of information which are used as input for the simulations.

The Project layer defines, with the usage of the Blocks, the base-network, the base-navigation network and the base-collection vessels for the research.

The final layer, Variant, belongs to a Project and is distinguished by one or more (small) changes in the characteristics of the base elements. Only with a Variant simulations can actually be run.

[3] Simulatie Verkeersafwikkeling Kunstwerken

Figure 6-1 shows a simplification of the program structure of SIVAK II with all Input, Network and Model parts, the Model itself and the Output. *Appendix 7; Program structure SIVAK II* contains a detailed description of the program structure of SIVAK II.

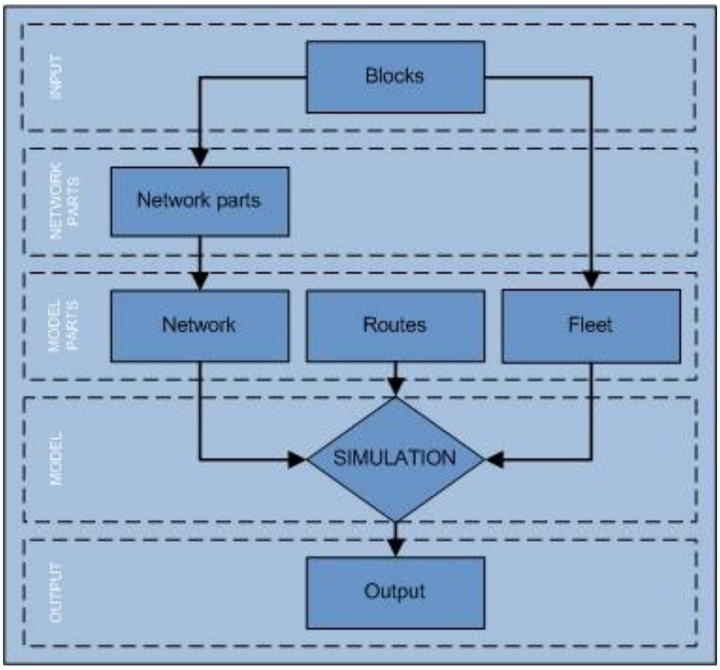


Figure 6-1: Simplification of the SIVAK II program structure

6.2.1 Blocks

The (input) Blocks contain lots of information needed to run the simulations. Therefore the creation of the Blocks is the first step to develop a simulation model. Underneath a window in SIVAK II is presented with all available types of Blocks.

For every model the blocks Arrival pattern, Ship Class, Ship Type, Fleet and Fleet share are input to create a Fleet for the simulation.
The blocks Chamber, Switch time correction, Locking regime, Lock, Passage time (lock), Waterway section are important in this research to create a network and to influence the behavior of the network and its navigations locks.

In the Lock-block characteristics of the locks and its regime can be inserted and thereby the behavior of the locks can be influenced. Important characteristics are Chamber priority, Locking method, Locking regime, Passage time parameters and of course the Chambers with their characteristics. Figure 6-3 presents the Lock-block window in SIVAK II with all the aspects that can be inserted.

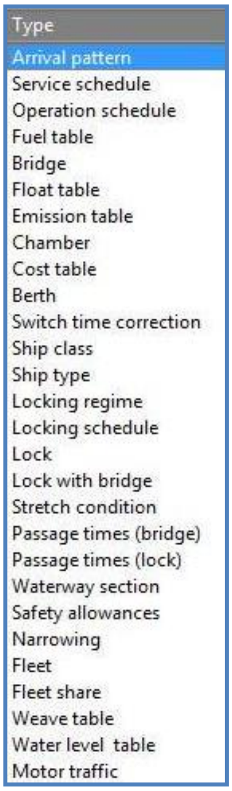


Figure 6-2: Available blocks in SIVAK II

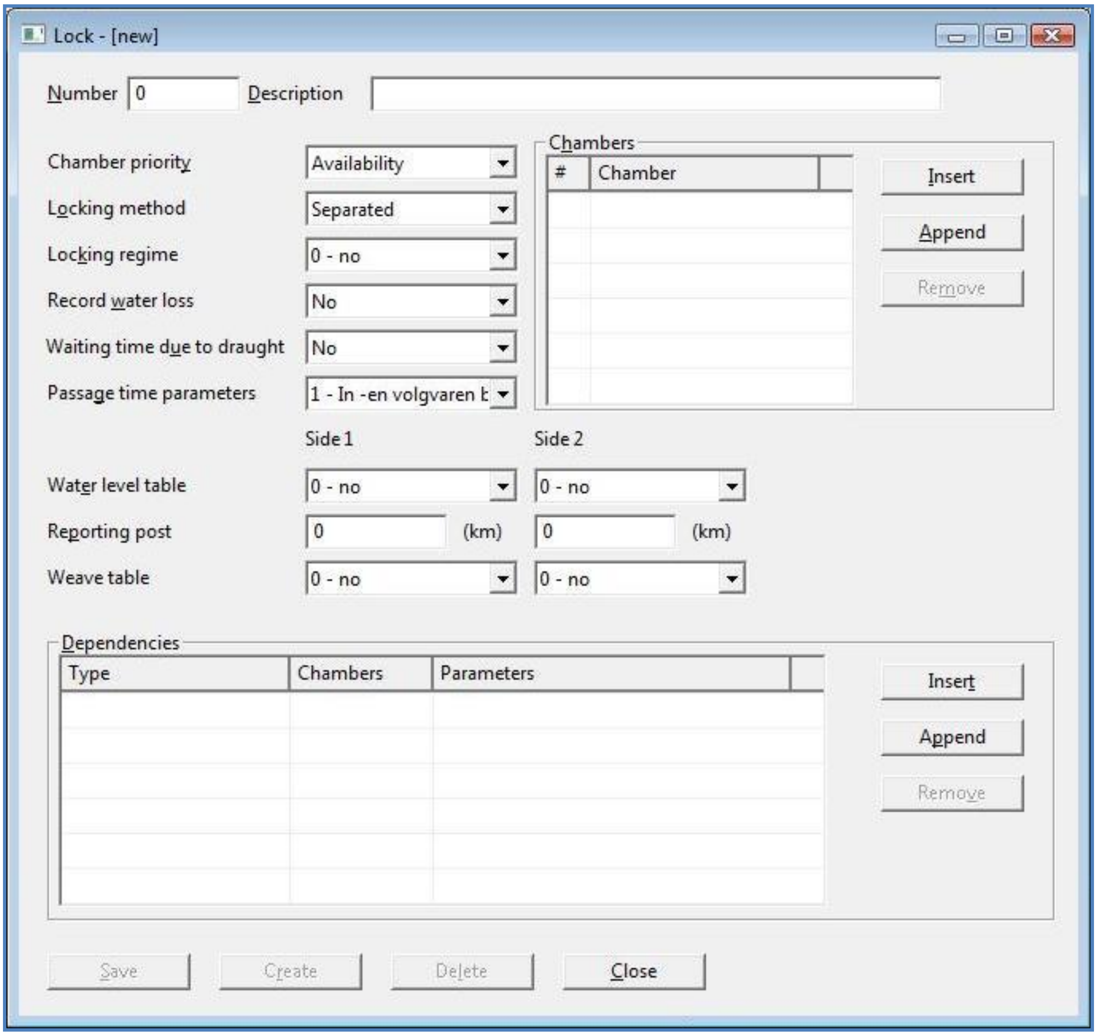


Figure 6-3: The window of the Lock-block in SIVAK II

6.2.2 Network

The creation of useful Blocks is followed by the creation of a network for the navigation flows. SIVAK II contains five standard network parts Narrowing, Waterway section, Lock, Lock with bridge and Bridge.

The process to develop a network which approaches reality as much as possible consists of several steps. The elements including the network have lots of impact on the behavior of the model because each element has its own characteristics and limitations.

The four obstacles, narrowing, lock, lock with bridge and bridge are connected with waterway sections. After completion of the network all routes on the network have to be created and extra information per route can be given. This supplementary information contains the maximum delay and depth per route and the alternative routes.

6.3 Specification of the Lorentz navigation locks-model

A simulation model always is an approach of reality. It is not useful to exactly copy the reality, so simplifications have to be made without harming the output.
There are three types of simplifications respectively Object classes and attribute characteristics, Time aspects and The process (Verbraeck, 2003). In sub-paragraph 6.3.1 these types are used to present the simplifications of the simulation model.

Another important aspect of the specification of a model is the data collection and analysis. For this research lots of different types of data collection are used.
First of all there is historical data which is mostly supplied by the Division Traffic and Navigation of the Dutch Directorate for Public Works and Water Management. This data contains navigation intensities, vessel dimensions and characteristics. Lots of this information comes from the IVS90 passage registration system. This system is installed on lots of objects along the major fairways in the Netherlands which makes it possible to follow vessels at their journeys through the Netherlands. This system includes information about the type of ship, time of passage and for professional navigation lots of other characteristics like the measurements of the vessels.
Secondly there are expert estimations collected with the usage of interviews. These experts are mainly employees of the Division Traffic and Navigation and the lockkeepers at the Lorentz locks. Data from expert estimations are process times; time needed to fill and empty a lock chamber with vessels, maximum waiting times and information about actions within the process.
Finally there is also some data collected by observations and from comparable systems. This is information about the time needed for leveling, open/close lock gates and the behavior of vessels at other navigation locks.

6.3.1 Simplifications and performance indicators

<u>Simplifications</u>

Object Classes and attribute characteristics:

- The assignment of vessel classes is randomly over all navigation taking in account the shares per vessel class.
- It is assumed that all vessels have a minimum speed of three kilometers per hour.
- Vessels do not overtake in the neighboring waterway sections of the locks.
- Opening and closing times of the lock gates are fixed per lock chamber.
- There is sufficient draught for all vessels on all network routes.
- The (small < 1%) class group "Remaining recreational navigation" is included in the class group “Motor/sailing ships > 20m".

Time aspects:

- The navigation intensities per hour are available but the distribution within the hour is randomly.

The process:

- The swing-swivel bridges at Kornwerderzand have no influence on the capacity of the navigation locks and are therefore excluded in this model.
- Vessels use the chamber which is available first.
- Professional navigation always uses the western lock chamber.
- The lock chambers are operated parallel, but in opposite directions.

Performance indicators

The most important performance indicators are the Passage time and the Loss time of the vessels. The Pass time is the time difference between the Actual Time of Departure (ATD) and the Actual Time of Arrival (ATA). The second indicator is the Loss time which is the difference in time between the Actual Time of Entrance (ATE) and the Actual Time of Arrival.

Passage Time = ATD-ATA
Loss time = ATE-ATA

ATE: Actual Time of Entrance
ATA: Actual Time of Arrival
ATD: Actual time of Departure

The Loss time includes the waiting time and demurrage time.

6.3.2 The model of the Lorentz navigation locks

As presented in Figure 6-1 the model consists of three main parts. These parts are the Fleet, the Network and the Routes.
The network part specifies the network parts and the total network. This includes information about the length, width, depth of the parts and maximum speed of the waterway sections. Structures like locks and bridges have supplementary information including (technical) operating times and guide jetty lengths.

Pentecost 2005, may 15th, is used as a test project in this research. The traffic intensities on this day are collected by using the tools of the Division Traffic and Navigation. An overview of this data is presented in Table 6-1 which immediately makes clear that there is an unequal spread of navigation over the day. This is a normal situation at the Lorentz locks during navigation season.

The Fleet

The Fleet part contains specific information for each vessel including the arrival time at the network route, the ship class, the dimensions, the speed, the load and if the vessel uses reservations or notifications.
For the Lorentz lock situation two Arrival patterns have to be created respectively navigation travelling from the IJsselmeer to the Waddenzee and vice versa. The distribution of the fleets over the day heading north and south are presented in Table 6-1.

The ships in the model are divided into four groups respectively;

- Professional navigation
- Motor ships < 20 meters (recreational)
- Sailing ships < 20 meter (recreational)
- Motor/sailing ships >20 meters (recreational)

During navigation season the shares of the class groups are 5, 6, 73 and 16 percent of the total passages at the Lorentz lock complex. The original navigation data includes a fifth group, remaining recreational ships, which has a share of the recreational navigation under 1%. (Ministerie Verkeer en Waterstaat & Centraal Bureau voor de Statistiek, 2003) This group includes charter ships[4], but is included in the "Motor/sailing ships > 20 meter group".

Table 6-1: Navigation intensities on Sunday may 15th 2005 per hour, per direction, at the Lorentz lock complex.

	# Navigation	
TIME	North	South
0	0	0
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	5	0
10	0	0
11	0	6
12	24	9
13	24	26
14	14	69
15	24	24
16	10	54
17	8	11
18	0	1
19	0	0
20	0	0
21	0	0
22	0	0
23	0	0
Total	109	200

[4] These are large, over 20 meters, (sailing) ships which sail with groups of tourist on the IJsselmeer and Waddenzee visiting neighboring harbors.

<u>The network</u>

The situation at Kornwerderzand and its Lorentz navigation locks is schematized within SIVAK II by the creation of four waterway sections and a navigation lock with two chambers. The four waterway sections are:

1. The IJsselmeer
2. An inner harbor on the IJsselmeer side
- **The Lorentz navigation locks**
3. An outer harbor on the Waddenzee side
4. The Waddenzee

Figure 6-4 shows the schematization of the network in the SIVAK II program compared with a view from above in reality.

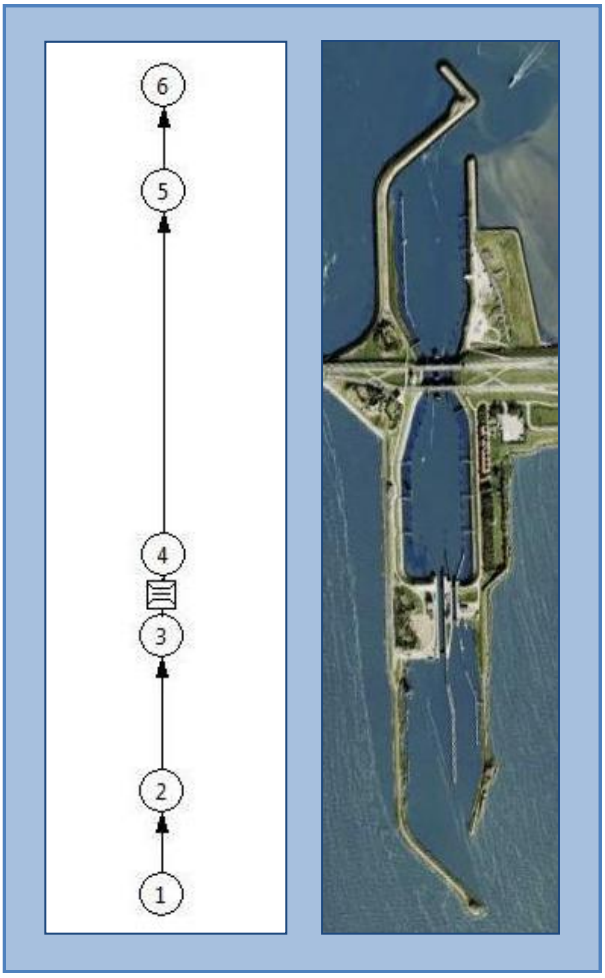


Figure 6-4: Comparison of the schematization of the network in the SIVAK II program with a view from above in reality.

The schematization does not include the swing-swivel bridges at Kornwerderzand because they have no, or very little, influence on the capacity of the Lorentz navigation locks.
Nevertheless there have been attempts during the development process of the model to include the bridges in the model. These attempts failed because it appeared to be impossible to approach the behavior of the Lorentz lock complex within the model. This is mainly caused by the fact that structures operate independently within SIVAK II and it's impossible to change, influence this sufficiently.

6.4 Behavior of the model

After construction of the model, simulations are run. The output of the simulations is used for validation and verification of the model or further adjustments.

6.4.1 Simulations within the model

In the Block Fleet navigation fleets are generated based on the blocks Arrival patterns, Ship classes and Fleet shares. Each route has its own fleet which consists of the departure time, ship class and belonging characteristics including width, length, height, speed per ship.

The fleets are "placed" into the network and cover their route through all waterway sections and structures. During the simulation the network and the ships in the network are visualized as shown in Figure 6-5.

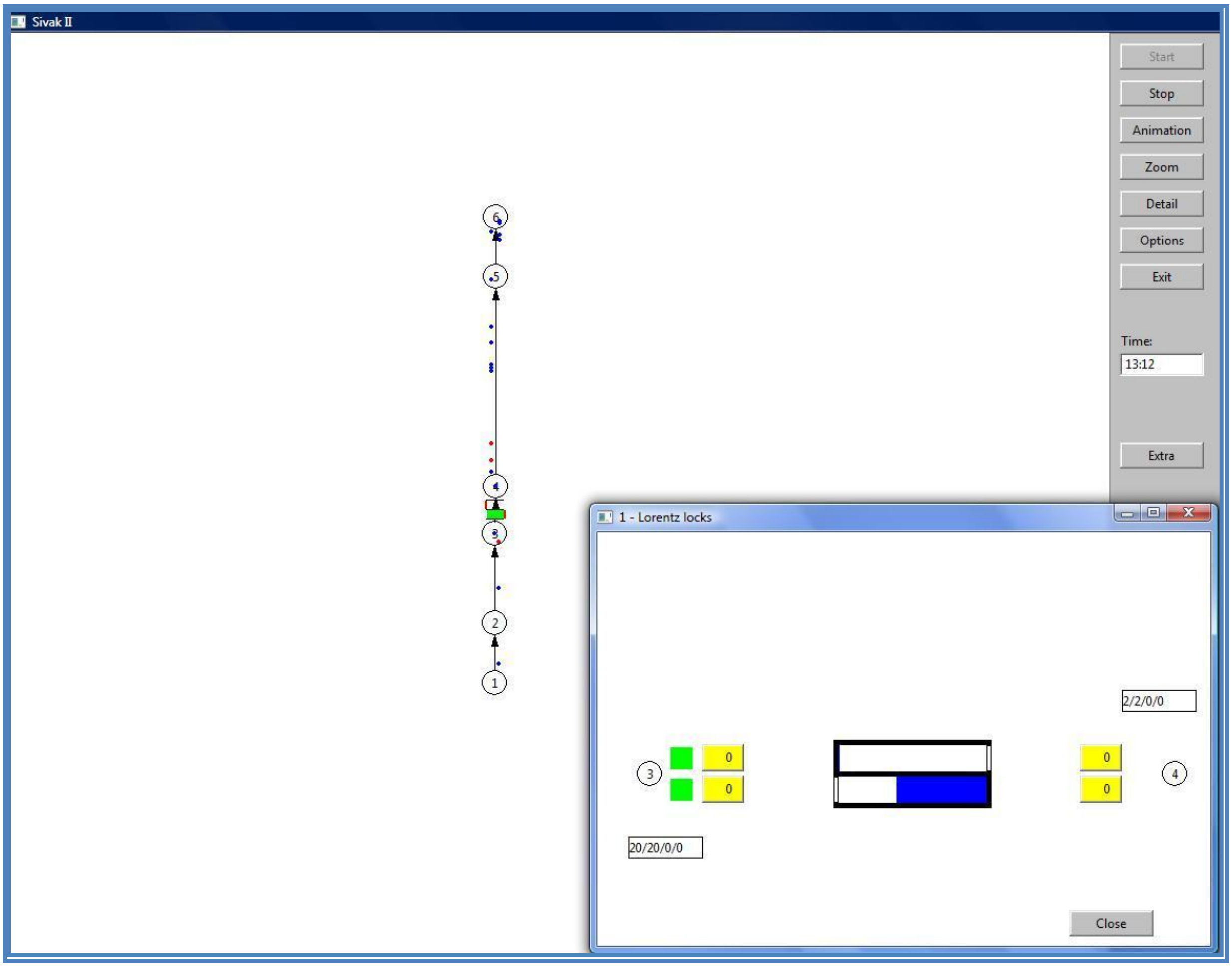


Figure 6-5: Network and detailed (lock) window in SIVAK II for visualization of a simulation

6.4.2 Output of the model

Because of the enormous amount of information within the simulation model it is impossible to present the output such that all questions concerning the simulated network can be answered in a standard way. Therefore a query-system is used which is based on the following saved information:

- The history of each simulated ship
- The configuration of the simulated system
- The data, characteristics, of each ship

Queries always refer to (parts of) route(s) between two nodes in the network and the ships using these routes. There are five types of queries available respectively Stretch, Bridge, Lock, Lock with bridge, Narrowing and Berth.
In this research the most important and challenging aspect of creating reality in the SIVAK modal is the behavior of the Lorentz locks in the network.

6.4.3 Verification and validation

After construction of the model the next steps are verification and validation. The goal of these steps is to take care that the simulation model resembles the reality.

<u>Verification</u>

Verification is needed that there are no errors in the models' software and that the software works properly. During verification is checked if the step from specification to the simulation model is correctly executed.
Verification checks specifically if the input variables and model-logic are coded correctly and if the output variables are calculated correctly. (Verbraeck, 2003)

- The input variables are exactly used as in reality or as described in the specification and no errors are occurring.
- The model-logic is coded correctly. The commands of a simulation run use the correct input on the correct locations and no errors occur.
- The output variables are comparable with the expected, historical, data and deviations can be explained by the decisions for the specification of the model.

<u>Validation</u>

Secondly there is a check to determine if the model is a correct representation of reality. This check is the validation of the model and determines if the model is representative for reality.
There are two ways to validate:

- Replication validation
  This type of validation is the comparison between the output of the model and actual, historical, data in reality.

- Structural validation
  It is not only sufficient for the model to resemble reality, because it can also be used to study alternatives. Therefore the model has to respond on changes of the input variables, so the models' response to impulses is checked.

For the replication validation the following output is compared with historical data:

- The number of lock cycles
- The cycle times
- The amount of vessels per day and per direction
- The amount of vessels per lock chamber
- The amount of covered surface by vessels in the lock chamber
- The vessel classes per lock chamber
- The position of vessel classes in the lock chamber
- The passage and loss times

All output data is similar to the historical data and (small) differences are caused by the decisions made during the specification of the model and do not decrease the usefulness of the model.

The structural validation is based on the reaction of the model on impulses. Therefore the input data of extreme simulations is inserted and the response of the model and its output is as expected which is acceptable.

6.5 Case Study; Scenarios 2005, 2006 and 2007

Previous paragraphs described the specification, verification and validation of the model. After these actions the model for the Lorentz locks is ready to simulate scenarios and experiments can be carried out. In this paragraph the scenarios for 2005, 2006, 2007 en 2020 are simulated.

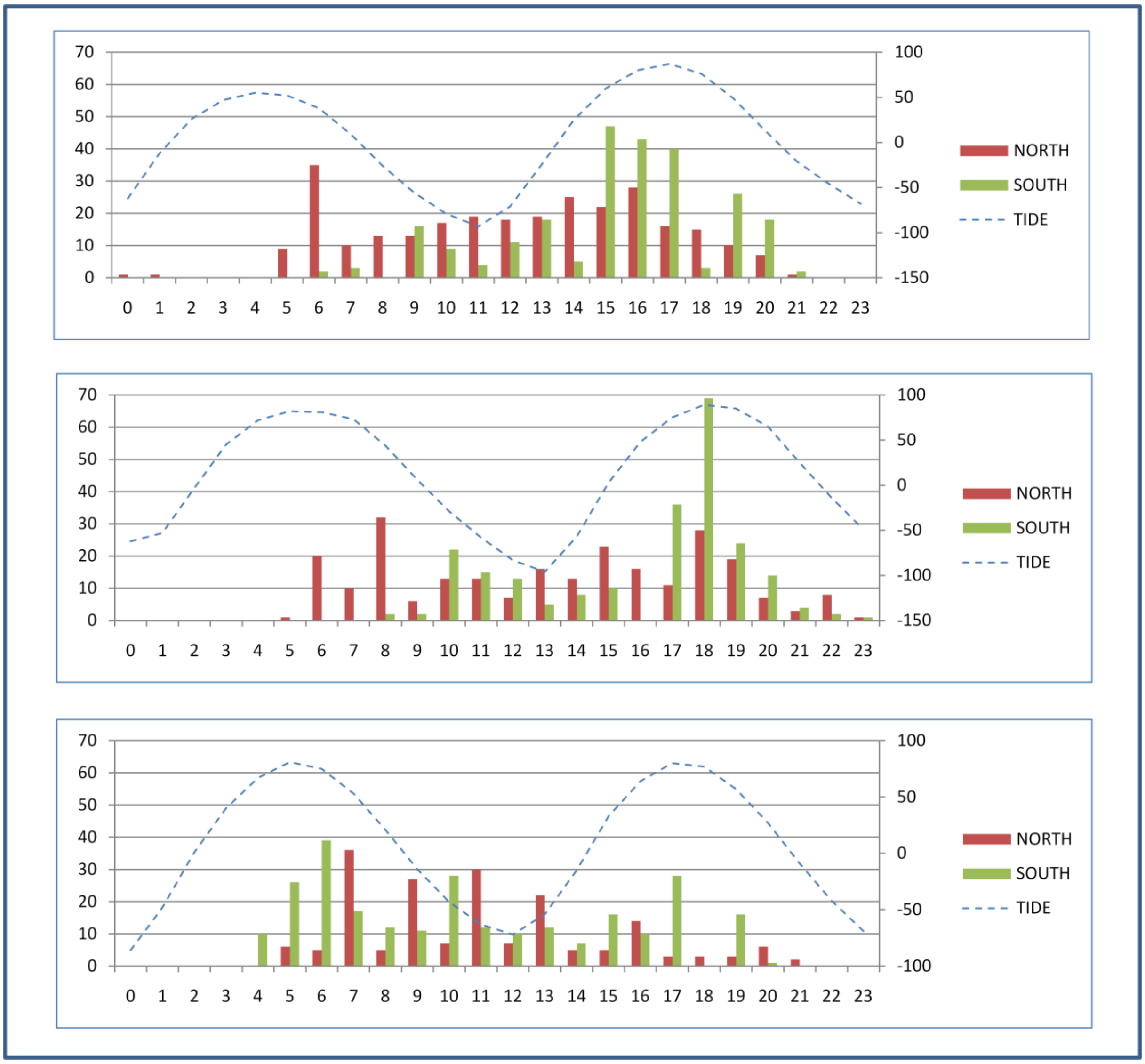


Figure 6-6: Navigation per hour and direction for the 10th busiest day in 2005, 2006 and 2007

The years 2005 until 2007 are simulated to determine the current situation at the lock complex at Kornwerderzand. The amount of congestion, loss time, in these years is compared with the guidelines for fairways 2005 to create an objective stand on the congestion issue of the Afsluitdijk.

- The standard, guidelines, for the total waiting time[5] of navigation at navigation locks on the main fairways:

  The average total waiting time for professional navigation in the defining month has a maximum of 30 minutes.
  The total waiting time for recreational navigation is at most one hour on the 10th busiest day of the season. (Ministerie Verkeer en Waterstaat, 2006)

The three 10th busiest days of the navigation seasons 2005, 2006 and 2007 were:

- Monday 18th of July 2005
- Friday 23rd of June 2006
- Saturday 25th of August 2007

Table 6-2: Maximum and average Loss and Passage times on 10th busiest days of the navigation season in 2005, 2006 and 2007

Year	2005		2006		2007	
Time (min)	Loss	Passage	Loss	Passage	Loss	Passage
Maximum	**219**	238	**186**	201	**75**	88
Average	50	64	48	62	28	41

Table 6-2 presents the maximum and average Passage and Loss times over the normative days in the years 2005, 2006 and 2007. According the guideline for recreational navigation the maximum total waiting time (Loss time) must be one hour. In the year 2005 this is over three and a half hours, in 2006 over three hours and in 2007 the maximum Loss time is hour and fifteen minutes!

The conclusion of this case study:

The Lorentz navigation locks do not meet the guidelines with regard to the total waiting times.

The figures show a decrease of the Loss and Passage times over the years 2005, 2006 and 2007. Unfortunately this is purely coincidence based on the weather during the navigation season and the distribution of navigation over the navigation season. This results in less passages and a more equal spread of the passage over the season.

[5] The total waiting time is the same as the Loss time; the sum of the waiting time and demurrage time.

6.6 The effect of possible improvements

In previous chapters 5 and 6 several adjustments are presented to reduce the congestion of navigation. The effects of these adjustments on waiting and passage times are determined with the usage of the simulation model and the case studies presented in previous paragraph 6.5 are used as a verification point.

The effects of the following improvements are quantified in this paragraph:

A. Technical, operational improvements
   Upgrade the small, eastern, lock of the Lorentz lock complex at Kornwerderzand to the level of the bigger, western, lock. In this way two identical locks are created which can operate parallel because they have the same characteristics.

B. Improved behavior of recreational navigation
   Improve the navigation behavior of recreational skippers. This results in an estimate reduction of ten percent of the times needed for entering, leaving lock chambers and mooring.

C. A more equal distribution of navigation over the day
   The travel advices explained in paragraph 5.5 result in more equally distributed navigation intensities over the day. An overview of the more equal distributions is presented in *Appendix 8; Equally distributed navigation intensities over the 10th busiest days in 2005, 2006 and 2007.*

	Year	2005		2006		2007	
	Time (min)	Loss	Passage	Loss	Passage	Loss	Passage
Benchmark	Maximum	219	238	186	201	75	88
	Average	50	64	48	62	28	41
A	Maximum	110	146	124	140	113	152
	Average	24	49	26	52	12	44
B	Maximum	190	208	172	190	66	78
	Average	42	56	43	56	25	37
C	Maximum	187	205	181	195	88	104
	Average	50	64	47	60	26	38

Figure 6-7: The effects of possible improvements on the Loss and Passage times.

6.6.1 Evaluation of the effects

Upgrading the small, eastern, lock has in general a positive effect on the Loss and Passage times. The (average) Loss times are reduced up to 50% and the impact on Passage times seems a bit smaller.
The year 2007 shows an increase (!) of maximum Passage and Loss times. Bigger locks can accommodate more vessels, but the entrance and exit of more vessels takes more time which result in longer cycle times. This means that a vessel on demurrage easily has lots of Loss time and with that Passage time. On the other hand the chance of demurrage is smaller, because more vessels can enter during one lock cycle. This aspect can explain the high maximum Loss, Passage times and the low average Loss time in 2007.

The improved behavior of navigation is the only improvement which has a positive effect on all Loss and Passage times in all years. The effect of the improvement is very clear. It is assumed that a ten percent reduction of the times needed for entering, leaving lock chambers and mooring is possible. This ten percent reduction is also the effect on all Loss and Passage times in all years.

A more equally distribution of navigation over the day has in general a small positive effect on the Loss and Passage times. The fact that the effect is small probably arises from structural lack of lock capacity during those busy days in 2005, 2006 and 2007. When there is structural insufficient capacity it doesn't matter when navigation arrives, because they all have to wait. In less busy periods a more equal distribution could have more effect.

6.7 Conclusions

According the guideline for recreational navigation the maximum total waiting time (Loss time) must be one hour. In the year 2005 this is over three and a half hours, in 2006 over three hours and in 2007 the maximum Loss time is hour and fifteen minutes. Therefore the conclusion of the case study is that the Lorentz navigation locks do not meet the guidelines with regard to the total waiting times.
Previous chapters 0 and 5 have presented three possibilities to reduce the congestion for navigation. These possible improvements are technical, operational improvements, improved behavior of recreational navigation and a more equal distribution of navigation over the day.
Improving the behavior of recreational navigation can result in a ten percent reduction of the maximum waiting time. A more equal distribution of the navigation supply at the navigation lock can reduce the maximum waiting time up to fifteen percent, but in general has less effect. The most effect has "upgrading the eastern navigation lock" with a reduction of the maximum waiting times up to 50 percent.

In this chapter the current amount of congestion and the effect of improvements on the waiting times for navigation became clear. In the next chapter, chapter 7, the focus shifts to the summated congestion for road traffic when they have to wait at both lock complexes. Eventually possibilities to prevent summated congestion for road traffic will be presented.

7 Analysis of the congestion for road traffic on the Afsluitdijk

Previous chapters 5 and 6 mainly focused on the navigation at the Lorentz lock complex at Kornwerderzand. In this chapter the focus shifts to the congestion problem for road traffic. To structure this chapter a distinction is made between the local congestion problem at the Lorentz lock complex and the combined congestion of both lock complexes at Kornwerderzand and Den Oever.

7.1 Local congestion for road traffic at the lock complexes

This paragraph pays attention to the local congestion for road traffic at the Stevin and Lorentz lock complexes at Den Oever and Kornwerderzand respectively. First the components influencing the amount of congestion are described followed by overviews of the characteristics of the waiting queues at Den Oever and Kornwerderzand. The characteristics include the duration of the bridge openings, the time needed to clear the queue, number of vehicles in the queue and the length of the queue.

7.1.1 The components influencing the queuing

The amount of local congestion is influenced by five components. These components are;

- The composition of the road traffic
- The number of lanes
- The saturation flow
- The intensity of the road traffic
- The duration of a landside bridge opening

<u>The composition of the road traffic</u>
Sub-paragraph 2.6.1 already presented the two types road traffic using the Afsluitdijk. First of all there are the passenger cars with a minimum share of 80 percent of the total road traffic and secondly there is the remaining freight traffic with a maximum share of twenty percent.

<u>The number of lanes</u>
The A7 national highway is two times two highway, so there are two lanes available per direction. At the lock complex there is insufficient space to meet the guidelines for the design of highways, so the width of the lanes is (only) three meters. This lack of space has consequences for the saturation flow.

<u>The saturation flow</u>
The saturation flow is the maximum number of vehicles that can pass the stop line of a single lane within an hour. The basic saturation flow is 1800 pcu/h, where pcu stands for 'passenger car unit'. Since lorries, busses and vans need more time than ordinary cars, they have a higher pcu value than 1,0. The saturation flow is affected by geometric and traffic conditions such as lane width, parked vehicles, turning movements etc. (Van Zuylen, 2007)

The road infrastructure at the lock complexes of the Afsluitdijk has a saturation flow of 3079 pcu/h. The calculation of this saturation flow is presented in *Appendix 9; Calculation of the saturation flow.*

The intensity of the road traffic

For the analysis of the congestion for road traffic the intensities of the road traffic in both directions are collected. The intensities from Den Oever to Kornwerderzand vary from 22 to 1157 vehicles per hour and for Kornwerderzand the variation is between 24 and 1030 vehicles per hour in the month July 2008 (Rijkswaterstaat, 2008).

The duration of a landside bridge opening

The durations of a landside bridge opening depends on the time needed for navigation to pass the bridge and the time needed to open, close the bridge and stop, allow road traffic. The interaction between these components is elaborately described in the Conflict Arena presented in chapter 0.
Based on data from the Dutch Directorate for Public Works and Water Management the duration of bridge openings at Den Oever varied from 2 to 13 minutes in July 2005. At Kornwerderzand there was a variation between two and a half and 14 minutes in this period.

Three of the five components determining the congestion are assumed to be fixed in this research. These components are the composition of the road traffic, the number of lanes and the saturation flow. The two remaining, and variable, components are the intensity of the road traffic of the landside bridge openings and thereby they determine the queuing and amount of congestion at the Afsluitdijk. The impact on, and relation between, the components and the congestion is presented in following (sub)-paragraphs.

7.1.2 Characteristics of the waiting queues at the lock complexes

All components presented in previous sub-paragraph 7.1.1 determine the queuing of road traffic at the swing-swivel bridges in the Afsluitdijk, but the intensity of the road traffic and duration of the bridge openings are the only two variables.
For the analysis of the queuing of road traffic assumptions are made. The first assumption is that freight traffic has an average passenger car unit value (pcu) of 2,0. Secondly the length of passenger cars is assumed to be seven meters. The third assumption is that vehicles arrive in a uniform way, with equal gaps between two vehicles. And finally there is the assumption that the queue does not continue to grow during the green phase when the bridge is free for road traffic again.
Important characteristics of the local congestion at the lock complexes are the maximum queue length and the time, after the start of a green phase, to clear a waiting queue. The following formula is used to determine the maximum queue length (Van Zuylen, 2005);

$$\text{Lqueue} = \text{Topen} \cdot \text{q} \cdot \text{Lpcu} \qquad [2]$$

Topen	The effective duration of a landside bridge opening (hour)
q	Intensity road traffic (pcu/hour)
Lpcu	Length of a passenger car unit

Table 7-1: Maximum queue length (m) as a result of the road traffic intensity and duration of a landside bridge opening.

Duration bridge opening (min)

Intensity road traffic (veh/h)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
150	11	22	33	45	56	67	78	89	100	112	123	134	145	156
200	15	30	46	61	76	91	106	121	137	152	167	182	197	213
250	19	39	58	78	97	116	136	155	174	194	213	233	252	271
300	24	48	71	95	119	143	166	190	214	238	262	285	309	333
350	28	57	85	113	142	170	199	227	255	284	312	340	369	397
400	33	66	100	133	166	199	232	265	299	332	365	398	431	464
450	38	76	115	153	191	229	267	306	344	382	420	458	497	535
500	43	87	130	174	217	261	304	348	391	435	478	522	565	609
550	49	98	147	196	245	294	343	392	441	490	539	588	637	686
600	55	110	164	219	274	329	384	439	493	548	603	658	713	767
650	61	122	183	244	305	366	427	487	548	609	670	731	792	853
700	67	135	202	270	337	404	472	539	606	674	741	809	876	943
750	74	148	223	297	371	445	519	593	668	742	816	890	964	1039
800	81	163	244	325	407	488	570	651	732	814	895	976	1058	1139
850	89	178	267	356	445	534	623	712	801	890	979	1068	1157	1246
900	97	194	291	388	485	582	679	776	873	970	1067	1164	1261	1358
950	106	211	317	422	528	634	739	845	950	1056	1161	1267	1373	1478
1000	115	229	344	459	573	688	803	918	1032	1147	1262	1376	1491	1606
1050	124	249	373	498	622	746	871	995	1120	1244	1368	1493	1617	1742
1100	135	270	404	539	674	809	943	1078	1213	1348	1482	1617	1752	1887
1150	146	292	438	583	729	875	1021	1167	1313	1459	1605	1750	1896	2042

For road traffic at the Afsluitdijk and the swing-swivel bridges at Den Oever and Kornwerderzand Table 7-1 gives an overview for all possible combinations of intensities and duration of the bridge opening in respect of the queue length.
The next step is to determine the time to clear a waiting queue. This is done by using the following formula (Van Zuylen, 2005);

$$\text{Tqueue} = \text{Topen} \cdot q \,/\, (s - q) \qquad [3]$$

Topen	The effective duration of a bridge opening (hour)
q	Intensity road traffic (pcu/hour)
s	Saturation flow (pcu/hour)

In Table 7-2 an overview off all possible combinations of intensities and duration of the bridge opening in respect of the time to clear a waiting queue is presented.

Table 7-2: Time to clear a waiting queue as a result of the road traffic intensity and duration of a landside bridge opening.

Intensity road traffic (veh/h)	Duration bridge opening (min)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
150	0	0	0	0	0	0	0	1	1	1	1	1	1	1
200	0	0	0	0	0	1	1	1	1	1	1	1	1	1
250	0	0	0	0	1	1	1	1	1	1	1	1	1	2
300	0	0	0	1	1	1	1	1	1	1	2	2	2	2
350	0	0	1	1	1	1	1	1	2	2	2	2	2	2
400	0	0	1	1	1	1	1	2	2	2	2	2	3	3
450	0	0	1	1	1	1	2	2	2	2	2	3	3	3
500	0	1	1	1	1	2	2	2	2	3	3	3	3	4
550	0	1	1	1	1	2	2	2	3	3	3	3	4	4
600	0	1	1	1	2	2	2	3	3	3	4	4	4	5
650	0	1	1	1	2	2	3	3	3	4	4	4	5	5
700	0	1	1	2	2	2	3	3	4	4	4	5	5	6
750	0	1	1	2	2	3	3	4	4	4	5	5	6	6
800	0	1	1	2	2	3	3	4	4	5	5	6	6	7
850	1	1	2	2	3	3	4	4	5	5	6	6	7	7
900	1	1	2	2	3	3	4	5	5	6	6	7	7	8
950	1	1	2	2	3	4	4	5	6	6	7	7	8	9
1000	1	1	2	3	3	4	5	5	6	7	7	8	9	9
1050	1	1	2	3	4	4	5	6	7	7	8	9	10	10
1100	1	2	2	3	4	5	6	6	7	8	9	10	10	11
1150	1	2	3	3	4	5	6	7	8	9	9	10	11	12

The total local congestion at the lock complexes is the sum of the duration of a bridge opening and the time to cleat a waiting queue.

7.2 The congestion of road traffic at Den Oever and Kornwerderzand

Besides the local congestion at the lock complexes separately, there is also the possibility of accumulated congestion when road traffic has to stop at both lock complexes. This problem is elaborately described in sub-paragraph 1.1.2 and this paragraph contains and analysis of the problem and possible solutions to prevent summated congestion of road traffic.

7.2.1 The difference in arrival times between the first and last vehicle.

To prevent summated congestion the travel times for road traffic between the swing-swivel bridges has to be determined. In this case road traffic is specified to traffic which already experienced congestion at previous lock complex.

Requirement to prevent summated congestion:

> *All traffic queued up at a lock complex travels to the other side of the Afsluitdijk and the swing-swivel bridges at that other, receiving, side have to be closed when they arrive.*

To determine the time period the bridges on the other side have to be closed, the difference between the first and last arrival times of vehicles in the queue have to be calculated. The difference in arrival times is determined by the distance between the bridges, the length of the queue, the time to clear the queue and the speeds of the vehicles.

$$\Delta Taf = \frac{Laf + Lqueue}{V2} + Tqueue - \frac{Laf}{V1} \quad [4]$$

Laf	Distance between the bridges at Den Oever and Kornwerderzand
Lqueue	Maximum length of the waiting queue
V2	Maximum speed of the last vehicle in the queue
Tqueue	The time needed to clear the waiting queue
V1	Maximum speed of first car in the queue

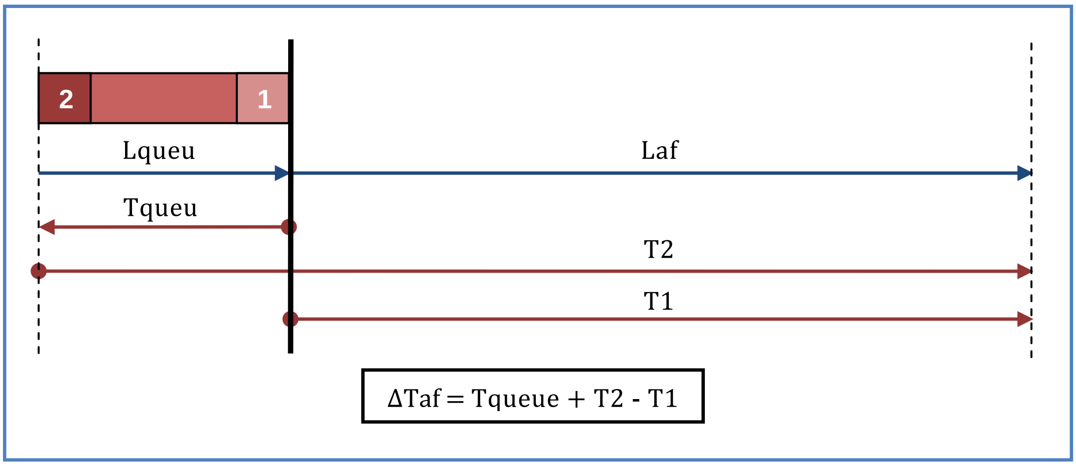


Figure 7-1: Visualization of the difference in arrival times

The worst situation is the situation with the biggest difference between arrival times, because the locks (and bridges) on the other side have minimum time for their own operations. Nevertheless this situation is normative, so the consequences of this worst case scenario are determined.

Characteristics of the worst case scenario:

- There is a fast passenger car in front of the queue
- There is slow freight traffic at the back of the queue.

In this situation most of the input to calculate the difference in arrival times is known. The distance between the bridges is about 26 kilometers (ANWB, 2008). The maximum speed for passenger cars is 120 km/h and for freight traffic 80 km/h. The unknown variables are the length of the queue and the time needed to clear the queue. In previous sub-paragraph 7.1.2 is already determined that these unknown variables again depend of the intensity of the road traffic and the duration of bridge opening. Therefore the relationship between the road traffic intensity, duration of a bridge opening and the difference in arrival times is presented in

Table 7-3: Difference in arrival times first and last vehicle at the other lock complex as a result of the road traffic intensity and duration of a landside bridge opening.

Duration bridge opening (min)

Intensity road traffic (veh/h)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
150	7	7	7	7	7	7	7	7	7	7	7	7	7	8
200	7	7	7	7	7	7	7	7	7	8	8	8	8	8
250	7	7	7	7	7	7	7	8	8	8	8	8	8	8
300	7	7	7	7	7	7	8	8	8	8	8	8	9	9
350	7	7	7	7	7	8	8	8	8	8	9	9	9	9
400	7	7	7	7	8	8	8	8	8	9	9	9	9	10
450	7	7	7	8	8	8	8	9	9	9	9	10	10	10
500	7	7	7	8	8	8	9	9	9	9	10	10	10	11
550	7	7	7	8	8	8	9	9	9	10	10	10	11	11
600	7	7	8	8	8	9	9	9	10	10	11	11	11	12
650	7	7	8	8	9	9	9	10	10	11	11	11	12	12
700	7	7	8	8	9	9	10	10	11	11	11	12	12	13
750	7	7	8	8	9	9	10	10	11	11	12	12	13	13
800	7	8	8	9	9	10	10	11	11	12	12	13	14	14
850	7	8	8	9	9	10	11	11	12	12	13	14	14	15
900	7	8	8	9	10	10	11	12	12	13	14	14	15	16
950	7	8	9	9	10	11	11	12	13	14	14	15	16	16
1000	7	8	9	10	10	11	12	13	13	14	15	16	16	17
1050	7	8	9	10	11	11	12	13	14	15	16	16	17	18
1100	7	8	9	10	11	12	13	14	15	15	16	17	18	19
1150	7	8	9	10	11	12	13	14	15	16	17	18	19	20

The maximum difference in arrival times is 20 minutes with a road traffic intensity of 1150 vehicles per hour and 14 minutes duration of the bridge opening.
The travel time for slow 80 km/h traffic is about 20 minutes from one side to the other, but the length of the queue can take an extra minute of travel time. Fast, 120 km/h, traffic only takes 13 minutes to cross the Afsluitdijk, so there is a difference between the travel times of about seven minutes.
The remaining difference in arrival times is a result of the times needed to clear the waiting queue which are presented in Table 7-2. In the situation with a maximum difference in arrival times, the time to clear the queue takes about nine minutes.

7.2.2 Possibilities to reduce the difference between arrival times:

The difference between arrival times on the other, receiving, side of the Afsluitdijk has lots of impact on the bridge operations. It is desirable to make this difference as small as possible to increase the time space for bridge operations. Therefore this sub-paragraph presents three possibilities to reduce this time difference within this research.

1. Lowering maximum speed to 100 km/h
   When the maximum speed is lowered to 100 km/h the difference in speed with the freight traffic is reduced with 20 km/h and thereby the difference in travel, and arrival, times is reduced.

2. No guarantee of a free passage for freight traffic
   By not guaranteeing a free passage for freight traffic the speed of all vehicles included is equal to 120 km/h, so there is no difference in speed and thereby the difference in arrival times increases.

3. Implementing ODYSA®
   ODYSA® (Optimalisatie Door Dynamische SnelheidsAdvisering) is a traffic management system which optimizes the traffic flows by giving dynamic speed advice. In this case the vehicles in front of the queue get an advice of 100 km/h and at the back of the queue the advice is 120 km/h. Because freight traffic has a maximum speed of 80 km/h they cannot be included within this system.
   Appendix 10; ODYSA® gives a detailed description of the system but unfortunately this description is only available in Dutch.

The first two possibilities are decisions policy makers have to make and the third possibility is a technical solution to compact the platoon of vehicles. Until now, this system has only been implemented on 80 km/h roads, but the system is suitable for utilization on the Afsluitdijk. The differences in travel times after implementation of the three possibilities described before, are presented in *Appendix 11; Effects of the possibilities to reduce the difference between arrival times*

7.2.3 Two scenarios of bridge operations

At the moment the swing-swivel bridges at Kornwerderzand and Den Oever are operated independently, but to prevent summated congestion there needs to be interaction. Paragraph 7.2 already presented the impact of the intensity for road traffic and duration of the bridge opening on the queuing of road traffic in front of the bridges, but concerning the interaction between the bridges also the frequency of bridge openings has to be taken into account.

Because of that, two scenarios are created to determine the feasibility of interaction between the bridges at the Stevin and Lorentz lock complex at Den Oever and Kornwerderzand respectively. In reality it never happens that the longest duration of bridge openings happens simultaneously with the highest frequency of bridge openings.
Normally long durations of bridge openings result from high amounts of vessels which have to pass the bridges. When lots of vessels need to pass the bridges, they also need to pass the navigation locks and when the supply of vessels is high, lock cycle time increases. As a result of the increased lock cycle time the frequency of lock cycles and with that bridge openings decreases.

Therefore the following two scenarios are distinguished:

- **Scenario 1:** An average frequency of bridge openings with a long duration of bridge opening. The average frequency is half an hour between bridge openings. The long duration is determined at 11 minutes.

- **Scenario 2:** An average duration of the bridge opening and high frequency of bridge openings. The average duration of the bridge opening is 6 minutes for the bridges at both sides. The high frequency is a result of only 15 minutes between bridge openings.

These values for the frequencies and durations of bridge openings are based on the distribution of the time between bridge openings and duration of bridge openings. The distributions are presented in *Appendix 12; Distribution Time between and Duration bridge openings.* The maximums are based on approximately 95% of the distributions and the average on the 50% points of the distributions.

The intensity of road traffic is for both scenarios determined at 800 vehicles per hour. This is approximately the 90 percent point of the distribution of the road traffic intensities. This means that about ninety percent of the intensities for road traffic are lower than 800 vehicles per hour. The complete distribution of the road traffic intensities, in both directions, is presented in *Appendix 13; Distribution of the road traffic intensities.*

7.2.4 Possibilities to prevent summated congestion

As mentioned before interaction between the bridges is needed to prevent summated congestion for road traffic. Therefore the following three interaction methods are described and investigated in this sub-paragraph.

- Bridge priority is determined by the navigation supply.
- Parallel bridge openings at Den Oever – Kornwerderzand with the implementation of a service schedule for the bridge.

Bridge priority is determined by the navigation supply

Navigation arrives at a lock complex and the bridges have to be opened to let the vessels pass. At the start of the bridge opening a message goes to the receiving side of the Afsluitdijk with the starting time of the opening and an estimated duration of the bridge opening.
With this information the lockkeepers on the receiving side can estimate when the first vehicle arrives and for how long their bridge has to stay closed. With this information they can start to anticipate, make the lock complex ready and try to minimize the delay for navigation.
When the bridge is closed at the other side a new message goes to the receiving lockkeepers. This message contains the bridge closure time, so they know that the first vehicle will arrive in 13 minutes and they can make final adjustments. Perhaps also a more accurate estimation of the length of the waiting queue can be communicated to determine for which time period the receiving bridge has to stay closed.

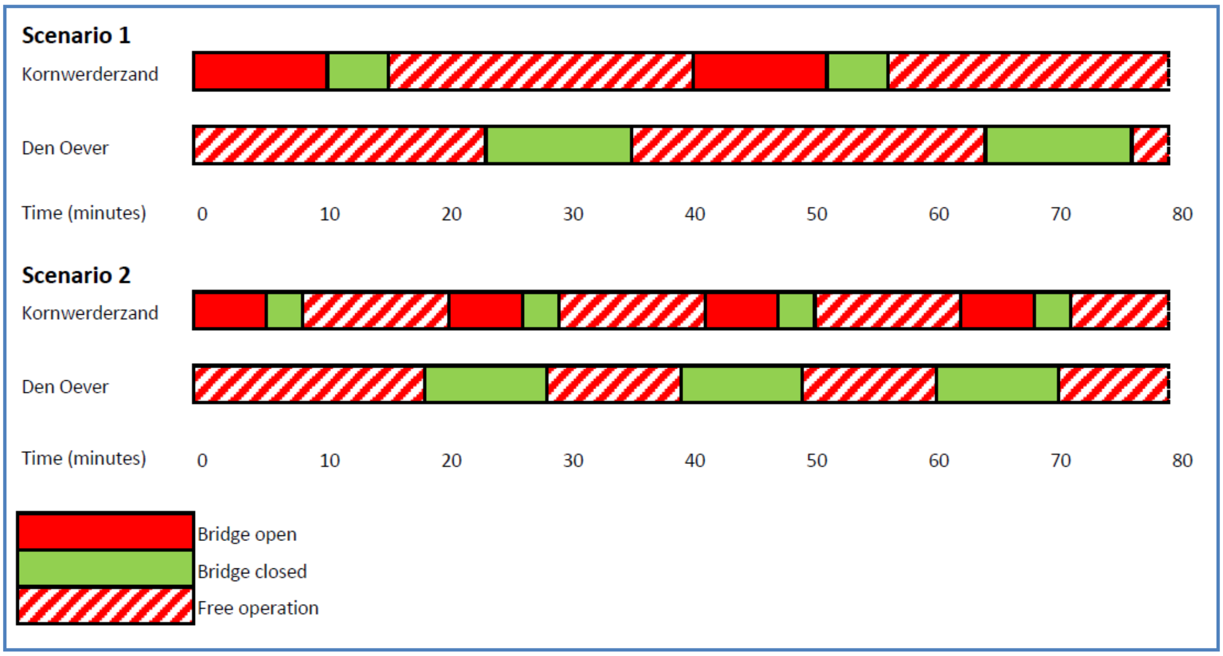


Figure 7-2: Example of bridge priority determined by navigation supply in scenarios 1 and 2

Simultaneous bridge openings with a service schedule and exclusion of freight traffic

In this type of interaction navigation is not determinative because the bridges are always operated simultaneously. In this manner conflicts are avoided because traffic from the other side can not arrive during a bridge opening. This type of interaction functions as long as the time between bridge openings is longer than the travel time to the other side plus the difference in arrival times. Unfortunately this is not the case in the second scenario therefore a possibility to reduce the difference in arrival times has to be used.
In this situation it is decided to not guarantee a free passage for freight traffic which reduces the differences between arrival times from twelve to six minutes for the first scenario and from ten to three minutes for the second scenario. Unfortunately the frequency of scenario 2, 15 minutes between bridge openings, still cannot be reached by one minute.

In this situation the starting time of bridge openings is fixed, so a service schedule for navigation has to be created. Of course there will be some extra delay for navigation, but this will be little because of the unique layouts of the Stevin and Lorentz lock complex. This layout with an outer harbor between the locks and the bridges enables the lockkeepers to continue the locking process and use the outer harbor as a buffer for navigation.

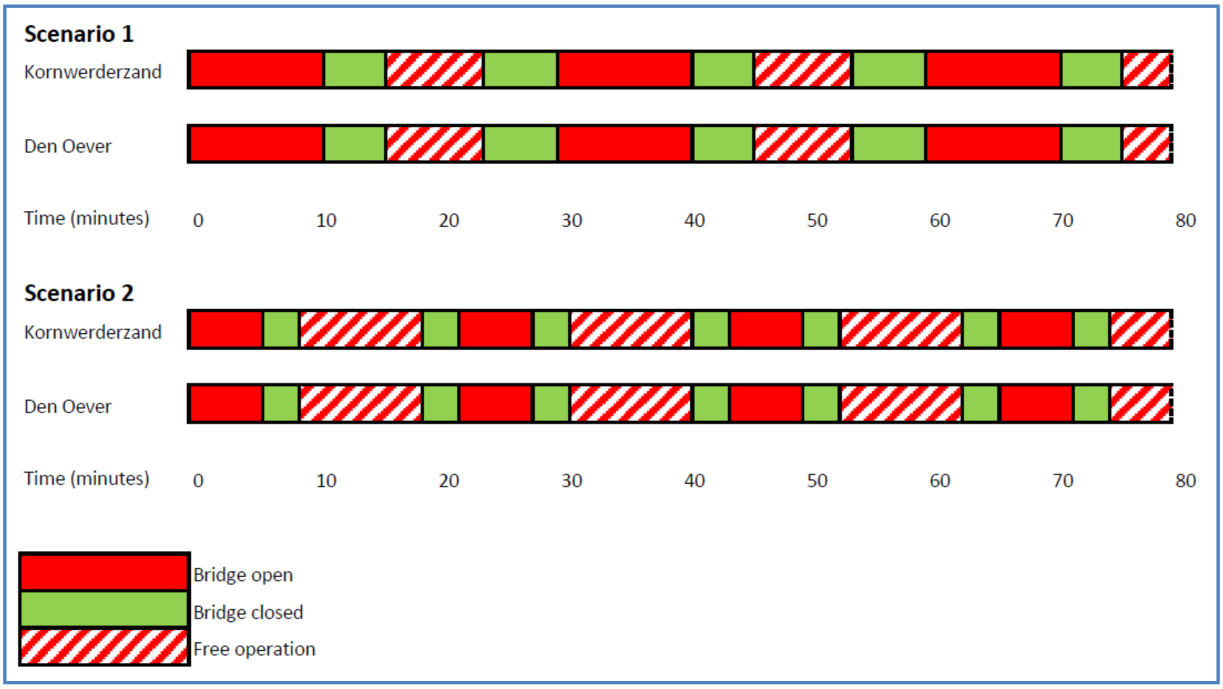


Figure 7-3: Example of simultaneous bridge openings in scenarios 1 and 2

Implementation of a dynamic traffic management system.

The entire queuing process and local waiting times are determined by two variables; the intensity of the road traffic and the duration of the bridge opening. Therefore the summated congestion problem is determined by these two variables.
It is practically and technological possible to design and implement a traffic management system which automatically detects the length of the waiting queues, or the intensity of the road traffic and herewith determines the time to clear the queue, the arrival times of the first and last vehicle of the queue on the other side of the Afsluitdijk and the time difference between these arrival times.
With the help of such a system the lockkeepers know exactly when they can or cannot open the bridges to prevent summated congestion for road traffic on the Afsluitdijk. Advantages of such a system is that there is no communication necessary between the independent control towers and there is no, or little, time lost because all times are determined more accurate.
Within a traffic management system the ODYSA® system can easily be integrated. This system compacts the platoon of vehicles and consequently reduces the difference in arrival times. The system is able to reduce the differences between arrival times from twelve to three minutes for the first scenario and from six to one minute for the second scenario. This way an integrated traffic management system creates maximum time to operate the bridges at the Afsluitdijk.

Nevertheless there will always be situations when a decision has to be made between delay for road traffic or navigation… Even with the implementation of dynamic traffic management system.

7.3 Conclusions

The queuing process and local waiting times for road traffic are determined by five components. These components are the composition of the road traffic, the number of lanes of the A7 highway, the saturation flow, the intensity of the road traffic and the duration of a landside bridge opening.
The first three components are assumed fixed in this research, which implies that there are only two variables determining the amount of congestion at a lock complex. These variables are the intensity of the road traffic and the duration of a landside bridge opening.

Besides the local congestion at the lock complexes separately, there is also the possibility of accumulated congestion when road traffic has to stop at both lock complexes. To prevent summated congestion the travel times for road traffic between the swing-swivel bridges is determined. In this case road traffic is specified to traffic which already experienced congestion at previous lock complex.
The requirement to prevent summated congestion is that all traffic queued up at a lock complex travels to the other side of the Afsluitdijk and the swing-swivel bridges at that other, receiving, side have to be closed when they arrive.
To determine the time period the bridges on the other side have to be closed, the difference between the first and last arrival times of vehicles in the queue have to be calculated. The worst situation is the situation with the biggest difference between arrival times, because the bridges (and locks) on the other side have minimum time for their own operations. The characteristics of the worst case scenario are a fast passenger car in front of the waiting queue and slow freight traffic at the back of the queue. This situation is normative, so the consequences of this worst case scenario are determined.

In the worst case scenario the maximum difference in arrival times is 20 minutes with a road traffic intensity of 1150 vehicles per hour and 14 minutes duration of the bridge opening. This means the bridge on the other side has to stay open for 20 minutes after the arrival of the first vehicle of the waiting queue.
It is desirable to make this difference as small as possible to increase the time space for bridge operations. There are three possibilities to reduce the difference between arrival times. The first one is lowering the maximum speed to 100 km/h, the second possibility is not guaranteeing a free passage for freight traffic and finally it is also possible to implement ODYSA®. ODYSA® is a traffic management system which optimizes the traffic flows by giving dynamic speed advice. The first two possibilities are decisions policy makers have to make and the third possibility is a technical solution to compact the platoon of vehicles.
Concerning the interaction between the bridges also the frequency of bridge openings has to be taken into account. In reality it never happens that the longest duration of bridge openings happens simultaneously with the highest frequency of bridge openings. Therefore there are two scenarios distinguished. The first scenario has an average frequency of bridge openings with a long duration of bridge openings and the second scenario has an average duration of the bridge opening and high frequency of bridge openings.
There are three methods to prevent delays for road traffic as a result of bridge openings at both sides of the Afsluitdijk. One manner is to give a bridge priority based on the navigation supply. If a vessel approaches one of the bridges, the bridge opens, and the bridge on the other side has to be closed when all vehicles pass that have been waiting in front of the bridge with priority.
The second option is “simultaneous bridge openings”. In this type of interaction between the bridges navigation is not determinative and the starting time of bridge openings is fixed, so a service schedule for navigation has to be created.
The third way is by implementation of a dynamic traffic management system. This system automatically detects the length of the waiting queues or the intensity of the road traffic and herewith determines the time to clear the queue. Subsequently the arrival times of the first and last vehicle of the queue on the other side of the Afsluitdijk and the time difference between these arrival times are determined. Following bridge operations can be adapted based on this information.
Herewith there is no communication necessary between the independent control towers and there is no, or little, time lost because all times are determined more accurate which creates maximum time to operate the bridges at the Afsluitdijk.

This chapter has covered the congestion of road traffic at the Afsluitdijk and brought up methods to prevent road traffic to have waiting time in front of both bridges in the Afsluitdijk. The following and final chapter, chapter 8, contains the conclusions resulting from the research presented in this and previous chapters. Finally recommendations for future research will be given in this chapter.

8 Conclusions and recommendations

The conclusions of this research are divided in primary and secondary conclusion. The primary conclusions are direct answers to the research question and the secondary conclusions are additional findings which are gained during the research process. After the conclusions recommendations for future research are presented in paragraph 0

8.1 Conclusions

Within this paragraph a distinction is made between primary and secondary conclusions. The primary conclusions are the answers to the research questions which are presented in subparagraph 1.4.3. Besides these conclusions; there are also other findings resulting from the analysis made within this research. These are the Secondary conclusions presented in subparagraph 8.1.2.

8.1.1 Primary conclusions

At the moment the congestion of navigation as well as road traffic at the Afsluitdijk and its lock complexes is unacceptable. The waiting times for navigation have exceeded the guidelines over 250 percent in 2005, over 200 percent in 2006 and over 25 percent in the year 2007. And in respect to the road traffic, the congestion is also unacceptable because situations occur when vehicles have to stop at both ends of the Afsluitdijk before the swing-swivel bridges.

Figure 8-1 presents all factors influencing the waiting time for navigation and road traffic at the lock complexes in the Afsluitdijk; and their interaction. The diagram of connections is divided in three main parts; “Road Traffic”, “Intersection” and “Navigation”. Within the main parts of the diagram of connections there are lots of components influencing the main subjects of this research “Waiting time road traffic” and “Waiting time navigation”.
Important components influencing the “Waiting time road traffic” are the intensity and composition of road traffic and “the duration of landside bridge opening”.
For “Waiting time navigation” the most important components are “Vessels per lock operation” and “Lock cycle time” which together determine the lock capacity. Besides these components, the intensity and composition of navigation have lots of influence on the “Waiting time navigation”.

There are three possibilities to reduce the congestion for navigation. These possible improvements are technical, operational improvements, improved behavior of recreational navigation and a more equal distribution of navigation over the day.
Improving the behavior of recreational navigation can result in a ten percent reduction of the maximum waiting time. A more equal distribution of the navigation supply at the navigation lock can reduce the maximum waiting time up to fifteen percent, but in general has less effect. The most effect has upgrading the eastern navigation lock with a reduction of the maximum waiting times up to 50 percent.

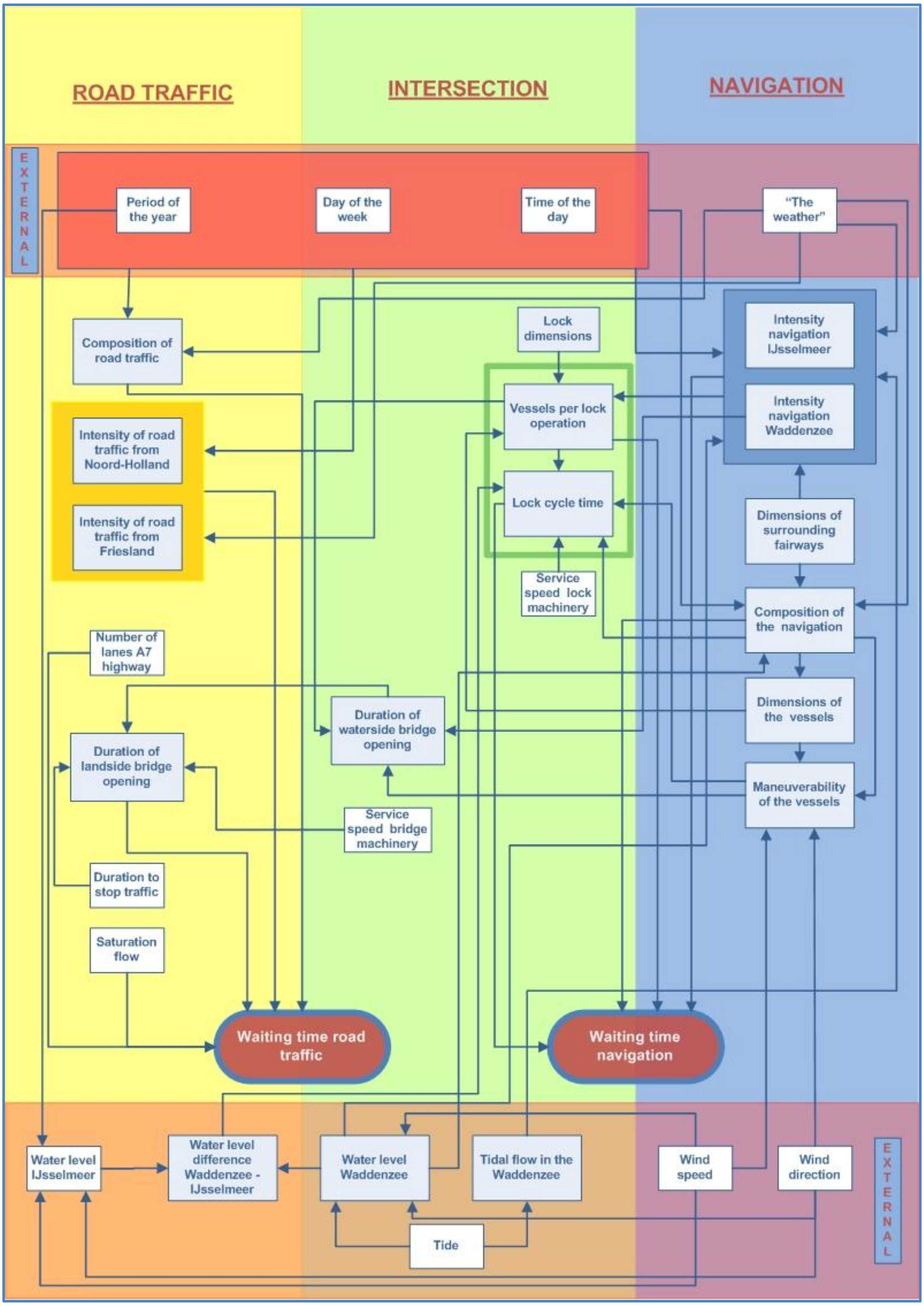


Figure 8-1: All factors influencing the waiting time for navigation and road traffic at the lock complexes in the Afsluitdijk; and their interaction.

Besides the waiting time for navigation at the Lorentz lock complex, there is also the waiting time for road traffic at the lock complex and the possibility of summated congestion when there is waiting time at both lock complexes.
The requirement to prevent summated congestion is that all traffic queued up at a lock complex travels to the other side of the Afsluitdijk and the swing-swivel bridges at that other, receiving, side have to be closed when they arrive.
There are three methods to prevent delays for road traffic as a result of bridge openings at both sides of the Afsluitdijk. One manner is to give a bridge priority based on the navigation supply. The second option is "simultaneous bridge openings". And finally there is the possibility to implement a dynamic traffic management system.

Recapitulating; the congestion at the Afsluitdijk and its lock complexes is unacceptable according the guidelines defined in this research. Within the current infrastructural situation the congestion for navigation at the Lorentz navigation locks at the Afsluitdijk can be reduced, but it cannot meet the guidelines. Opposite; congestion for road traffic can become acceptable by implementing presented improvements.

8.1.2 Secondary conclusions

As mentioned in the introduction of paragraph 8.1; this subparagraph presents secondary findings resulting from the analysis made within this research.

Navigation

The Lorentz lock complex has a unique layout with the swing-swivel bridges and navigation locks separated by an outer harbor. Nevertheless the swing-swivel bridges and navigation locks at Kornwerderzand are operated as a whole. In general there are no vessels aloud between the bridges and the locks so vessels have to wait on the Waddenzee side before the bridges or at the Ijsselmeer side before the navigation locks.
To minimize the amount of bridge openings the navigation locks are operated parallel in the same direction. The maximum capacity of the Lorentz navigation locks are about 47 vessels per hour and direction.

External factors like season of the year, holidays, weekends, time of the day, "the weather" and the Waddenzee tide influence the intensities of the navigation at the Lorentz lock complex. The influence of these factors is more for recreational navigation than professional navigation and the share of recreational navigation is over 90 percent at the lock complex at Kornwerderzand. Therefore the external factors have lots of influence regarding the distribution of navigation over the year and day.
This influence of factors including season of the year, holidays, weekends and "the weather" results in an unequal distribution of navigation over the year. Over 95 % of the yearly passages at Kornwerderzand are during the months April till November with the peak in July. The distribution over the day is mainly influenced by the time of the day and the Waddenzee tide.

There are three main fairways used by navigation on the Waddenzee. These fairways are:

- Kornwerderzand – Harlingen, eastern Waddenzee
- Kornwerderzand – Terschelling, Vlieland and the North Sea
- Kornwerderzand – Den Helder, Texel and the western Waddenzee

Professional navigation only uses the first two fairways and recreational navigation uses all. Recreational navigation is about equally distributed over the three connections and most professional navigation has Harlingen as their origin or destination.

As mentioned previously, the distribution of navigation over the day is mainly influenced by the time of the day and the Waddenzee tide. Of course recreational, and professional navigation, prefers to navigate during the day, but they also want to use the tidal flows resulting from the Waddenzee tide. These tidal flows can increase the navigation speed and therewith decrease travel times. Besides the tidal flows, navigation is also interested in the water level of the Waddenzee, because they need sufficient draught for their vessels. This motive mainly applies for professional navigation. Based on these motives the distribution of navigation at the Lorentz lock complex heading North and South can be predicted.
For navigation using the Lorentz locks, two tidal situations are distinguished to predict the distribution of navigation. These situations are; high tide is the central tide during the day and low tide is the central tide during the day. When the high tide is the central tide, the distribution of navigation can reasonably be predicted. If the low tide is the central tide, the theories do not apply and navigation is less concentrated and more equal spread over the day. The conclusions regarding the distributions of navigation in the distinguished situations are presented underneath.

High tide is the central tide:

- There is a concentration of navigation around high tide for both directions.
- Navigation heading north is more concentrated before high tide during the rising of the Waddenzee's water level.
- Navigation heading south is reasonably equally spread over the periods of rising and ebbing water, but not equally spread within those periods.

Low tide is the central tide:

- Navigation is more equally spread over the day and the tides for both directions.
- Navigation heading in both directions is a bit more concentrated before low tide, during ebbing water.

The predictions of the distribution of navigation at the navigation locks can be used to inform skippers. This can be done in two ways; first the distribution of navigation over the year, month and week can be made public. This distribution presents the busy periods, days and skippers can decide to avoid those days and periods. Secondly the distribution over the day can be presented to the skippers and yachtsmen so they can choose to avoid congestion.
When sufficient navigation tries to avoid the busy periods, a more equal distribution of navigation will be the result which again results in less waiting time at the Lorentz navigation locks.

Road traffic

The amount of local congestion at a lock complex at the Afsluitdijk is influenced by the composition of the road traffic, the number of lanes, the saturation flow, the intensity of the road traffic and the duration of a landside bridge opening.
To prevent summated congestion, it is important to know the difference in arrival times on the receiving side between the first and last vehicle which have been in the queue on the other side. The difference between arrival times on the other, receiving, side of the Afsluitdijk has lots of impact on the bridge operations. It is desirable to make this difference as small as possible to increase the time space for bridge operations. There are three possibilities to reduce the difference in arrival times.

- Lowering maximum speed to 100 km/h.
- Excluding freight traffic; not guaranteeing a free passage.
- Implementing a traffic management system which optimizes the traffic flows by giving dynamic speed advice.

In reality is never happens that the longest duration of bridge openings happens simultaneously with the highest frequency of bridge openings. This is because long bridge openings are normally a result of high amounts of vessels which have to pass. These high amount of vessels result in an increase of the lock cycle time and thereby the frequency of bridge openings decreases.

General

There is no unambiguous stand concerning the congestion at the Afsluitdijk in previous research as well as at the sections of the Dutch Directorate for Public Works and Water Management.

A model combining the navigation locks and bridges at Kornwerderzand, and their behavior, cannot be created within the SIVAK II micro-simulation software which is used by the Dutch Directorate for Public Works and Water Management.

8.2 Recommendations

The Dutch Directorate for Public Works and Water Management, IJsselmeergebied, controls the Afsluitdijk and its lock complexes, but has no official, clear stand concerning the acceptable amounts of congestion. First this stand has to become clear before the decision can be made which improvements are necessary. Subsequently additional research is needed to determine the feasibility of improvements.

Additional research is needed about the characteristics and behavior of recreational navigation. With the increasing influence and impact of recreational navigation on their surroundings and the economy, also their characteristics must become clearer. This way the behavior of navigation at the Lorentz lock complex and in its surroundings can be determined more accurate which again positively influences the development of possible improvements.

Development of the SIVAK II micro simulation software of the Dutch Directorate for Public Works and Water Management, Centre for traffic and Navigation, to make it applicable for the situation at the Afsluitdijk. Especially the blocks “Bridge” and “Lock” must be altered to approach the real situation and its behavior.

Glossary

Aquatic sports association	Watersport vereniging
Be on demurrage	Bijliggen
Behind the dike	Binnendijks
Berth	Ligplaats
Boulder clay	Keileem
Casemate	Kazemat
Chamber utilization grade	Kolkbezettingsgraad
Control tower	Bedieningstoren
County Alderman	Gedeputeerde staten
Dikebreach	Dijkdoorbraak
Draught	Diepgang
Dutch Directorate for Public Works and Water Management	Rijkswaterstaat
Fairway	Vaarweg
Flush	Spuien
Flushing tubes	Spuikokers
Frisian Islands	Waddeneilanden
Guide jetty	Fuik
Halt-line	Stopstreep
IJsselmeer-area	IJsselmeergebied
Inner harbor	Binnenhaven
Landing stage	Steiger
Lock	Schutsluis
Lock	Schutten
Lock approach	Voorhaven
Lock gate	Sluisdeur
Lock sill	Sluisdrempel
Lock-head	Sluishoofd
Lockkeeper	Sluiswachter
Lockmaster	Sluismeester
Lockplan	Schutplan
Mattress	Zinkstuk
Moor	Aanmeren
Moor, berth	Aanmeren
Navigation lock	Schutsluis
Outside the dike	Buitendijks
Outer harbor	Buitenhaven
Sand-dam	Zandlichaam
Saturation flow	Afrijdcapaciteit
Scouring sluice	Spuisluis
Seepage	Kwel
Shutter	Luik
Sluice gate	Schuif
Sluice wall	Sluismuur
Storm surge barrier	Stormvloedkering
Vessel rank	Opstelplaats

Wadden-area	Waddengebied
Water management	Waterhuishouding
Waterretaining	Waterkering (functie)
Water-retaining structure	Waterkering (constructie)
Wave runup	Golfoploop
Yacht harbor	Jachthaven

Kramers Engels woordenboek
Euroglot Professional 5.0
Dictionary Dutch-English of the master Coastal and Marine Engineering and Management at Delft University of Technology.

Figures and tables

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Appendices

Appendix 1; Deficiencies of the Afsluitdijk

Focused on today's questions concerning the Afsluitdijk, they concern three different parts of the Afsluitdijk. The first part is the dam itself, secondly there are the two lock-sluice complexes at Den Oever and Kornwerderzand and finally there is the road infrastructure which connects the provinces Noord-Holland and Friesland.
All parts of the Afsluitdijk have different functions like retaining, flushing and connecting and these functions are necessary in the areas of hydraulics, water management and accessibility. Previous research already showed that there are problems regarding the functions of the Afsluitdijk. These problems are described in the following paragraphs.

In addition there is, next to improving the current functions, the subject of adding new functions to the Afsluitdijk like recreation, generating electricity and housing. A report of the Dutch Directorate for Public Works and Water Management has given an overview about plans concerning the Afsluitdijk, but unfortunately housing and recreational plans are excluded.

<u>Hydraulic engineering problems</u>

On 15 January 1996 the "Law on water-retaining structures" took effect. In article 9 of this law it is defined that controllers of primary water-retaining structures have to report to the County Alderman[6] every five years about the general state of the water-retaining structures within their area of control.
The first check, 1996 – 2001, has been a rough check with the focus on height, but the controllers agreed that the next check would be a complete one. The results of the second check were made public in 2006 and proofed that the Afsluitdijk does not come up to the current requirements for water-retaining structures. (Provincie Noord-Holland, 2006)

Underneath, there is a more detailed description of the insufficiencies on the water-retaining structures of the Afsluitdijk.

- **Dam**

  Height
  The majority of the dam has not sufficient height to meet the safety criteria determined on an average chance of exceeding from 1/10000 a year for the representative water level.

  Facing
  The facing of the dam is at long distances not robust enough to resist the wave and water loads and for some places the robustness of the facing is not yet determined. Therefore an advanced research is still in progress.

[6] Gedeputeerde Staten

- **Lock-sluice complexes**

  Stability locks

  The navigation locks and scouring sluices are the weakest spots of the Afsluitdijk. The navigation locks are designed on a water level difference of about 5 meters, but at the moment the maximum difference is 7,45 meters. When this water level difference has to be retained, the walls of the navigation lock will probably tilt and thereby the lock will lose its waterretaining function.

  Closure scouring sluices

  Each scouring sluice has two sluice gates per tube. The gate on the Waddenzee side has to resist the wave loads and the representative water level difference. When these Waddenzee sluice gate breaks down the IJsselmeer-gate will probably follow soon.
  In the past there were "point doors" behind the scouring sluices as an extra sluice closure, but nowadays these doors are out of service. (Provincie Noord-Holland, 2006)

Water management problems

The Afsluitdijk has two locations with scouring sluices, respectively Den Oever (Noord-Holland) and Kornwerderzand (Friesland). The scouring sluices flush water from the IJsselmeer into the Waddenzee under free fall. This means flushing is only possible when the water level in the Waddenzee is lower than the water level in the IJsselmeer, so flushing normally happens when it is ebb tide in the Waddenzee. A result from this condition is the limitation of the flush capacity which makes it difficult to maintain the right water level in the IJsselmeer during winter.
In the future this problem will increase because of the changing climate which results in a higher water level in the Waddenzee and higher maximum discharge during winter in the IJsselmeer. These changes will result in a further increase of the need for flush capacity, especially if the current advisable water levels in the IJsselmeer have to be maintained. (Ministerie V&W, 2000)

At the moment plans are being developed to build a new scouring sluice complex to create sufficient flush capacity until 2050. It is expected that construction will start around 2010 and the project will be finished in 2013.

Accessibility problems

Besides hydraulic engineering and water management problems, there is another point of attention concerning the Afsluitdijk. There are accessibility problems for road traffic and navigation at the Lorentz lock complex where both modalities intersect.
Navigation also has its own problems because the fairways have not got sufficient depth for some ships using the navigation locks. And for road traffic the infrastructure on the Afsluitdijk, A7 national highway, does not meet the guide-lines for the design of roads.

- **Congestion**

  Road traffic
  The intersection between road traffic on the national highway A7 and navigation between Waddenzee and the IJsselmeer at the Lorentz locks at Kornwerderzand results, in combination with high intensities of the navigation and road traffic during summer, in waiting times of several tens of minutes for road traffic on the A7. (Ministerie V&W, 2001) The same problem occurs at the Stevin lock at Den Oever, but with a lower frequency and shorter waiting times. In the worst case road traffic even has to wait at both lock complexes, because of opened sing-swivel bridges.

  Navigation
  At the Lorentz locks at Kornwerderzand there are high navigation intensities during summer (navigation season) mainly caused by recreational navigation. During this period the capacity of the Lorentz locks is sometimes not sufficient which shows in waiting times over three hours for the navigation.
  Previous research has detected this problem, but has not made clear the exact level and frequency of nuisance. Nevertheless it is expected that these waiting times will increase because of the increasing navigation, navigation on tide windows and increasing road traffic. (Ministerie V&W, 2001)

Infrastructure

Road traffic
The lay-out of the A7 highway located on the Afsluitdijk deviates from the guide-lines for the design of highways (ROA). (RWS en ARCADIS, 1999)
The infrastructure for cyclist is for most parts located between the A7 highway and the elevation on the Waddenzee side. This means there is no clear view to the Waddenzee and IJsselmeer, lots of inconvenience from road traffic on the highway and above all an unsafe situation.

Navigation
The lock sill depth at the Lorentz navigation lock at Kornwerderzand is not sufficient. The lock sill depth on the IJsselmeer side is NAP -4 meter which makes it sometimes difficult to pas for ships with a draught over 3,5 meter.(Ministerie V&W, 2001)

Functional problems

For years different individuals and organizations have been creating the wildest plans for the Afsluitdijk. These plans probably derive from the feeling that there are great possibilities for the Afsluitdijk. It's an impressive and important structure, but nevertheless there is some sort of general feeling that it could become even more important and impressive by implementation of some adjustments.

The report "Integrale verkenning Afsluitdijk" (RWS IJsselmeergebied and Witteveen+Bos, 2006) contains descriptions and evaluations of several plans for the Afsluitdijk and the IJsselmeer area. Unfortunately plans concerning housing and recreation are not included in the report. The report is an integral exploration of the Afsluitdijk and the starting-point of their future research regarding the Afsluitdijk, so all subjects in reference to the Afsluitdijk should be included. Fortunately other organizations have covered these hiatus in the exploration of the Afsluitdijk and have presented plans including housing and recreation along the Afsluitdijk.

In the future government has to decide what to do with the Afsluitdijk. This will be a consideration between preservation of the unique peaceful, open landscape and cultural value of the Afsluitdijk on one hand and boundless opportunities to create an even more impressive "Dutch icon".

Appendix 2; Interview with the lockkeepers of the Lorentz lock complex at Kornwerderzand

Lockkeepers:

- Douwe van de Veen
- Hans Meeuwsen
- Minne van der Werf
- Saco Eekma
- Heer Roucema

Lockkeepers' information

What are the responsibilities of the lockkeepers?

- Navigation locks
- Swing-swivel bridges
- Scouring sluices

Fast and safe traffic management with the usage of the navigation locks and swing-swivel bridges. Important activities are locking AND waiting.

Other activities:

- Control the scouring sluices. Orders come from the Dutch Directorate for Public Works and Water Management, IJsselmeergebied.
- Control the storm surge barrier.
- Administrative tasks for the IVS system.
- Administrate the 7 digit Europe number, cargo (type and weight), origin, destination, number of passengers and draught of each (professional) vessel.

What are the shifts of the lockkeepers?

The Lorentz lock complex is occupied 24-hours by three shifts from 23.00-7.00, 7.00-15.00 and 15.00-23.00. From 9.00-17.00 the complex is occupied by two lockkeepers and in total there are seven lockkeepers.

Navigation

What are the characteristics of the navigation intensities?

Both professional as well as recreational navigation uses the tide of the Waddenzee. For professional navigation the depth of the Boontjes fairway is normative. The depth of the Boontjes is -3 meter NAP and can only be passed at high tide on the Waddenzee. The draught of professional vessels is between 3 - 3,25 meter en the tide of the Waddenzee varies between -0,8 and +0,8 meters NAP.

Recently also the depth of the lock approach becomes a problem, because of little and pore dredging.

For recreational navigation the depth is sufficient, but recreational skippers often think it is a problem. Anyway recreational navigation always tries to use descending tide to the Frisian Islands.

This results in busyness at the Lorentz locks at high tide.

What is the estimation of navigation intensities?
The intensities are about 200 recreational and 50 professional vessels per day, so an 80-20% distribution. Charters are professional navigation.

Recreational navigation normally heads for, or come from, the Frisian Islands (Terschelling, Vlieland etc) and surrounding harbors (Makkum, Harlingen etc.)

What is the percentage of the vessels with announcement?
All professional navigation, charters and 10% of the recreational navigation announce themselves.

What is the time between announcement and arrival?
5/10 minutes for professional navigation and for recreational navigation there is no time difference.

What is the distance between the vessels and the control tower from which lockkeepers can start to anticipate on arriving vessels? When do vessels become perceptible?
About 300 meters, sometimes until Makkum, but the destination of the vessel is not clear at that distance.

What is the minimal-maximum waiting time for navigation?
About 30 minutes until a maximum of two hours.

Waiting time factor professional navigation compared to recreational navigation?
The waiting time for professional navigation is five times more important than recreational navigation.

What are the maximum speeds in the harbors?
In the harbors this is about 6 km/h.
Professional navigation reaches about 13-15 km/h and recreational navigation about 10 km/h. Both speeds are without tidal flows.

On some trajectory (Margriet lock) the maximum speed is calculated based on the tonnage/length.

Regime

What are the steps to pass the Lorentz lock complex?

1. Announcement vessels

First vessels announce themselves. Professional navigation and charters are obliged to announce and about 5%-10% of recreational navigation place an announcement.
Further communication is by the usage of speakers, local phone at mooring facilities and lock stewards[7].

2. Exchange information

Inquire information, measurements, with the usage of the Europe number for professional navigation and visual for recreational navigation.

3. Give directions

Verbally with the usage of marine telephone and speakers.

Traffic lights.

- Lock lights

Red => No entrance.
Red-Green => Get ready.
Green => Entre.
Red-Red => Not in use.

- Bridge lights

No light => No entrance.
Single light => Entrance allowed with possible oncoming traffic.
Double lights => Entrance allowed and no oncoming traffic.

4. Lock operation

Locks and bridges are almost always operated simultaneously to stimulate the navigation flows, fast passages and prevent chaos in adjacent harbors.

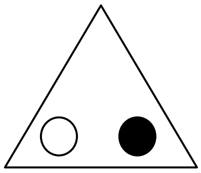
5. Shipping-movements

Is there radar available and which communication tools are most often used?
Radar is available, but the marine telephone is most often used. "Direct" sight is used a lot during day.

[7] Companions on shore during the navigation season which give directions to (recreational) skippers.

How are the lock chambers assigned to the vessels?

There are no arrows, but lights (see picture). When the left lock is available the left light flashed and vice versa.



No minimum chamber utilization grade.

What is the maximum waiting time for a vessel before locking starts?

<10 minutes, but is influenced by many aspects. What kind of vessel is waiting on the other side, which vessels are approaching? And so on..

What are the leveling times at the Lorentz lock complex?

- Big chamber:

Total locking time (without entering, leaving time vessels) about 4 to 5 minutes from which half is the time needed for leveling. A large difference in water levels, about 1,3 meters, takes 2 to 3 minutes, but there is little difference in leveling times for other water level differences.

Maximum water level difference is about 2,6 meters (+2,1 meters to -0,5 meters NAP) which takes about 5 minutes to level.

- Small chamber:

All times about double compared to big chamber because of slower lock gates and smaller shutters for leveling. The smaller chamber is an old chamber with old mechanics.

The maximum water level difference of about 2,6 meters takes this chamber about 9 minutes to level, because of the smaller shutters.

What is the time needed to fill the chambers at the Lorentz lock complex?

- Big chamber:

During navigation season about 30 minutes including opening gates, entering chamber, closing lock gates, leveling, opening lock gates and leaving.
The chamber can accommodate a maximum of 30-35 yachts or 6 charters.

- Small chamber:

Also takes about 30 minutes including opening gates, entering chamber, closing lock gates, leveling, opening lock gates and leaving, because there are less vessels but it takes more time to level.
The small chamber accommodates a maximum of 10-12 yachts.

Is there interaction between the operations of the lock chambers?
During navigation season both chambers are used. Mostly they are used parallel and bridges will not be opened before both lock chambers are empty/ready.

Infrastructure

What are adjustments in the last ten years?

- Berths

The construction of floating landing stages is about ten years ago.

- Maintainance

- Deepening of the faiways

Dutch Directorate for Public Works and Water Management has a contract with a contractor to keep the fairways on sufficient depth for the navigation.

- Bridges

A new south bridge is placed about two years ago.

- Control tower

About ten years ago, a new control tower is build at the Lorentz lock complex at Kornwerderzand.

What is the amount of berths at the Lorentz complex?
About 4 times 200 meters on both (Waddenzee & IJsselmeer) sides.

On the Waddenzee side there are floating berths available.
Vessels of mussel fishermen lie between the navigation locks and the bridges.

○ Locks

What is the fyke length (per side, per kolk)? This is the distance between the first vessel waiting to enter the lock chamber en the entrance of the lock chamber en is used by vessels leaving the chamber to maneuver.
Recreation stays far away, but professional navigation approaches until 300 meters.

What is the depth of the lock sill (per side)?
-4,4 meters NAP and locking is allowed until -3,5 meters NAP.

Time needed to open and close the lock gates?
1 minute and 15 seconds, with double gates, and half with single gates. Double gates are used when the water levels at the IJsselmeer and the Waddenzee are about equal.

○ Bridges

What is the time to open bridge?
It takes a total of three minutes to open bridges which is divided in two minutes to stop road traffic and one minute to open the bridges.

What is the time to close bridge?
About one minute.

What is the maximum time for bridge opening?
Less than 15 minutes. Slow vessels need to wait for next bridge opening.

What is the height of the bridge?
+4,9 meters NAP.

Road traffic

Is there interaction between the Lorentz lock complex and the Stevin complex at Den Oever?
No, professional navigation is normative in combination with the Waddenzee tide. Only when there are huge disturbances there is interaction to reduce, minimize congestion.

What are the maximum intensities for road traffic?
Morning rush-hour: 6.00-8.00
Evening rush-hour: 16.00-19.00
Friday evening rush-hour is the busiest.

What is the composition of the road traffic?
Mainly traffic of the surrounding regions only during summer there is some recreational navigation. Most traffic is commuters which leave in the morning and return in the evening.

What is the waiting time for road traffic at a bridge opening?
Outside the navigation season it's about five minutes and during navigation season on average about ten minutes.

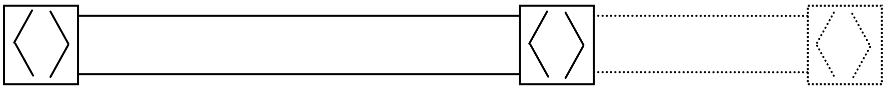
What are the restraints concerning road traffic?
The bridges are preferably not opened during rush-hours and when the Interliners (bus service) at .40 passes from Holland to Friesland and .50 from Friesland to Holland passes.
During extreme fog when there is too little visibility for navigation, lockkeepers and road traffic.

Opportunities

What are the opportunities in respect to infrastructure?

Lengthening of the current lock chamber(s) with 60+ meters.

At this moment the big lock chamber can resist a maximum water level difference of 2,1 meters. This can be increased by building a new lock-head followed by the sluice walls. This new part of the lock chamber can have more draught to reduce inconvenience for vessels.



What are the opportunities in respect to the lock regime?

Contact with the aquatic sports association to increase the awareness of recreational navigation with regard to their behavior on the water. This way navigation flows at lock complexes can be stimulated and passage times can be reduced.

Aquatic sports associations appear to have more influence than the directions of lockkeepers and lock stewards.

Examples of negative behavior at the lock complex are:

Slowly leaving locks, harbors and pass bridges.

Obstructing the lock chamber.

Not letting professional navigation to enter the lock chamber first.

And so on...

The entering and leaving of locks and passage time of bridges can be reduced with circa 10% (estimation). The incidents (obstruction, order of entrance, mooring) can always occur and therefore possible time reductions are impossible to quantify.

Appendix 3; CEMT vessel classes

AVV-2002 Classificatie voor studies, statistiek en prognoses

CEMT Klasse	Motorvrachtschepen (Motorvessels) AVV Klasse	Karakteristieken maatgevend schip** Naam	Breedte (m)	Lengte (m)	Diepgang (geladen) (m)	Classificatie Laadvermogen (t)	Classificatie Breedte en lengte (m)	Duwstellen (Barges) AVV Klasse	Karakteristieken maatgevend duwstel** Combinatie	Breedte (m)	Lengte (m)	Diepgang (geladen) (m)	Classificatie Laadvermogen (t)	Classificatie Breedte en lengte (m)	Koppelverbanden (Convoys) AVV Klasse	Karakteristieken maatgevend koppelverband** Combinatie	Breedte (m)	Lengte (m)	Diepgang (geladen) (m)	Classificatie Laadvermogen (t)	Classificatie Breedte en lengte (m)	Doorvaarthoogte* incl. 30 cm schrikhoogte (m)
0	M0	Overig				1-250	B<= 5,00 of L<= 38,00															
I	M1	Spits	5,05	38,5	2,5	251-400	B= 5,01-5,10 en L>=38,01	BO1		5,2	55	1,9	0-400	B<=5,20 en L= alle	C1l	2 spitsen lang	5,05	77-80	2,5	<= 900	B<= 5,1 en L=alle	5,25*
															C1b	2 spitsen breed	10,1	38,5	2,5	<= 900	B=9,61-12,60 en L<= 80,00	5,25*
II	M2	Kempenaar	6,6	50-55	2,6	401-650	B=5,11-6,70 en L>=38,01	BO2		6,6	60-70	2,6	401-600	B=5,21-6,70 en L=alle								6,1
III	M3	Hagenaar	7,2	55-70	2,6	651-800	B=6,71-7,30 en L>=38,01	BO3		7,5	80	2,6	601-800	B=6,71-7,60 en L=alle								6,4
	M4	Dortmund Eems (L < = 74 m)	8,2	67	2,7	801-1050	B=7,31-8,30 en L=38,01-74,00	BO4		8,2	85	2,7	801-1250	B=7,61-8,40 en L=alle								6,6
	M5	Verl. Dortmund (L > 74 m)	8,2	80-85	2,7	1051-1250	B=7,31-8,30 en L>=74,01															6,4
IV	M6	Rijn-Herne Schip (L <= 86 m)	9,5	80-85	2,9	1251-1750	B=8,31-9,60 en L=38,01-86,00	BI	Europa I duwstel	9,5	85-105	3,0	1251-1800	B=8,41-9,60 en L=alle								7,0*
	M7	Verl. Rijn-Herne (L > 86 m)	9,5	105	3,0	1751-2050	B=8,31-9,60 en L>=86,01															7,0*
IVb															C2l	Klasse IV + Europa I lang	9,5	170-185	3,0	901-3350	B=5,11-9,60 en L=alle	7,0*
Va	M8	Groot Rijnschip	11,4	95-110	3,5	>=2051	B>9,60 en L>=38,01	BII-1	Europa II duwstel	11,4	95-110	3,5	1801-2450	B=9,61-15,10 en L<=111,00								9,1*
								BIIa-1	Europa IIa duwstel	11,4	92-110	4,0	2451-3200	B=9,61-15,10 en L<=111,00								9,1*
								BIIL-1	Europa II Lang	11,4	125-135	4,0	3201-3950	B=9,61-15,10 en L=111,01-146,00								9,1*
Vb								BII-2L	2-baksduwstel	11,4	170-190	3,5-4,0	3951-7050	B=9,61-15,10 en L>=146,01	C3l	Klasse Va + Europa II lang	11,4	170-190	3,5-4,0	3351-7250	B=9,61-12,60 en L>=80,01	9,1*
VIa		Rijnmax ***	17,0	135	4,0			BII-2b	2-baksduwstel breed	22,8	95-145	3,5-4,0	3951-7050	B=15,11-24,00 en L<=146,00	C2b	Klasse IV + Europa I breed	19,0	85-105	3,0	901-3350	B=12,61-19,10 en L<=136,00	7,0*
															C3b	Klasse Va +Europa II breed	22,8	95-110	3,5-4,0	3351-7250	B>19,10 en L<=136	9,1*
VIb								BII-4	4-baksduwstel (incl. 3-baks lang)	22,8	185-195	3,5-4,0	7051-12000 (7051-9000)	B=15,11-24,00 en L=146,01-200	C4	Klasse Va + 3 Europa II	22,8	185	3,5-4,0	>=7251	B>12,60 en L>=136,01	9,1*
VIc								BII-6l	6-baksduwstel lang (incl 5-baks lang)	22,8	270	3,5-4,0	12001-18000 (12001-15000)	B=15,11-24,00 en L>=200,01								9,1*
VIIa								BII-6b	6-baksduwstel breed (incl. 5-baks breed)	34,2	195	3,5-4,0	12001-18000 (12001-15000)	B>=24,01 en L=alle								9,1*

* Bij de klasses I, IV, V en hoger zijn de doorvaarthoogtes aangepast voor 2 respectievelijk 3 en 4-laags containervaart. (doorvaarthoogte op kanalen t.o.v. Maatgevend Hoog Water = 1% overschrijding/jaar)

** De karakteristieken van het maatgevend schip hebben in de lengte een marge van ± 1 meter en in de breedte van ± 10 cm

*** Het aantal schepen is voorlopig nog beperkt en vormt daarom nog geen aparte klasse.

Een maatgevend schip is een schip waarvan de afmetingen bepalend zijn voor de dimensionering van de vaarweg en de kunstwerken daarin.
Bij nieuwbouw wordt uitgegaan van het grootste maatgevende schip binnen een CEMT-klasse. Klasse M3, M4 en M6 mag alleen worden toegepast bij reconstructie van vaarwegen.
De kleinste afmetingen van een maatgevend schip vormen de ondergrens om een vaarweg in een bepaalde gestandaardiseerde klasse in te delen.

Appendix 4; Process to pass a navigation lock

The Dutch ministry of Traffic and Public Works has also drawn up guidelines for the operation of navigation locks. In this appendix this process is described.

A1: Pre-announcement
This happens normally automatically by an information system, so it doesn't need an action of the skipper.

B1/2: Gather information
Gathering information is normally combined with the announcement.

A2: Operational announcement
At this announcement all relevant information for locking has to be, or become, clear. An operational announcement can be done in different ways:
Marine telephone:
Phone at the mooring facilities at the lock complex:
Especially for recreational navigation which has not got a marine telephone.
(Mobile) phone:
At the lock operations office:
This is only possible when the lock is operated at the lock complex.

Of course there is also visual reconnaissance by the lock keepers through direct sight, camera images or even radar. It is necessary to let the shipper know if his request can be granted or not. If not, it is useful to tell the expected waiting time.
Nowadays the Europe number is used to identify the professional navigation and automatically know some characteristics, measurements, of the vessels.

A3: Order of arrival
The lock keepers determine the order of arrival by using direct sight or technical tools like radar or camera images.

C1: Designate waiting spot
If the vessel cannot join the next lock sequence, the lockkeepers have to designate a waiting spot. Direct sight on the waiting spot is not necessary, but support by radar or camera images is desirable.

B3: Make a lockplan
By drawing up a lockplan the lockkeepers have to take into account the order of arrival, rules and guidelines for dangerous cargo, weather conditions, the presence of recreational navigation and so on. For the busy locks, the lockplan can be generated by a computer.

B4: Provide information
The information of the lockplan has to be provided to the vessels. Usually the marine telephone is uses, but it is also possible to use the speakers. If there are more lock chambers at the complex, the usages of arrows (traffic-signals) is recommended to show at which lock chamber the vessel is assigned. If there are more outer harbors, this can also be assigned with traffic signals.

C2: Designate vessel rank
The vessel rank is only for ships which are taking part in the next lock sequence. Sight on the vessel rank is recommended, especially at big locks. Support can be given with the use of camera images, radar or direct sight, or a combination of those.

C3: Order of lock entrance and position in the lock chamber
Before entering the lock, all vessels need to know what the correct order is and which position in the chamber is theirs. This information can be transmitted by using the marine telephone, speakers or even digital.

C4: Preparing entrance
By showing a red/green traffic-signal, navigation knows that entrance starts shortly.

D1: Opening lock (entrance) gates
When opening the lock gates, lockkeepers have to see to it that it happens safely and no-one is on the gates.

C5: Allowing entrance
Before the green entrance signal is shown, the lockkeepers have to verify that no other ships are in the lock chamber.

C6: Directions for lock entrance
The lockkeepers see to it that there is a safe and smooth entrance of the vessels and give directions if necessary with the available communication systems.

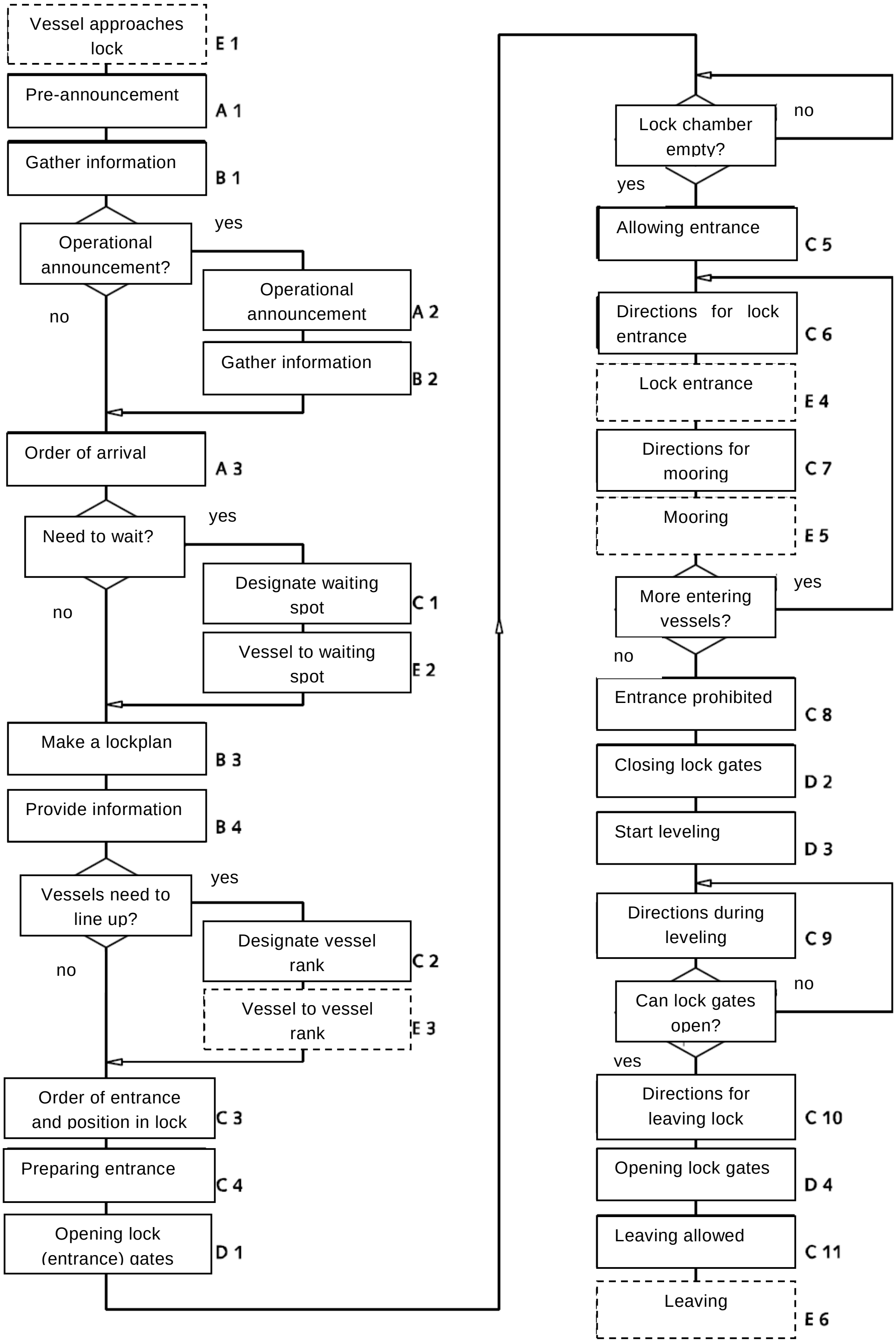
C7: Directions for mooring
These directions could concern positioning of the vessel, space between vessels, switching of propeller and so on. The lockkeepers can give directions by using the available communication systems.

C8: Entrance prohibited
When the last vessel has entered the lock chamber, a red signal shows that entrance for following vessels prohibited.

D2: Closing lock gates
Before gate closure lockkeepers need to verify that there are no vessels near or between the lock-heads and the moored vessels need to be within the halt-lines.

D3: Start leveling
The start of the leveling needs to be announced with an acoustic signal. The signal, normally a siren, has a strength of 112 dB. In urban area there is a maximum of 85 dB allowed.

C9: Directions during leveling
The personal at the locks needs to see into possible problems with lowering or tightening the mooring cables. Especially the recreational vessels sometimes have some problems with the mooring cables. The lockkeepers can give directions by using the available communication systems. The mooring is, and stays, a responsibility of the skipper.



Global scheme lock passage (Ministerie Verkeer & Waterstaat, 2006)

C10: Directions for leaving the lock chamber

Normally there are no directions necessary during the leaving. Is necessary, the lockkeepers can give directions by using the available communication systems.

D4: Opening the lock gates

When opening the (exit) lock gates, lockkeepers have to see to it that it happens safely and no-one is on the gates. If it is necessary technical tools can be used. To stimulate the fluency of the lock process, the lock gates can be opened when there is still a water level difference of less than 20 centimeters and no small vessels in the lock chamber.

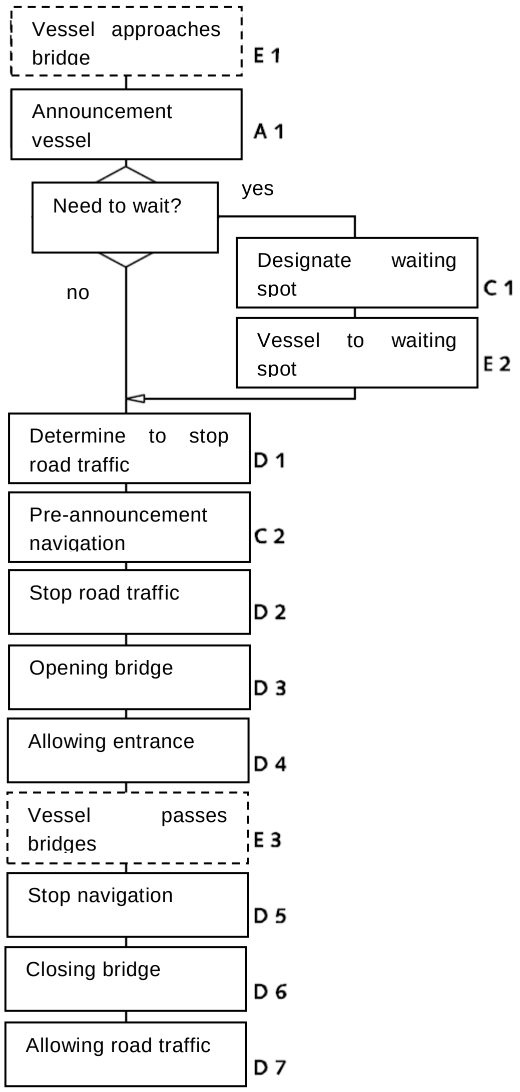
C11: Leaving the lock chamber is allowed

The green sign allows leaving the lock chamber.

(Ministerie Verkeer & Waterstaat, 2006)

Appendix 5; Process to pass a bridge

The Dutch ministry of Traffic and Public Works has also drawn up guidelines for the operation of a bridge. In this appendix this process is described.



Global scheme bridge passage (Ministerie Verkeer & Waterstaat, 2006)

A1: Announcement vessel
A vessel can announce that it wants to pass the bridge by the usages of a prescribed sound signal (long-short-long) or by using the marine telephone, telephone, and so on. Usually the bridge keepers have already spotted the vessel and taken action.

C1 Designate waiting spot
It is necessary to let the skipper know when he is spotted, if his request can be granted and the estimated waiting time.
If the vessel cannot pass the bridge immediately, the bridge keeper has to designate a waiting spot. There need to be a sufficient amount of waiting spots at the bridge.

D1: Determine to stop road traffic
The bridge keeper determines the moment the operation process starts en monitors the situation on the bridge for blockades, traffic jams or accidents. Because it is difficult for navigation to stop and moor, navigation normally gets priority above road traffic.

C2: Pre-announcement navigation
The vessels at the side of the bridge that can pas first, get a red/green lightsignal. At the other side the light stays red and becomes red/green or green when the passage has sufficient progress.

D2: Stop road traffic
Switching on warning lights, followed by the bridge opening, is attended by an acoustic signal. By lowering the barriers the road traffic is stopped.

D3: Opening bridge
After the bridge keepers have checked if the bridge-deck is empty, the bridge can be opened for the navigation. There has to be a possibility to stop the process at all time, in case someone still gets on the bridge-deck.

D4: Allowing entrance
By switching the lightsignal from red/green to green, the bridge keeper allows free passages for navigation. By switching the lightsignals on both sides the bridge keeper arranges the order of passage. To prevent claims resulting from damage, passage is only allowed when the bridge is totally opened.

D5: Stop navigation
By switching on the red lightsignals on both side of the bridge entrance, the bridge keeper stops navigation.

D6: Closing bridge
After the bridge keeper has checked if there are no vessels in, or near to the, bridge passage, he can give the command to close the bridge. If visual sight on the bridge(-deck) is not sufficient, supplementary (technical) tools are necessary. The bridge closure always has to be accompanied with an acoustic signal and most be able to stop in case of emergency.

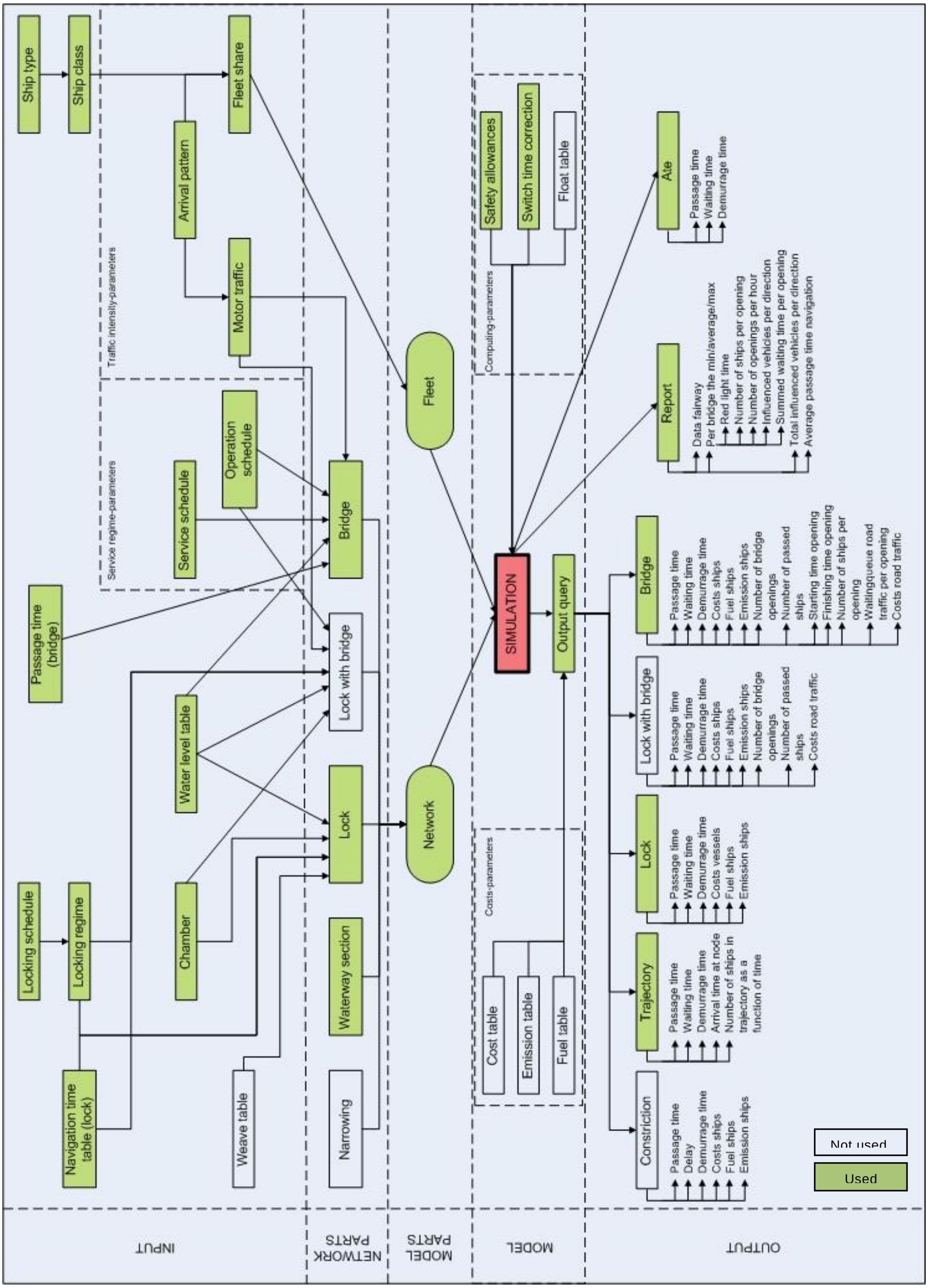
D7: Allowing road traffic
After the bridge-deck is totally closed en locked, the barriers can open, the lightsignals on the landside can be switched of and the bridge is free again for road traffic.

(Ministerie Verkeer & Waterstaat, 2006)

Appendix 6; Navigation intensities and tidal movement July 2005

		00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	Total
1 july sun	north										23	54	26	16	30	16	10	15		6		2	3		3	204
	south									2	6	9	22	20	30	7	4	8	9			12	5		2	136
2 july mon	north	4	4		2					3	16	50	31	23	32	15	29	7	8	17	4	5	2	3		255
	south	2	2		2					1		10	37	37	21	18	10	11	7	9		6	4	6		183
3 july tue	north	2		2						26		19	38	32	43	15	18	1	3		15	1	4	1	9	229
	south	5		5					1	3		25	20	22	37	19	33	4	2		21	2	6	7	4	216
4 july wed	north	1					2		7	7	16	11	24	35	23	33	13	11	6	6	4	3		4	2	208
	south						5	1	2	6	6	9	30	19	28	11	16	24	6	7	4	2	8	4	6	194
5 july thu	north					1		2		8	16	21	25	42	53	20	32	7	10	16	5	2	2		6	268
	south							4		8	19	9	24	18	62	18	37	13	15	14	1	2	3		2	249
6 july fri	north			2						5	10	4	22	6	5			3		1			13			71
	south	2		1						4	6	9	19	2	7		9	1					2			62
7 july sat	north						2		4	13	17	19	17	51	23	13	8	14	3	8	2	2	1			197
	south						2		10	6	9	32	17	22	25	10	7	11	18	9	12		1			191
8 july sun	north				2	6	10	9	7	9	10	30	39	62	98	79	55	31	23		10	2	2		3	487
	south				1		5			7	3	14	28	40	52	43	40	33	31	6	7	8		2	1	321
9 july mon	north		4		3	7	5			18	14	9	20	27	12	41	38	24	23	17	7	4	2	2		277
	south		2			2	4			1	12	13	9	9	10	19	22	23	22	17	21	6			1	193
10 july tue	north	2				8	5	3	6	21	13	20	39	31	16	26	25	32	14	13	1	4				279
	south	1			1	1	3	2		7	13	20	9	40	12	8	28	36	35	4	5	5				230
11 july wed	north				2		4		23	3	14	10	8	12	23	15	8	8	8	8	6	2	5	4		163
	south				2	1	1	2	12	9	7	17	15	8	17	27	25	23	25	39	18		5			253
12 july thu	north						2	8	7	2	9	16	12	28	13	22	24	20	17	6	9	12	3			210
	south	1						8	4	1	8	21	20	21	21	27	40	13	35	21	10	4	2		2	259
13 july fri	north	2					2	2	32	32	29	30	28	41	25	30	47	31	31	12	42	5	13	21		455
	south	1					1		7	7	7	17	11	30	45	31	31	30	5	15	23	10	3	10		284
14 july sat	north								18	35	44	54	37	20	55	35	22	8	67	8	8	7	2			420
	south			11						7	15	26	18	42	60	30	15	34	13	11	5	2	1			290
15 july sun	north							3	5	26	54	75	32	26	59	24	30	32	13	21	11	13	2	10	3	439
	south								2	13	24	39	59	63	39	21	27	45	11	17	42	8	9	3		422
16 july mon	north		3						4	19	9	44	49	43	18	17	10	18	4	7	15	4	4	3		271
	south	1		2				3		3	15	22	23	60	50	13	22	11	2	17	12	10	10	3	2	281
17 july tue	north								2	4	5	22	32	33	23	21	11	7	4	3	5	9			3	184
	south									6	4	10	21	20	25	36	15	8	6	4	9	2		3		169
18 july wed	north							3		18	11	70	61	66	62	14	10	17	13	11	4	5	4	4	1	374
	south							2		4	9	14	47	17	74	29	24	58	22	6	2	10	14	3	2	337
19 july thu	north	2	2		3	4	3	3	3	15	13	59	72	19	27	42	40	18	27	4	6	2	2	3	2	371
	south	7	2		2	1		1	4	5	12	15	38	48	54	58	51	31	19	8	10	3	2	4		375
20 july fri	north		8				5	2		2	17	22	16	16	13	2	14		9				3			129
	south	3	5				2		2	9	3	20	17	3	16	26	15	8	6	2						137
21 july sat	north				3	6			2	8	24	23	56	75	55	52	36	42	21	19	7	2	3			434
	south				1			2	1	2	17	25	47	43	72	47	14	30	23	7	8		4			343
22 july sun	north		5							3	28	35	41	111	51	39	52	31	5	2	2		3			408
	south							1		3	13	50	32	34	95	63	46	24	27		9					397
23 july mon	north		4			2	6	11	7	9	22	22	44	38	79	66	33	41	26	6	4	1	1			422
	south		1	3			2	3	2	12	6	34	25	34	45	76	69	44	26	13	2	3	2		2	404
24 july tue	north	5					2			3		5	2	5		6	10	7	5	10	19	2			2	83
	south			2			2			2		4	9	11	6	8	8	10	2	9	12	6		2		93
25 july wed	north						5	15	26	7	23	25	42	64	46	42	28	31	11	3	16	6	3		1	394
	south					2	1	4	2	26	35	7	46	36	43	78	44	52	52	68	23	1	6			526
26 july thu	north							22		19	24	8	20	23	31	11	5	12	11	3	1					190
	south			2				10	8	15	21	9	27	54	12	8	20	14	15	5	2			2		224
27 july fri	north						5		3	3	1	15	4	14	9	10	11	11	8	5	4	7	2	3		115
	south						3	2	2	3	2	7	11	7	12	14	7	13	15	2	2	7	3	1		113
28 july sat	north							2	17	26	13	35	45	9	13	7	28	10	12	9	4	2	2	8		242
	south							3	2	12	16	39	52	39	10	20	11	24	31	20	35	4	6	4		328
29 july sun	north								11	25	23	48	38	14	18	18	7	14	6	3	1	4			2	232
	south							1		8	19	35	30	64	30	13	28	4	18	8	6		1	1		266
30 july mon	north									6	5	5	11	13	12	5	9	7	2	5		2	8	5		95
	south	3									4	17	14	16	10	12	5	6	3	2	3	1	2	3		101
31 july tue	north	2						7	2	2	14	52	67	44	51	29	55	24	10	2	10	11	4	3		389
	south	1						3	2	4	11	9	43	31	49	28	16	11	18	13	9	9	5			262
Total		47	42	30	24	41	89	144	249	573	839	1499	1818	1949	2087	1583	1457	1191	919	584	535	244	197	132	61	16334

Appendix 7; Program structure SIVAK II

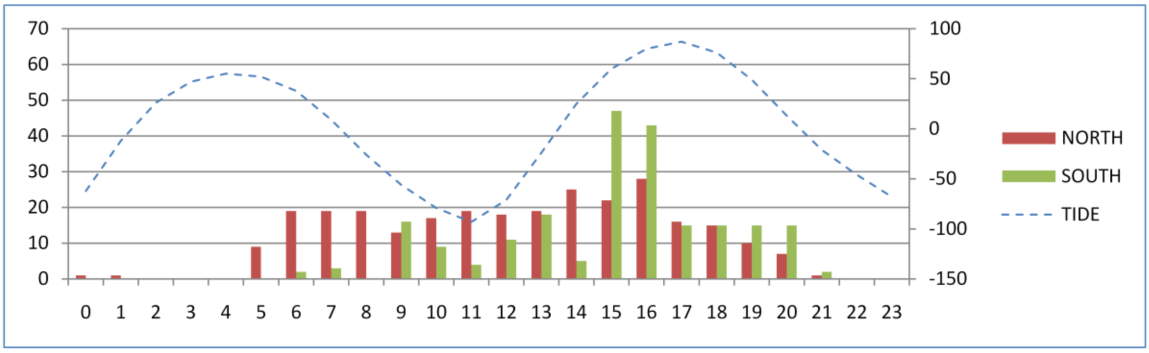


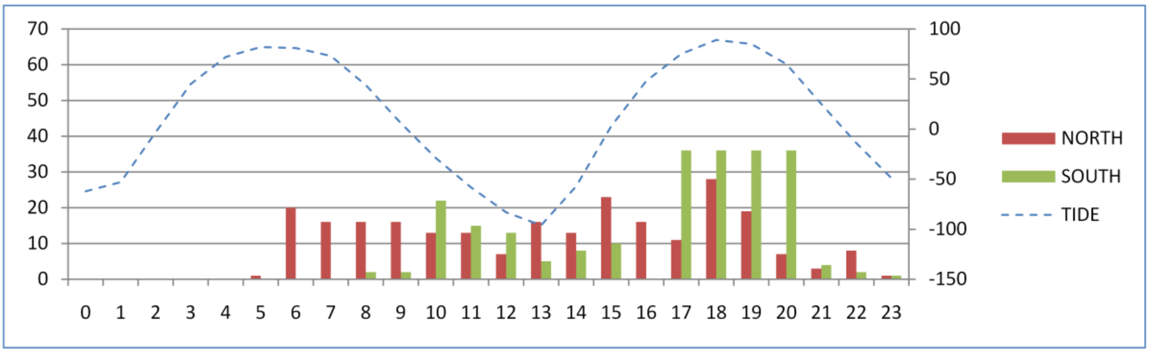
(Hofma, 2005)

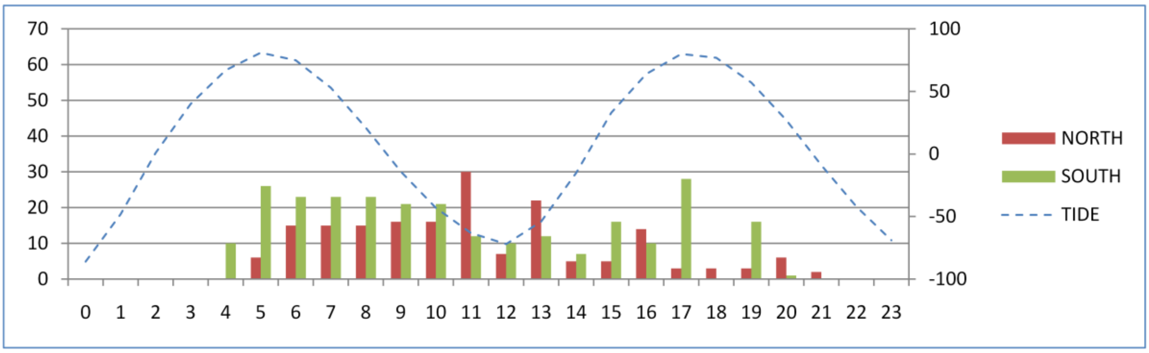
Appendix 8; Equally distributed navigation intensities over the 10th busiest days in 2005, 2006 and 2007

The 10th busiest days in 2005, 2006 and 2007 are all days with low tide as the central tide during the day, but unfortunately the 10th busiest days in 2005 and 2006 do not totally suit the general picture and matching travel advices.

Navigation heading north has on all days some peak intensities during ebbing water so those peaks are more equally spread over the period with ebbing water. Also the peak intensities during ebbing water for navigation heading south are more equally spread over the ebbing periods, but there were also some peaks which cannot be explained based on the navigation characteristics presented in chapter 5. This mainly concerns the year 2007 and those peaks are not altered.







Appendix 9; Calculation of the saturation flow

SATURATION FLOW

Saturation flow (s)

s = B1 * So

So	Basic saturation flow	1800 pcu/h
B1	Adjustment factor for geometric conditions	

B1 = Nlanes * Fw * Fhv * Fg * Fp * Fbb * Fa * Frt * Flt

Nlanes	2	
Fw	0,94	
Fhv	0,91	
Fg	1	
Fbb	1	
Fa	1	
Frt	1	(right turning movements)
Flt	1	(left turning movements)

B1	1,71

s	3079 pcu/h

Table 5.6.1 Lane width adjustment factor				
Lane width	2.6	3.0	3.5	4.0
f_w HCM	0.88	0.94	0.99	1.03
f_w *CAPCAL*	0.93	1.00	1.02	1.03

Table 5.6.2 Adjustment factor for heavy vehicles									
Percentage heavy vehicles	0	2	4	6	8	10	15	20	25
f_{HV}	1.00	0.99	0.98	0.97	0.96	0.95	0.93	0.91	0.89

Table 5.6.3 Adjustment factor for grade							
	Downhill				Uphill		
Grade %	-6	-4	-2	0	+2	+4	+6
f_g HCM	1.03	1.02	1.01	1.00	0.99	0.98	0.97
f_g CAPCAL	1.06	1.04	1.02	1.00	0.98	0.96	0.94

Table 5.6.4 Adjustment factor for parking (HCM)						
	# parking maneuvers per hour					
n_{lanes}	Not allowed	0	10	20	30	40
1	1.00	0.90	0.85	0.80	0.75	0.70
2	1.00	0.95	0.92	0.89	0.87	0.85
3	1.00	0.97	0.95	0.93	0.91	0.89

Table 5.6.5 Adjustment factor for bus blockage					
	# stopping buses per hour				
# lanes in lane group	0	10	20	30	40
1	1.00	0.96	0.92	0.88	0.83
2	1.00	0.98	0.96	0.94	0.92
3	1.00	0.99	0.97	0.96	0.94

Table 5.6.6 Adjustment factor for area type (HCM)		
Area type	Central business district	All other areas
f_{area}	0.90	1.00

Appendix 10; ODYSA®

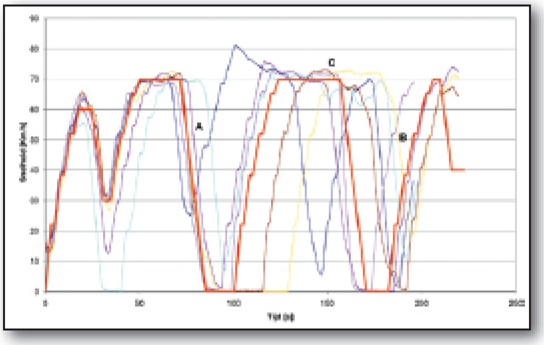
Een groene golf bij kruispuntafstanden tot meer dan 1000 meter, in beide rijrichtingen, tussen meerdere kruispunten en dat ook nog eens voor zowel het doorgaande als invoegende verkeer: het leek tot voor kort onmogelijk. Toch zijn dit de kenmerken van een nieuw verkeersregelsysteem, dat door DTV Consultants is ontwikkeld en op meerdere wegen is gerealiseerd.

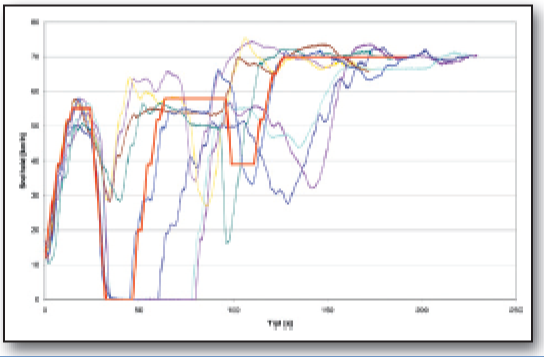
ODYSA® (Optimalisatie DoordYnamische SnelheidsAdvisering) is bedoeld om de doorstroming voor het doorgaande verkeer te verbeteren door het snelheidsgedrag van de weggebruikers af te stemmen op de verkeerstechnische situatie. Het snelheidsadvies wordt met behulp van speciaal ontwikkelde matrixsignaalgevers gecommuniceerd. Als de weggebruiker deze snelheid aanhoudt, is deze gegarandeerd van groen licht bij het eerstvolgende verkeerslicht op de doorgaande richting. Het advies wordt voor ieder voertuig afzonderlijk berekend, ongeacht of het verkeer op de hoofdrichtingen of van de zijrichtingen betreft. Indien de berekende adviessnelheid (voor ondergeschikte) zijstromen onder een instelbare minimum waarde ligt, wordt gecommuniceerd dat een groene golf niet mogelijk is. Dit geschiedt ook bij tijdelijke verstoringen van de doorstroming (door bijvoorbeeld een landbouwvoertuig) of in geval van congestie. Het systeem is opgebouwd rond meerdere halfstarre netwerkregelingen, waarbij met behulp van verkeersafhankelijke programmaselectie steeds de meest geschikte regeling wordt gekozen voor de periode van de dag. De ODYSA® functionaliteit is geïntegreerd in en wordt aangestuurd vanuit de normale verkeersregelinstallaties. ODYSA® is geschikt voor alle wegen met een wettelijk toegestane snelheid van 70 km/uur of 80 km/uur en met een relatief hoog percentage doorgaand verkeer.

ODYSA® zorgt voor een substantiële verbetering van de reistijden voor het doorgaande verkeer en een dito vermindering van het aantal stops. Daarmee verbetert niet alleen het rijcomfort voor weggebruikers, maar kan het systeem tevens als milieumaatregel worden ingezet. Als gevolg van het homogeniseren van de snelheden en het zoveel mogelijk voorkómen van plotselinge roodfasen levert het systeem daarnaast ook een bijdrage aan het verbeteren van de verkeersveiligheid.

Betere doorstroming

Het effect van ODYSA® op de doorstroming wordt zichtbaar gemaakt in de onderstaande grafieken, gebaseerd op een floating-car onderzoek op de Westpoortweg in Amsterdam. De geaccentueerde (rode) lijn is het referentieprofiel. De overige lijnen zijn de verschillende gemeten individuele ritten. De bovenste grafiek laat het snelheidsprofiel zien in de situatie waarbij op elk kruispunt een voertuigafhankelijke regeling in bedrijf is. Duidelijk zijn de scherpe snelheidsdalingen (A) te zien, de acceleratieperioden (B) en de (relatief korte perioden) met een constante snelheid (C). De onderste grafiek laat het snelheidsprofiel zien in de situatie waarbij ODYSA® actief is. Duidelijk is te zien dat de acceleratie en deceleratieperioden vrijwel verdwenen zijn en er gedurende lange tijd met een constante snelheid gereden kan worden. Ten opzichte van de traditionele voertuigafhankelijke regelingen heeft ODYSA® een positief effect op de reistijd en gemiddelde snelheid tot wel 18%. Door het instellen van een groene golf en de snelheidsadvisering met signaalgevers is een homogener en daarmee constanter rijgedrag te bereiken.





Frissere lucht

Met een in de verkeerstroom meerijdend voertuig, zijn een beperkt aantal emissiemetingen voor het ODYSA®-systeem op de Westpoortweg in Amsterdam uitgevoerd. Voor het meetvoertuig (voorzien van een benzinemotor) resulteert dit, ten opzichte van de voertuigafhankelijke regelingen, in een sterke afname van schadelijke stoffen:

- koolwaterstof (HC) met 84%;
- koolmonoxide (CO) met 91%;
- kooldioxide (CO_2) met 17%;
- stikstof (NO_x) met 66%.

Beleving

Uit een uitgebreid gebruikersonderzoek is gebleken, dat de weggebruikers het systeem op prijs stellen, al is de waardering van het doorgaande verkeer hoger dan van het zijverkeer. Een grote meerderheid van het doorgaand verkeer zegt het snelheidsadvies op te volgen en meent dat de verkeersveiligheid door het systeem wordt verbeterd. Opmerkelijk is dat bestuurders van vrachtwagens nog positiever over het systeem oordelen dan die van personenvoertuigen.

INLICHTINGEN

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Appendix 11; Effects of the possibilities to reduce the difference between arrival times

1. Lowering maximum speed to 100 km/h

Duration bridge opening (min)

Intensity road traffic (veh/h)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
150	4	4	4	4	4	4	4	4	5	5	5	5	5	5
200	4	4	4	4	4	5	5	5	5	5	5	5	5	5
250	4	4	4	4	5	5	5	5	5	5	5	5	6	6
300	4	4	4	5	5	5	5	5	5	5	6	6	6	6
350	4	4	4	5	5	5	5	5	6	6	6	6	6	7
400	4	4	5	5	5	5	5	6	6	6	6	7	7	7
450	4	4	5	5	5	5	6	6	6	6	7	7	7	7
500	4	4	5	5	5	6	6	6	7	7	7	7	8	8
550	4	5	5	5	6	6	6	7	7	7	7	8	8	8
600	4	5	5	5	6	6	6	7	7	8	8	8	9	9
650	4	5	5	6	6	6	7	7	8	8	8	9	9	10
700	4	5	5	6	6	7	7	7	8	8	9	9	10	10
750	4	5	5	6	6	7	7	8	8	9	9	10	10	11
800	4	5	6	6	7	7	8	8	9	9	10	10	11	11
850	4	5	6	6	7	7	8	9	9	10	10	11	12	12
900	5	5	6	6	7	8	8	9	10	10	11	12	12	13
950	5	5	6	7	7	8	9	10	10	11	12	12	13	14
1000	5	5	6	7	8	8	9	10	11	12	12	13	14	15
1050	5	6	6	7	8	9	10	11	11	12	13	14	15	16
1100	5	6	7	7	8	9	10	11	12	13	14	15	16	16
1150	5	6	7	8	9	10	11	12	13	14	15	16	17	18

2. No guarantee of a free passage for freight traffic

Duration bridge opening (min)

Intensity road traffic (veh/h)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
150	0	0	0	0	0	0	1	1	1	1	1	1	1	1
200	0	0	0	0	0	1	1	1	1	1	1	1	1	1
250	0	0	0	0	1	1	1	1	1	1	1	1	2	2
300	0	0	0	1	1	1	1	1	1	2	2	2	2	2
350	0	0	1	1	1	1	1	1	2	2	2	2	2	3
400	0	0	1	1	1	1	1	2	2	2	2	3	3	3
450	0	0	1	1	1	1	2	2	2	2	3	3	3	3
500	0	1	1	1	1	2	2	2	3	3	3	3	4	4
550	0	1	1	1	2	2	2	3	3	3	3	4	4	4
600	0	1	1	1	2	2	2	3	3	4	4	4	5	5
650	0	1	1	2	2	2	3	3	4	4	4	5	5	5
700	0	1	1	2	2	3	3	3	4	4	5	5	6	6
750	0	1	1	2	2	3	3	4	4	5	5	6	6	7
800	1	1	2	2	3	3	4	4	5	5	6	6	7	7
850	1	1	2	2	3	3	4	5	5	6	6	7	7	8
900	1	1	2	2	3	4	4	5	6	6	7	7	8	9
950	1	1	2	3	3	4	5	5	6	7	7	8	9	9
1000	1	1	2	3	4	4	5	6	7	7	8	9	10	10
1050	1	2	2	3	4	5	6	6	7	8	9	10	10	11
1100	1	2	3	3	4	5	6	7	8	9	10	10	11	12
1150	1	2	3	4	5	6	7	7	8	9	10	11	12	13

3. Implementing ODYSA®

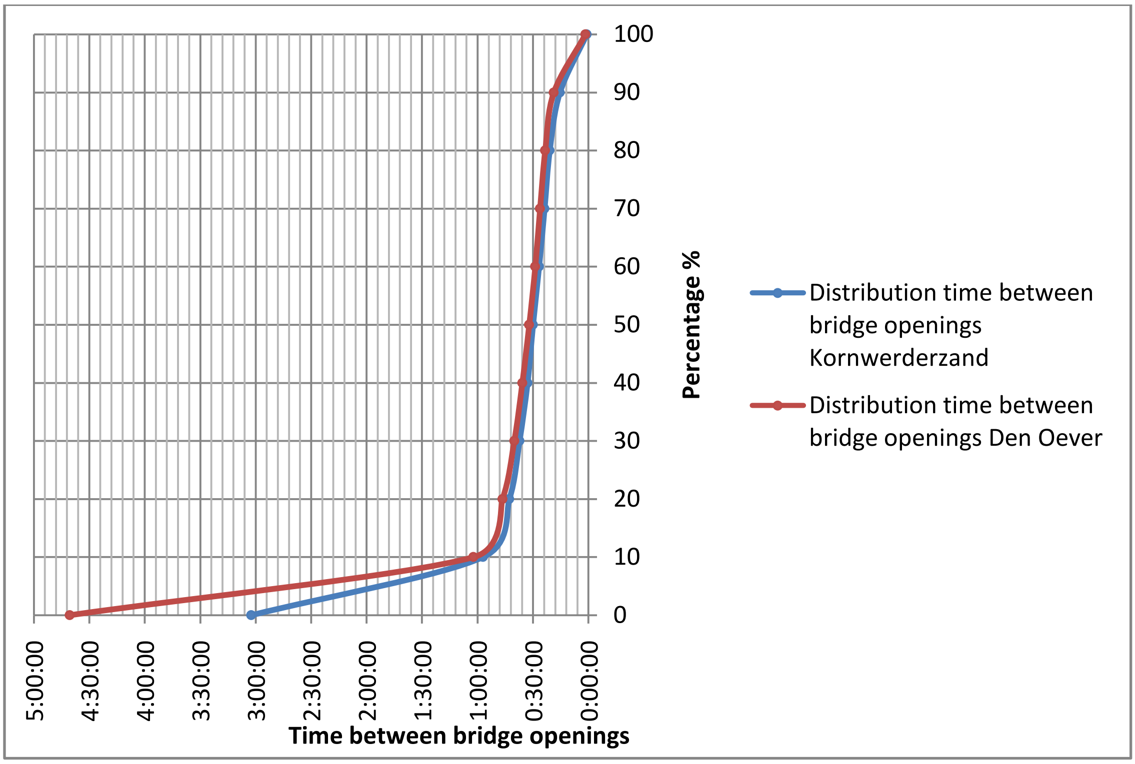
Duration bridge opening (min)

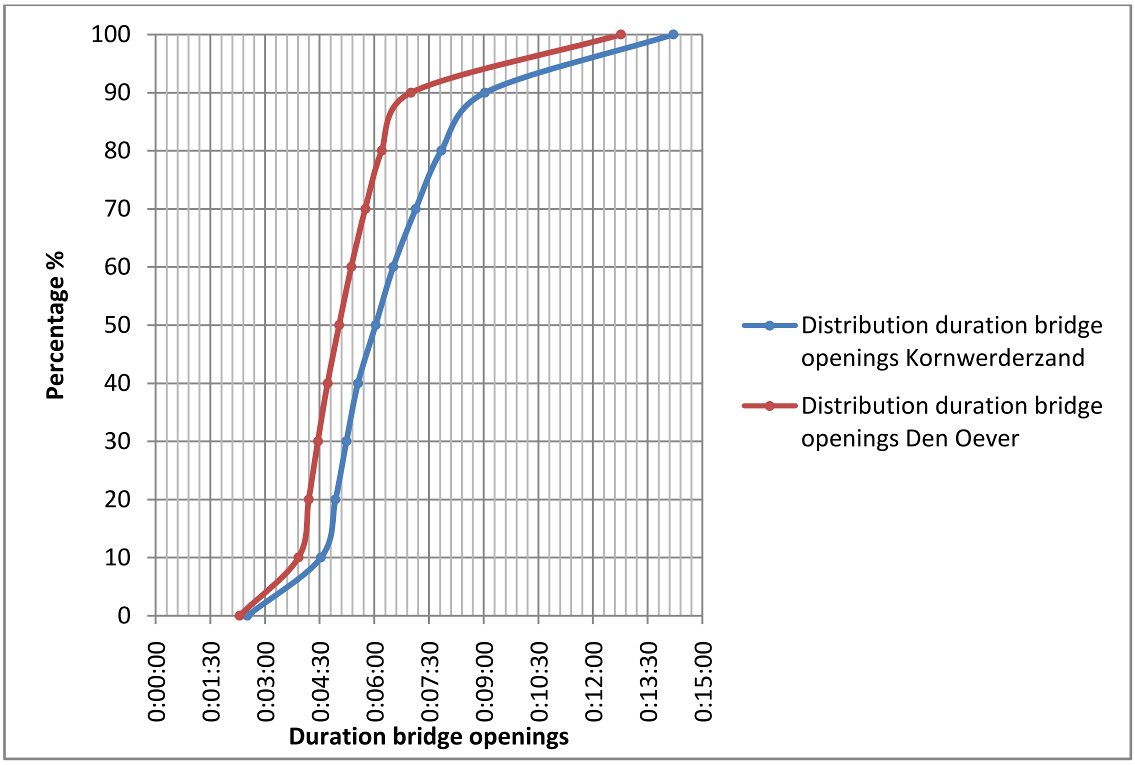
Intensity road traffic (veh/h)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
150	-3	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
200	-3	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-1	-1	-1
250	-2	-2	-2	-2	-2	-2	-2	-2	-1	-1	-1	-1	-1	-1
300	-2	-2	-2	-2	-2	-2	-2	-1	-1	-1	-1	-1	-1	0
350	-2	-2	-2	-2	-2	-2	-1	-1	-1	-1	-1	0	0	0
400	-2	-2	-2	-2	-2	-1	-1	-1	-1	0	0	0	0	0
450	-2	-2	-2	-2	-1	-1	-1	-1	0	0	0	0	1	1
500	-2	-2	-2	-1	-1	-1	-1	0	0	0	0	1	1	1
550	-2	-2	-2	-1	-1	-1	0	0	0	1	1	1	1	2
600	-2	-2	-2	-1	-1	0	0	0	1	1	1	2	2	2
650	-2	-2	-1	-1	-1	0	0	1	1	1	2	2	2	3
700	-2	-2	-1	-1	0	0	0	1	1	2	2	3	3	3
750	-2	-2	-1	-1	0	0	1	1	2	2	3	3	4	4
800	-2	-2	-1	-1	0	1	1	2	2	3	3	4	4	5
850	-2	-1	-1	0	0	1	1	2	3	3	4	4	5	5
900	-2	-1	-1	0	1	1	2	2	3	4	4	5	5	6
950	-2	-1	-1	0	1	1	2	3	3	4	5	6	6	7
1000	-2	-1	0	0	1	2	3	3	4	5	5	6	7	8
1050	-2	-1	0	1	1	2	3	4	5	5	6	7	8	9
1100	-2	-1	0	1	2	3	3	4	5	6	7	8	9	9
1150	-2	-1	0	1	2	3	4	5	6	7	8	9	10	10

These results are approximations based on the philosophy behind the ODYSA® system. This is slowing down the first, fast, vehicles and speed up the last, slow, vehicles to compact the platoon of vehicles and therefore reducing the difference between the arrival times of the vehicles in the platoon.

Appendix 12; Distribution Time between and Duration bridge openings





Appendix 13; Distribution of the road traffic intensities