Final report

Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

A feasibility study

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“A rising tide lifts all boats”

- John F. Kennedy -
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Preface

This graduation report marks an important milestone in my studying career at the Delft University of Technology. The master thesis is part of the master Ports & Waterways at the faculty of Civil Engineering and Geosciences. In the field of Ports & Waterways this report describes a feasibility study towards optimizing the passage of fast ferry navigation at the Schellingwoude lock complex. This study has been performed in cooperation with Ingenieursbureau Gemeente Amsterdam.

This report provides detailed insight into the introduction of fast ferry navigation to the existing lock operation process at the Schellingwoude lock complex. In order to optimize the passage of fast ferry navigation the feasibility of multiple lock system alternatives are investigated.

This study is carried out under supervision of the graduation committee as stated on the previous page. I’d like to thank all members of the graduation committee for their support and guidance during the graduation period. I also like to thank ir. J. Karst (DRO) and ir. F. Pantano (IBA) for sharing their knowledge on related subjects. Next to that I’d like to thank the employees of Rijkswaterstaat, especially the lock operators at the Schellingwoude lock complex, for providing valuable information on the functional demands associated with the lock complex. Last but not least I’d like to thank my friends and family for their support during my whole studying career.

Marco J. Rispens
October 2011
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Summary

Traditionally, water based public transport has a large contribution to the accessibility of rural areas in the Netherlands. Initiated by the industrial revolution a major shift from water based to land based public transport occurred. Until recent history water based public transport was considered unfeasible. Nowadays land based transport modes are threatened by their own success. The shortage of land available for land based public transport in rural areas creates congestion on highways and endangers the accessibility of many city centres. City centres which adopted their metropolitan status due to their location near the waterfront. This fact gives rise to investigate the feasibility of water based public transport in existing city centres and areas to be developed. The expansion of Almere, being part of the Amsterdam metropolitan region, outside the existing flood defence system in lake Markermeer is a strong example showing a large potential on accessibility by means of fast ferry navigation. An integral planning of water and land based infrastructure serving commuter related passenger transport, among other success factors, increases the success of tackling bottlenecks in the existing hydraulic infrastructure. For the water based public transport connection between Amsterdam Central Station and Almere the passage of the Schellingwoude lock complex is considered to be the most significant bottleneck causing previous attempts of shipping companies on this route to fail due to a lack of feasibility. Contradictory functional demands present at this lock complex in combination with the large yearly volume of commercial and recreational navigation passing this lock complex during the normative month (August) causes the lock operation process to involve an average passage time of fast ferry navigation outside the target conditions associated with water based public transport. In order to optimize the passage of fast ferry navigation at the Schellingwoude lock complex the feasibility of multiple lock system alternatives is investigated, being:

- Alternative 1a – Priority arrangement;
- Alternative 1b – Priority arrangement and separate locking method;
- Alternative 2a – Reservation of one lock chamber;
- Alternative 2b – Reservation of two lock chambers;
- Alternative 3 – Priority arrangement and reservation of one lock chamber;
- Alternative 4a – Additional minimal lock chamber;
- Alternative 4b – Additional CEMT-class Vlb lock chamber;
- Alternative 5 – Additional innovative structure.

The performance criteria determining the feasibility of the proposed lock system alternatives are based on the target conditions associated with water based public transport derived from a travel time analysis on the preferred route between Amsterdam Central Station and Almere. The actual performance analysis is elaborated using the SIVAK2 simulation model. From the performance analysis it is concluded that reservation of one lock chamber (Alternative 2a) and the construction of an additional lock chamber with minimal dimensions serving fast ferry navigation (Alternative 4a) are the best performing alternatives. Both alternatives lead to an average passage time of fast ferry navigation within the target conditions associated with fast ferry navigation and within the prescribed target conditions applied for commercial and recreational navigation. The best performing alternatives are further
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investigated using a social cost-benefit analysis. This analysis shows that alternative 4a involves the least costs associated with direct effects compared to alternative 2a during a life span of 100 years. This is mainly due to the effect of large financial consequences of additional waiting time of commercial and recreational navigation passing the Schellingwoude lock complex.
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List of abbreviations

AR
RK

Amsterdam Rhine Channel
CBS

Statistics Netherlands
CEMT

Conférence Européenne des Ministres de Transport
CEVNI

European Code for Inland Waterways
DNWP

Dutch National Water Plan
DRO

Department of spatial planning of the city of Amsterdam
OEI

Overview Impacts Infrastructure
GE

Global Economy
HLL

Highest Locking Level
IBA

Ingenieursbureau Gemeente Amsterdam
IVS-90

Information and Tracking system
IWT

Inland Waterway Transport
LLL

Lowest Locking Level
MER

Environmental Impact Assessment
MIRT

Dutch framework of Long-Term Programme for Infrastructure, Spatial Planning and Transport
MKBA

Social Cost-benefit Analysis
NZK

North Sea canal
RWS

Rijkswaterstaat
SIVAK

Simulation model on handling of traffic at hydraulic structures
TAW/ENW

Dutch Advisory Committee on flood defences
WLO

Welfare and Living environment
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PART 1: General description
1 Introduction

Chapter 1 describes the background of the problem handled in this research. It also focuses on the approach of objectives within this study.

1.1 Background

The cities of Amsterdam and Almere are ambitious to expand. In 2009, the Dutch government approved the National Order Amsterdam-Almere-Markermeer in which 60,000 newly-built houses are planned. Due to this expansion, the city of Almere will become the fifth largest city of the Netherlands. The planned housing is located in lake Markermeer, westward of the current city of Almere. This area is also referred to as Almere IJland. This large scale plan comprises building outside the existing flood defence system in the Netherlands. Housing in a water rich environment provides opportunities for water based public transport. Water based public transport by means of a fast ferry can play a major role in the accessibility of this area to be developed. Next to regional expansion, the increasing congestion of motorways connecting Amsterdam and Almere is an important motivation to explore the possibilities of water based public transport. A fast, reliable and direct connection between Amsterdam Central Station and Almere IJland will increase the economic value of both cities [1]. Focussing on regional accessibility IBA was asked by the department of spatial planning of the city of Amsterdam (DRO) to perform a study towards the technical feasibility of a water based public transport connection on the route between Amsterdam Central Station and Almere IJland.

1.1.1 Transport demand

Spatial planning studies by local governments and project developers show a future transport demand based on a forecast. Figure 1 illustrates the spatial planning developments generating the transport demand in the region. The blue line indicates the possible future transport demand on the route between Amsterdam Central Station and Almere IJland, which forms an important motivation to perform this study. The future transport demand is expected to increase depending on regional developments at the waterfront in both regions [1].

Figure 1: Spatial planning development in the Amsterdam-Almere region [2].
To meet the future increase of transport demand in the region, additional supply of transport capacity is required. The transport capacity is recorded in accessibility plans written by the cities of Amsterdam and Almere. In these plans a large transport capacity is attributed to land based infrastructure, the so-called IJmeer fixed link. The role of water based public transport is not included in these plans, due to bottlenecks on the route between Amsterdam Central Station and Almere IJland. These bottlenecks are explained in paragraph 1.2. DRO acknowledges the added value of a multi modal transport network in the region and is willing to investigate the feasibility of such a water based public transport connection. Within regional accessibility, water based public transport is expected to have a complementary role, serving approximately 2% of the total daily passenger transport between Amsterdam and Almere in 2020 [1]. The exact transport capacity that can be covered by water based public transport is largely dependent on the vessel type and timetable. In this research a transport capacity ranging between 150 and 300 passengers per direction per hour is adopted, providing sufficient capacity to serve the expected transport demand. The main goal of the connection is to serve commuter related passenger transport.

1.1.2. Preferred route
Passengers prefer to travel to their destination in a short and reliable time frame with the least amount of transfers. A transfer is considered to be an additional risk towards a possible delay and forms an important factor in the individual assessment of passengers on the preferred transport mode. In a multi modal public transport network, transfers cannot be prevented. In order to minimize the travel time and number of transfers, a direct water based connection between large regional public transport hubs is essential. With respect to the transport demand on the route between Amsterdam Central Station and Almere IJland, a direct water based public transport connection is possible. This implies that the hydraulic infrastructure is present. In the existing situation only one route provides this connection. This is due to the urban character of the region. The preferred route is the shortest route, which also crosses the least number of hydraulic structures. This will lead to the shortest possible travel time if the waterway width is sufficient to maintain a minimal service velocity. The crossing of a hydraulic structure is unavoidable in the existing situation. Other possible routes crossing the Amsterdam Rhine Channel (ARK) ask for a physical adaptation of the hydraulic infrastructure and are not preferred due to the restricted navigational space within this channel and in combination with a large volume of commercial navigation. In figure 2 the preferred route of a water based public transport connection between Amsterdam Central Station and Almere IJland is shown. This route crosses the Schellingwoude lock complex situated between lake Binnen-IJ and lake Buiten-IJ.
1.1.3. Travel time analysis
The travel time of a water based public transport connection depends on the sailing distance along the preferred route and sailing velocity during the various stages of a one-way trip. A one-way trip is described by a direct connection between two locations without stops in between. The total sailing distance between Amsterdam Central Station and Almere is approximately 16 km. In this assumption the berth of the vessel at Almere is located at the most westerly location at the existing dike near Almere IJland. This location provides an optimal transfer between land and water based public transport in the existing and future situation. The exact location of the berth does not influence the locking process at the Schellingwoude lock complex.

As mentioned in paragraph 1.1 the deployment of a fast ferry on the route between Amsterdam Central Station and Almere is essential. A fast ferry is capable of sailing with a service velocity ranging up to 60 km/h. A high average velocity during the various stages of a one-way trip will shorten the total travel time, leading to a more competitive transport mode. In table 1 an overview of stages contributing to the total travel time of fast ferry navigation on the preferred route is listed. The average sailing velocity during the sailing stages is based on existing water based public transport connections in the Netherlands and interviews with representatives of the shipping companies of Connexxion [25] and Aqualiner [26]. Additional specifications on the fast ferry are discussed in paragraph 6.4. The time involved during the stage of lockage is based on interviews with the lock operators of Rijkswaterstaat at the Schellingwoude lock complex [24]. Rijkswaterstaat is the executive arm of the Dutch Ministry of Infrastructure and the Environment. On behalf of the Minister and State Secretary, Rijkswaterstaat is held responsible for the design, construction, management and maintenance of the main infrastructure facilities in the Netherlands. The calculated travel time analysis is not supported by results from sailing trails. Planned trails by a public shipping company were cancelled in 2006, due to financial reasons [26]. As a result of changing nautical conditions the possible deviation of the average partial time per stage is added to provide information on the variability of the calculated value.
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

Table 1: Stages contributing to the total travel time, direction East.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Location</th>
<th>Distance</th>
<th>Average velocity</th>
<th>Partial time</th>
<th>Mean (µ)</th>
<th>St. dev. (σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embarking</td>
<td>Amsterdam Central Station</td>
<td>-</td>
<td>-</td>
<td>2.00 min</td>
<td>0.50 min</td>
<td></td>
</tr>
<tr>
<td>De-berthing</td>
<td>Amsterdam Central Station</td>
<td>200 m</td>
<td>20 km/h</td>
<td>1.00 min</td>
<td>0.00 min</td>
<td></td>
</tr>
<tr>
<td>Sailing</td>
<td>Lake Binnen-IJ</td>
<td>3.700 m</td>
<td>50 km/h</td>
<td>4.50 min</td>
<td>1.00 min</td>
<td></td>
</tr>
<tr>
<td>Sailing</td>
<td>Western outer port</td>
<td>300 m</td>
<td>12 km/h</td>
<td>1.50 min</td>
<td>0.00 min</td>
<td></td>
</tr>
<tr>
<td>Lockage</td>
<td>Lock chamber at Schellingwoude</td>
<td>-</td>
<td>-</td>
<td>15.00 min</td>
<td>10.00 min</td>
<td></td>
</tr>
<tr>
<td>Sailing</td>
<td>Eastern outer port</td>
<td>300 m</td>
<td>12 km/h</td>
<td>1.50 min</td>
<td>0.00 min</td>
<td></td>
</tr>
<tr>
<td>Sailing</td>
<td>Lake Buiten-IJ / Lake Markermeer</td>
<td>11.000 m</td>
<td>50 km/h</td>
<td>13.50 min</td>
<td>3.00 min</td>
<td></td>
</tr>
<tr>
<td>Berthing</td>
<td>Almere IJLand</td>
<td>200 m</td>
<td>20 km/h</td>
<td>1.00 min</td>
<td>0.00 min</td>
<td></td>
</tr>
<tr>
<td>Disembarking</td>
<td>Almere IJLand</td>
<td>-</td>
<td>-</td>
<td>2.00 min</td>
<td>0.50 min</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>Preferred route</td>
<td>15.700 m</td>
<td>22.5 km/h</td>
<td>42.00 min</td>
<td>10.50 min</td>
<td></td>
</tr>
</tbody>
</table>

From the travel time analysis we can conclude that the locking process at the Schellingwoude lock complex is of great influence on the total travel time. It also shows that the locking process adds largely to the possible deviation of the total travel time. A possible stop at the developing area at IJburg is left out of the travel time analysis since this area is already made accessible with a high capacity land based public transport connection (IJtram). It is calculated that an additional water based public transport connection is not competitive with the IJtram and also leads to an increase of the total travel time on the route between Amsterdam Central Station and Almere. Additional travel time which decreases the transport demand on the proposed connection. In table 2 an overview of competitive transport modes on the route between Amsterdam Central Station and Almere IJLand is listed.

Table 2: Competitive transport modes on preferred route.

<table>
<thead>
<tr>
<th>Transport mode</th>
<th>No. of transfers</th>
<th>Distance</th>
<th>Rush hour</th>
<th>Average velocity</th>
<th>Travel time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean (µ)</td>
<td>St. dev. (σ)</td>
</tr>
<tr>
<td>Car [4]</td>
<td>0</td>
<td>27.5 km</td>
<td>No</td>
<td>59 km/h</td>
<td>28 min</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
<td>33 km/h</td>
<td>50 min</td>
</tr>
<tr>
<td>Land based public transport [5]</td>
<td>1</td>
<td>32.5 km</td>
<td>No</td>
<td>56 km/h</td>
<td>35 min</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
<td>56 km/h</td>
<td>35 min</td>
</tr>
<tr>
<td>Water based public transport</td>
<td>0</td>
<td>15.7 km</td>
<td>-</td>
<td>22.5 km/h</td>
<td>42 min</td>
</tr>
</tbody>
</table>

In order to make sure that water based public transport offers a reasonable alternative to land based public transport, the average travel time of water based public transport should be lowered by 7 minutes. This margin can only be found within the locking process at the Schellingwoude lock complex. This results in an optimal average target passage time of fast ferry navigation in the order of 8
minutes. To ensure a minimal reliability of the passage time the 95% confidence band of the average target passage time should not exceed 15 minutes. The target conditions associated with passage of fast ferry navigation at the Schellingwoude lock complex is listed in table 3. The standard deviation ($\sigma$) is calculated based on the assumption that the 95% confidence band is 7 minutes above average.

Table 3: Target average passage time of fast ferry navigation.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Location</th>
<th>Passage time</th>
<th>Mean ($\mu$)</th>
<th>St. dev. ($\sigma$)</th>
<th>Upper 95% confidence band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lockage</td>
<td>Lock chamber at Schellingwoude lock complex</td>
<td>8.00 min</td>
<td>3.60 min</td>
<td>15.00 min</td>
<td></td>
</tr>
</tbody>
</table>

### 1.2. Bottlenecks

In the travel time analysis assumptions of the average velocity have been made to calculate the total travel time. From the point of view of a shipping company the average velocity of a fast ferry depends on internal and external factors. Internal factors are related to the strengths and weaknesses internal to the organization of a shipping company. As stated before the average velocity is largely dependent on the governing vessel type, which can be considered as an internal factor controlled by the shipping company. External factors are related to the opportunities and bottlenecks presented by the external environment to a shipping company. Large deviations in time associated with the various stages during a sailing trip supplying a minimal transport demand on the route between Amsterdam and Almere are considered to be a bottleneck. Bottlenecks are the main reasons why water based public transport connections between Amsterdam and Almere lack feasibility. On this route the following bottlenecks are listed in order of relevance:

- Locking process at Schellingwoude lock complex (Operational time);
- Non-operational time at Schellingwoude lock complex;
- Sailing velocity at lake Binnen-IJ;
- Icing at lake IJmeer.

#### 1.2.1. Locking process at Schellingwoude lock complex (Operational time)

The Schellingwoude lock complex is considered to be the most significant bottleneck on the route between Amsterdam Central Station and Almere. The passage time involved in the locking process adds significantly to the total travel time on the route between Amsterdam Central station and Almere [9]. The bottleneck induced by the locking process at the Schellingwoude lock complex is the main topic of this study. The exact problem definition related to this bottleneck is discussed in paragraph 1.3.
1.2.2. Non-operational time at Schellingwoude lock complex
In principal the Schellingwoude lock is operational to serve all navigation on surrounding waters. Only during operational time the locking process is performed. During non-operational time the locking process is aborted. Non-operational time occurs due to:

- Extreme locking levels;
- Extreme wave conditions;
- Icing inside the lock chambers;
- Inspection and maintenance activities;
- Accidents.

Extreme locking levels and wave conditions also affect the locking process during operational time before it is decided to abort the lock operation process. The return period of these hydraulic phenomena are determined in this study. Icing inside the lock chamber is expected to occur with the same frequency as icing at lake IJmeer as described in paragraph 1.2.4. Maintenance and repair affects the lock capacity in case of local abortion of the locking process at one of the lock chambers. This factor is further investigated in paragraph 4.4.3.

1.2.3. Sailing velocity at lake Binnen-IJ
The maximum sailing velocity at lake Binnen-IJ is limited to 12 km/h due to the limited waterway width in combination with the relative high traffic intensity. This regulation applies to all navigation, excluding vessels of competent authorities. In the travel time analysis on the route between Amsterdam Central Station and Almere an average sailing velocity of 50 km/h is assumed. The assumption is based on the fact that in various cases a permit allowing a sailing velocity above 12 km/hr is granted to specific vessel types. A permit can be granted if the conditions regarding nautical safety are not endangered. The permit granted to Connexxion on sailing above the maximum sailing velocity at the Noordzeekanaal (NZK) is an example of such an exception. Based on similar situations in the Netherlands it is concluded that the maximum sailing velocity within a certain area should not be a reason in advance to dismiss the possibilities of fast ferry navigation [8]. With respect to the sailing distance along lake Binnen-IJ (3.900 m), a permit granting a higher maximum sailing velocity would decrease the total travel time. Until a permit is granted, the limited sailing velocity at lake Binnen-IJ is considered to be an important bottleneck. This bottleneck is not discussed in this research.

1.2.4. Icing at lake IJmeer
A third bottleneck on the route between Amsterdam Central Station and Almere is caused by icing during the winter period. From recent winter periods it is known that icing of freshwater at lake Markermeer causes inland navigation to sail in a convoy behind an icebreaker or even may come to a halt. In both situations the average sailing velocity of a fast ferry can no longer be according to the service schedule. The design of fast ferries is not suited for sailing in these conditions. In 2010 icing at lake IJmeer was recorded during 10 days. Icing is considered to be a force majeure and is not further investigated in this research.
1.3. Problem definition

As concluded in paragraph 1.2.1 the locking process at the Schellingwoude lock complex is considered to be a significant bottleneck in the water based public transport route between Amsterdam Central Station and Almere. This conclusion is supported by Rijkswaterstaat and multiple (public) shipping companies involved in previous attempts to exploit a feasible water based public transport connection passing the Schellingwoude lock complex [24]. Until today little research is done to investigate effect and feasibility of the addition of fast ferry navigation to the existing lock operation process. It is known that the average passage time adds a significant contribution to the total travel time of a fast ferry on a one-way route. Also the large variability of the passage time is considered to be a bottleneck. This value is strongly related to the fluctuations in volume and arrival pattern of all navigation passing the Schellingwoude lock complex. The variations in passage time contradict with punctual performance associated with a water based public transport connection which are recorded in the target service level. Among other factors determining the service level of water based public transport, passengers need to rely on a punctual performance of a timetable in order to prefer water based public transport above other transport modes. Also an integral joining of water based and land based public transport connections leads to an increase of transport demand enhancing the feasibility of a water based connection. Globally the following problem statement is defined:

The existing lock operation process at the Schellingwoude lock complex needs to be optimized to incorporate fast ferry navigation and the functional demands associated with water based public transport.

1.4. Objectives

The objectives of this research are related to the locking process at the Schellingwoude lock complex, within the water based public transport connection between Amsterdam Central Station and Almere IJland. This means that the problem definition related to the passage time of fast ferry navigation is investigated and optimized in accordance with the boundary conditions imposed by water based public transport in general and functional demands related to the locking process at the Schellingwoude lock complex. This involves:

- investigating water based public transport in general;
- investigating water based public transport in relation to a lock passage;
- investigating functional demands of the Schellingwoude lock complex;
- investigating factors and components in the locking process at the Schellingwoude lock complex;
- performing a sensitivity analysis on factors influencing the locking process;
- analysing possible lock system alternatives optimizing the passage time of fast ferry navigation and their effect on other navigation;
- investigating future navigation scenarios (including fast ferry navigation);
- analysing the performance of lock system alternatives in combination with normative traffic scenarios;
- determining the feasibility of lock system alternatives by means of a social cost-benefit analysis.
It is mentioned that this research provides general information on water based public transport on the connection between Amsterdam Central Station and Almere. Research on the locking process focuses on the specific situation at the Schellingwoude lock complex.

1.5. Research methodology

In order to achieve the objectives stated in paragraph 1.4 multiple research methods are applied. Initially a literature study is performed to identify the background of the problem definition and the deviation between the existing situation and the possible water based public transport connection. A literature study also provided information on similar situations abroad and detailed information on boundary conditions leading to the present design of the Schellingwoude lock complex. Together with interviews and site visits historical data on navigation and previous attempts of the passage of fast ferry navigation were obtained. Historical data on navigation is extrapolated to provide information on short term navigation scenarios (2012). From literature, midterm scenarios (2020) are derived to account for future trends in Inland Waterway Transport (IWT). To assess the feasibility of the proposed lock system alternatives in relation to various normative navigation scenarios a performance analysis and a social cost-benefit analysis are executed. The performance analysis is elaborated using a simulation model. This approach is explained is paragraph 7.1.

1.6. Report structure

This report is divided into two parts. Part 1 provides general information on subject discussed in this report. Part 2 focuses on the elaboration of the feasibility analysis measuring and judging the performance of various lock operation alternatives in combination with normative scenarios.

1.6.1. Part 1

In chapter 2 general information on the water based public transport is provided, leading to the identification of boundary conditions related to public transport. Chapter 3 describes the functional demand leading to the present state of the Schellingwoude lock complex. In chapter 4 variables part of the lock operation system at the Schellingwoude lock complex are listed.

1.6.2. Part 2

Chapter 5 describes possible lock system alternatives leading to the optimization of the passage time of fast ferry navigation. In chapter 6 normative navigation scenarios are identified based on historical data and forecasts of future developments. Chapter 7 focuses on the approach and results of the performance analysis using a simulation model. This chapter also includes a sensitivity analysis of factors influencing the locking process. Chapter 8 contains the social cost-benefit analysis based on the best performing alternatives. In chapter 9 an overview of conclusions and recommendations is added.
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

2 Water based public transport

Chapter 2 describes important aspects related to water based public transport in general. This information leads to the identification of public transport related boundary conditions relevant for optimizing the passage of fast ferry navigation at the Schellingwoude lock complex.

2.1 History

The Netherlands are involved in a long tradition related to water based public transport. Until the start of the twentieth century sailboats, barges and steamships were used to provide public transport. Especially in the western part of the Netherlands this type of public transport was commonly used. This low-lying part of the Netherlands is characterized by a delta landscape and therefore provided with a large natural hydraulic infrastructure network. interconnected water systems made it possible to transport large volumes of goods and people without the construction of expensive infrastructure. Later in history land based public transport became more attractive, driven by the industrial revolution. Public transport by means of trains and trams surpassed passenger vessels as a common form of transport, due to the fast and flexible potential of land based public transport. After World War 1 the role of water based public transport was largely taken over by bus. Apart from the passenger services across the inland seas and some tourist driven connections across inland waters, water based public transport was considered to be unfeasible from the mid-fifties until the end of the twentieth century. The emerging automobile industry also contributed to this phenomena. From the moment many land based infrastructure suffered from an increase of congestion, water based public transport connections became attractive again. Especially highly populated urban areas with a large natural network of hydraulic infrastructure show a large potential on water based transport capacity [3].

2.2 Present

In 1996 the Dutch Ministry of Infrastructure and Environment started the campaign Samen werken aan Bereikbaarheid, to enhance water based public transport and to ease the congestion on roads. During this campaign multiple water based public transport connections were established using subsidy of local and national governments. These connections were commissioned to serve additional transport capacity within the existing public transport network. Minimal requirements related to these connections were applied to increase the regional accessibility of urban areas [3]. Globally these requirements were:

- Sailing according to a fixed timetable;
- No transport of vehicles;
- Minimum sailing velocity of 30 km/h.

Within the period of these experiments five water based routes were operated by (public) shipping companies under supervision of Rijkswaterstaat:

1. The first route commissioned was the route between Velsen Zuid and Amsterdam Central Station. On the 27th of April 1998 the operator Fast Flying Ferries, member of the Connexxion company, started to exploit this water based transport...
route in the province of Noord-Holland. The vessels deployed to support this connection were Ukraine-build hydrofoils. Initially these hydrofoils were planned to sail on a reduced service. This timetable was expanded later on due to an increase of transport demand. Every hour two vessels depart from both directions. This service is still running today. The success of this connection is largely depending on the bad accessibility of the Velsen area by car and land based public transport.

2. On the route between Amsterdam and Lelystad operations started on the 20th of September 1999. The operation was owned by the Amsterdam-based shipping company Flevo Ferries. In January 2000 also the route Amsterdam – Almere was added to the schedule. Clients of this route were the province of Flevoland and Amsterdam metropolitan governance. During rush hour there was a departure every thirty minutes, outside rush hour an hourly schedule was offered. Because of the Schellingwoude lock complex on the route between Amsterdam and Almere/Lelystad, the liability of the timetable was very uncertain. To prevent the passage of the Schellingwoude lock complex a connecting bus service was offered from the island of Zeeburg to Amsterdam Central Station. Additional travel time and a lack of comfort due to poor transfer facilities resulted in large decrease of transport demand. This service was aborted on the 16th of March 2000. At that time no further research was performed on the passage of fast ferry navigation at the Schellingwoude lock complex.

3. On the 1st of November 1999 the operator Waterbus B.V., member of the Connexxion company, and a division of the municipality of Dordrecht started the exploitation of two water based routes in the tributaries of the Maas-river in the Drechtsteden-area. Every city in the area was connected to a thirty-minute timetable. The vessels used were catamaran-type vessels which are capable of carrying 120 passengers with a speed of 35 km/h. This service is still running today as a result of the congested road network during rush hour in this area.

4. Also on the 1st of November 1999 the FastFerry was introduced in the Rotterdam-area. This route between Dordrecht Merwede kade and Rotterdam Willemskade was exploited by a combination of companies, which were Doeksen Transport Groep, Heymen Shipping and Connexxion together with the municipality of Dordrecht. The client of this route was the province of Zuid-Holland. The high speed catamaran used to accommodate this route is capable of carrying 150 persons and sailing with a speed of 55 km/h. This connection is still exploited today and serves a large volume of commuters in the area.

5. Operator Aqualiner, partially property of the Doeksen Transport Groep, started the exploitation of a ferry service between Almere Haven and Huizen on the 3rd of January 2000. During rush hour a thirty-minute timetable was executed. Outside rush hour an hourly timetable was executed [1]. This service is no longer available, due to a lack of transport demand on this route.
From the recent history of water based public transport it can be derived that a limited number of water based public transport connections is established. In the present situation even less water based public transport connections are still operative. From the analysis the connections above and on interviews with representatives of shipping companies Connexxion [25] and Aqualiner [26] it can be concluded that water based public transport is largely dependent on the regional transport demand on the route offered. The transport demand is directly connected to the service level of competing transport modes in the area. The factors determining the service level of water based public transport are explained in paragraph 2.3. Next to that it is known that water based public transport cannot be exploited without subsidy. In order to offer water based public transport against the same rate as land based public transport clients are forced to grant subsidy to (public) shipping companies exploiting specific connections. In comparison to other transport modes, water based transport involves large investments costs and a relatively high energy consumption. Referring to energy consumption, possible renewable energy sources enables (public) shipping companies to tackle this drawback in the near future. In figure 3 an overview of water based public transport connections in the Netherlands in recent history is added.

Figure 3: Water based public transport connections in the Netherlands [7].
2.3. **Success factors**

Water based public transport by means of fast ferry navigation can be a feasible addition to the existing public transport network in the Netherlands [8]. In several areas in the Netherlands additional water based routes are added to the multi modal public transport network. The success of these routes is largely dependent on the transport demand in the region. Urban areas which adopted their metropolitan status as a result of their location at a waterfront, often show a significant transport demand. Within the Netherlands the routes are concentrated around the Amsterdam and Rotterdam area. Governments, shipping companies and other involved parties have a positive attitude towards introducing this type of public transport to serve commuters. Fast and reliable public transport connections accelerate the economic growth in the region. The transport demand is determined by the individual assessment of transport modes by individual passengers. Therefore the service level should be adjusted to commuter related passenger transport. The service level determining success can be expressed by the following factors [7]:

- Travel time
- Timetable
- Comfort
- Ticket price

2.3.1. **Travel time**

In relation to other transport modes on the preferred route, the total travel time is the most important factor determining the success of fast ferry navigation. With respect to travel time both quantitative and qualitative values are important. The quantitative travel time is related to the actual time to be transported from A to B and vice versa. From a survey on passenger demands it is known that passengers of water based public transport are willing to increase their travel time up to 1.5 times compared to land based transport modes. Given this value the target conditions on the passage time of fast ferry navigation at the Schellingwoude lock complex might be interpreted less strictly. The qualitative value of the travel time is expressed by the amount of delayed trips sailing from A to B and vice versa. This value is also expressed by reliability. Previous attempts of shipping companies passing the Schellingwoude lock complex show that reliability of travel time is more important than travel time itself. Reliability is dependent on a great variety of internal and external factors. Insight into these factors is an important aspect in determining feasibility of a connection. An unreliable transport connection will lead to a major decrease in transport demand, since reliability is a highly appreciated value in passenger transport. This factor also drives the competition of water based public transport with other transport modes. In the Netherlands the feasibility of water based public transport is directly related to the increase of congestion on land.

2.3.2. **Timetable**

The transport capacity of water based public transport must be sufficient to cope with the expected transport demand stated in paragraph 1.1.1. The transport demand of commuter related passenger transport fluctuates throughout the day. The availability of fast ferries needs to be tuned with the fluctuations in transport demand. The availability is expressed by the timetable of the departure and arrival
times of a fast ferry. In general a timetable indicating a minimal arrival and departure frequency of 30 minutes is assumed to be sufficient serving a minimum transport demand. On the preferred route the transport demand during rush hour is doubled. An arrival and departure frequency of 15 minutes per one-way trip doubles the transport capacity on this route. During the weekend and holiday period, when the transport demand of commuter related passengers is below average, an arrival and departure frequency of 30 minutes throughout the day is assumed to be sufficient. With respect to the punctuality of the timetable a delay of 2 minutes per one-way trip is considered to be the maximum range appreciated by passengers [25].

2.3.3. **Turnaround time**
As a result of the travel time and the timetable under normative transport demand the turnaround time of a vessel can be calculated. This value is an important factor on the deployment of the minimum number of vessels at one time. Assuming a turnaround time of double the total travel time during a one-way trip, the turnaround time equals 84 minutes. As a result of a minimum arrival and departure frequency of 15 minutes during normative circumstances, a minimum number of six vessels is necessary to operate the connection. Extreme large deviation in the passage time of fast ferries at the Schellingwoude lock complex also affect the minimum number of vessels deployed. Lowering the number of deployed vessels by decreasing the mean passage time of fast ferries at the lock is expected to be unfeasible.

2.3.4. **Comfort**
People travelling with public transport prefer to minimize the number of transfers to prevent possible delays. A direct connection also minimizes the travel time. Since transferring in a multi modal public transport network cannot be prevented, it is considered to be a natural consequence of travelling by means of public transport. Therefore the optimization of transfer facilities is an important aspect related to comfort. This asks for an integral joining of water based public transport with other transport modes, by means of well positioned jetties and boarding facilities. A second aspect related to comfort is the lack of parking facilities and the trend of banning cars in many city centres. These trends enhance the success of a direct public transport connection accessing city centres. A third aspect related to comfort is the perception of individual passengers. From the interview with the representative of *Aqualiner* it is known that the perception of a passenger of a fast ferry is different from passengers on other transport modes. When travelling on schedule passengers tend to have less understanding in case of a delay as a result of a locking process then in case of an additional train stop. In this case the physical bottleneck formed by the lock complex also exists in the mind of passengers. Other relevant aspects regarding the comfort of passengers are the availability of electricity to extend the working hours of commuters, sailing behaviour, noise level and service offered by onboard personnel.

2.3.5. **Ticket price**
The ticket price in relation to other transport modes should reflect the value of the product offered by the fast ferry connection. The exploitation costs which drive the ticket price regarding land based public transport connection is above average. This
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

is due to the large investment costs and high energy consumption of fast ferries. In most cases the public transport connection is subsidized. The amount of subsidy granted depends on the regional social benefits recognized by clients.

2.4. Legal aspects

Operating a water based public transport connection using fast ferry navigation is bounded by law. This paragraph discusses legal aspects related to:
- Fast ferry navigation;
- Obligations related to exploitation.

Other relevant legal aspects related to the definition of public transport and the interpretation by law (Wet Personenvervoer) referring to subsidy, are not discussed in this research.

2.4.1. Fast ferry navigation

Navigation on European inland waterways is subject to legislation prepared by the Inland Transport Committee of the European Union. The legislation is recorded in the European Code for Inland Waterways (CEVNI) which contains a set of rules for inland navigation. CEVNI covers signs and marks on vessels and waterways, visual and sound signals, rules of the road and berthing rules, as well as the prevention of water pollution and waste disposal from vessels. In the Netherlands this European Code is enforced by law, referred to as Binnenvaartpolitiereglement. In APPENDIX 1 relevant articles in the CEVNI regarding fast ferry navigation and passage of a navigation lock are added. Below the consequences of the CEVNI legislation on the locking process of fast ferries at the Schellingwoude lock complex is listed.

Table 4: CEVNI legislation regarding the passage of fast ferries at locks [28].

<table>
<thead>
<tr>
<th>Article</th>
<th>Paragraph</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.01</td>
<td>-</td>
<td>Hydrofoils and hovercrafts are required to leave all other vessels enough room to hold their course and to manoeuvre; they may not require such vessels to give way to them.</td>
</tr>
<tr>
<td>6.28</td>
<td>3</td>
<td>Passage through lock shall be in the order of arrival in the lock basins.</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Overtaking in or near locks, and especially in lock basins, is prohibited.</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Vessels and convoys showing the marking referred to dangerous cargo shall not be locked with passenger vessels.</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>On approaching the lock basin and on entering and leaving a lock, high-speed vessels shall move at a speed that will preclude any damage to the locks, to vessels or to floating equipment and that will not cause any danger for the persons on board.</td>
</tr>
<tr>
<td>6.29</td>
<td>-</td>
<td>By derogation from article 6.28, paragraph 3, the following shall have priority of passage through locks:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Vessels belonging to the competent authority or to the fire, police or customs services under way on urgent duty;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Vessels to which the competent authority has expressly granted priority, and carrying the red pennant. When these vessels approach lock basins or are made fast in them, other vessels shall facilitate as much as possible passage by such vessels.</td>
</tr>
</tbody>
</table>
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

The CEVNI legislation allows for different interpretation of articles, but it is clear that possible management related measurements optimizing the passage of fast ferries at the Schellingwoude lock complex are in conflict with prevailing legislation. A priority arrangement conflicts with article 6.28 paragraph 3 in which the passage through lock is recorded to be in order of arrival. Adaptation of legal obligations associated with optimizing the passage of fast ferry navigation is not part of this study.

2.4.2. Obligations related to exploitation
Legal obligations regarding the exploitation of water based public transport connections call for two essential elements. These are:
(1) a permit/concession for a specific route, based on a proof of professionalism;
(2) a punctual performance of a timetable.
The latter is recorded within the permit/concession. The definition of a punctual performance is described as the percentage of one-way trips of a high speed vessel which arrive and depart according the prescribed timetable relative to all trips carried out on a yearly basis. The variation of arrival and departure times is allowed to be within a specified range. The percentage is only influenced by culpable punctuality, i.e. mechanical failure, high density traffic pattern or locking operations. Non-culpable punctuality concerns bad visibility, icing or other types of force majeure.
From existing water based connections it is known that the target punctual performance is set to be 98% [25]. This implies that 2% of the one way trips of a fast ferry, based on a yearly average, can have a delay outside the prescribed range of variability. The range of variation of passage time associated with a punctual performance applied at the passage of the Schellingwoude lock complex is set to 2 minutes accounting for the unreliability of the passage time involved in the locking process. The target conditions applied to fast ferry navigation in the performance analysis of the Schellingwoude lock complex are described in paragraph 7.2.3.

2.5. Comparable situations abroad
The deployment of fast ferries providing water based public transport connections is increasing worldwide. Various types of fast ferries are becoming part of the fleet sailing on coastal and inland waterways. Especially in urban areas, located near waterfronts, the deployment of these types of vessels proves to be a valuable addition to the accessibility of these areas. To indicate the potential of water based public transport a reference has been made to Sydney, Australia. Although many worldwide urban areas are situated near waterfronts and show a large similarity with the Amsterdam area, little situations are confronted with the passage of a lock complex. At the Voronezh river in Russia a comparable situation on the passage of fast ferries through locks is recognized to indicate the order of importance of the functional demands associated with a lock complex.

2.5.1. Sydney, Australia
Sydney is famous for its ferries and can be considered a target situation on large scale water based public transport in urban areas. Sydney Ferries operates approximately 175,000 services, transporting more than 14 million people across
Sydney Harbour and the Parramatta River each year. An extensive network connects 39 destinations and spans approximately 37 kilometers from East to West. The fleet deployed by Sydney Ferries consists of 28 vessels of which 13 can be considered fast ferries. The arrival and departure frequency of vessels varies from 1 hour to 30 minutes. The success of Sydney Ferries is largely dependent on large natural hydraulic infrastructure in which the urban area of Sydney is located. The absence of locks creates unrestricted maneuverability for navigation [16].

2.5.2. Voronezh River, Russia

In Russia the potential performance of fast ferry navigation to serve water based passenger transport are recognized since the 70’s of the previous century. From this period on many hydrofoils crafts were built and deployed on Russian inland waterways. Their operating experience shows that the performance capability of these vessels is reduced significantly during the passage through locks. During the approach of the locks, considerable time is lost in waiting for lockage, and the lockage process itself. With respect to time spent sailing, it shows that this is not consistent with the high-speed method of passenger transport. Furthermore, fast ferries and recreational crafts have light hulls and their lockage along with other type of large vessels, does not provide the necessary conditions for protecting them against damage. Another aspect regarding the locking process is the fact that the manoeuvrability of a hydrofoil vessel is reduced, due to the low velocities involved in the entering and leaving of the lock chamber.

The contradictions between the performance potentialities of fast ferry navigation and the increase of functional demands of a lock complex are growing. The tonnage of the conventional fleet and the intensification of navigation asks for a sustainable solution. According the Leningrad Design Department of Steel Hydraulic Structures (Lengidrostal’) these contradictions can be eliminated by constructing lifts in addition to the existing and planned locks. This institute developed a number of designs of these lifts of which two were eventually built. On the reservoir on the Voronezh River the cost of the lock with respect to the capital investments proved to be higher compared to a lift with a turntable and two chambers. Furthermore the traffic capacity was considerable greater. In the summer of 1976 this lift was completely assembled and began operating in 1977 [17]. Due to a lack of design aspects and detailed information traffic intensity the capacity of this hydraulic structure is not investigated.

2.6. Conclusion

Recent history shows that a water based public transport connection can fulfil an valuable addition to the existing public transport network providing an increased accessibility of urban areas near waterfronts. Economic growth generating regional transport demand can be facilitated by a reliable multi modal public transport network including water based public transport connections. The opportunities of water based public transport are also strongly related to the congestion of regional highways. From established water based connection in the Netherlands we can conclude that the factors determining success are bounded by local conditions and service level offered to passengers. Failed attempts on water based public transport connections are related to a deviation between the offered service and passenger...
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

demands. Although prevailing legislation on inland waterways is not focussed on water based public transport connections, the target conditions on these connections should not be lost out of sight. The extensive water based public transport network in the city of Sydney is a good example of a robust transport system contributing to the regional economy. Similar situations abroad on water based passenger transport in combination with the passage of a navigation lock learns that the presence of a lock is commonly considered to be a constraint imposed by the environment. From this perspective one can say that the priority of the nautical function is listed below the hydraulic and environmental functions of a lock complex. Next to that the punctual performance level associated with public transport strongly contrasts with arbitrary characteristics of traffic intensity at lock complexes. Given the functional demands related to water based public transport, the reliability of the passage time is considered to be more important than the actual duration of the passage time.
3 Functional demands

Chapter 3 identifies and prioritises the specific functional demands imposed by the surrounding area, leading to the physical layout and operational management of the existing lock complex at Schellingwoude. Next to the functional demands related to water based public transport, the following functional demands can be recognized:

- Nautical function;
- Water retaining function;
- Environmental function.

3.1 Nautical function

The Schellingwoude lock complex is located within the main navigation fairway of the North Sea canal (NZK), lake Binnen-IJ en lake Buiten-IJ, which forms an important corridor for IWT connecting Amsterdam with the cities in the northern part of the Netherlands. This fairway is made accessible for commercial navigation up to CEMT-class VIb, due to the realization of the Prins Willem-Alexandersluis in 1995. The nautical management of the lock complex including the surrounding waters is assigned to Rijkswaterstaat division Noord-Holland. The nautical chart of surrounding waters at the Schellingwoude lock complex is shown in figure 4.

![Figure 4: Nautical chart of surrounding waters [6].](image)

To improve the transport capacity of inland waterways guidelines are developed by nautical managers in cooperation with users of these waterways. The guidelines address the nautical management of locks being part of inland waterway network as well as design aspects for newly built locks, the rehabilitation or upgrade of an
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

existing navigation lock. Because of the importance of navigation locks within the hydraulic infrastructure network in the Netherlands, the nautical aspects of waterways in relation to navigation locks always need to be handled carefully. Globally the nautical function of a navigation lock can be described as to see after a sufficiently fast and safe passage of:

1. a normative allowable vessel,
2. a normative combination of vessels and
3. a normative supply and fleet composition in relation to fairway class.

This depends on the fleet composition and applies to both the current situation as well as a future situation.

3.2. Water retaining function

The Schellingwoude lock complex prevents the natural exchange of water between lake Binnen-IJ and lake Buiten-IJ. The water retaining function is imposed by the:

- Flood defence system;
- Water management system;
- Dutch National Water Plan.

3.2.1. Flood defence system

The Netherlands are part of a low lying delta area. In this delta area a flood defence system prevents inundation of land from outside water. The Dutch flood defence system consists of a network of primary water retaining structures in the shape of dunes, dikes and dams. The network of primary water retaining structures protects the dike ring area enclosed. According to the Flood Defence Act, the hydraulic boundary conditions at all dike ring areas have to be established. These hydraulic boundary conditions are registered in the publication "Hydraulische randvoorwaarden voor primaire waterkeringen". The exact hydraulic conditions are related to the risk of exceedence of the design frequency [31]. The hydraulic boundary conditions can be translated into functional requirements concerning:

1. the permitted overflow and overtopping;
2. strength and stability;
3. reliability in closing the gates.

The Schellingwoude lock complex is part of a primary retaining structure. The area protected by the primary retaining structure is referred to as dike ring area 44 (Kromme Rijn). Dike ring area 44 prevents the inundation of Amsterdam from lake Markermeer, which is considered to be outside water. Constant wind from direction Northeast in combination with the large surface area of lake Markermeer can cause large water level variations and waves at lake Buiten-IJ. This results in a high hydraulic load on the flood defence at the Schellingwoude lock complex. The exact hydraulic conditions are based on a safety margin in accordance with an average yearly probability of inundation due to failure of the primary flood defence equal to 1/1250 (design frequency).

1. The permitted overflow and overtopping requirement concerns the retaining height of the lock complex, including level of the outer gates, lock heads and the connecting levees.
2. Strength and stability requirements are related to the structural design elements of a lock being a retaining structure, type 1 (independent water retaining function). This must satisfy this highest possible demand on strength and stability under governing hydraulic loads due to the presence of waves and head differences. The presence of waves coming from lake Markermeer into lake Buiten-IJ limits the locking process at Schellingwoude lock complex.

3. Concerning the reliability in closing the gates within a lock complex, a guideline Hydraulic Structures was developed by the Dutch Advisory Committee on flood defences (TAW/ENW) [32]. In the beginning at least one of the gates of a navigation lock is closed to fulfil the requirement imposed by the Flood Defence Act. This requirement distinguishes a navigation lock from a floodgate or a storm surge barrier. Since the gates provide the passage of navigation crossing the lock complex, the gates open and close continuously depending on the traffic intensity.

3.2.2. Water management system

The Schellingwoude lock complex separates two water systems each with a different target water level regime. These target water levels are maintained by the authorities of these separated water systems. The target water levels serve the flushing of fresh water and also agricultural purposes. Regarding lake Binnen-IJ / NZK the target water level also serves the preservation of wooden poles in the subsoil on which many houses in the old centre of Amsterdam are founded. Also the vertical clearance of bridges in Amsterdam and the sill height at the navigation lock in the river Amstel require a fixed target water level. Nevertheless the authorities cannot prevent the fluctuation of water levels, due to natural causes or the risk of failure of hydraulic structures. Based on the understanding of factors influencing these fluctuations, the degree and the return period of deviation of the target water level can be approximated. This information is supplied by the competent authorities managing the water systems adjacent to the Schellingwoude lock complex. In table 5 an overview of target water levels and extreme water levels occurring with a return period of 1000 years are listed.

Table 5: Target and extreme water levels.

<table>
<thead>
<tr>
<th>Water system</th>
<th>Target water level</th>
<th>Extreme water level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Binnen-IJ / NZK</td>
<td>High water</td>
<td>NAP -0.40 m</td>
</tr>
<tr>
<td></td>
<td>Low water</td>
<td>NAP -0.40 m</td>
</tr>
<tr>
<td>Lake Buiten-IJ / IJmeer / Markermeer</td>
<td>High water</td>
<td>NAP -0.20 m (summer)</td>
</tr>
<tr>
<td></td>
<td>Low water</td>
<td>NAP -0.40 m (winter)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NAP -0.70 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NAP +0.55 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NAP -2.80 m</td>
</tr>
</tbody>
</table>

Prevention of extreme fluctuations of the target water levels requires active water management. In general the prevention of extreme water levels is controlled by means of sluicing of water under gravity. In case of extreme fluctuations in the degree and return period of deviation of the target water level, the locking process at the lock complex is suspended. The sill height prevents a safe passage of navigation during extreme low water levels on either side of the lock complex. Extreme high water levels prevent the safe passage of navigation due to the physical restriction of the vertical dimensions as a result of economic considerations.
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

Based on the analysis of water level observations at lake Buiten-IJ the return period of the extreme locking levels can be derived. The analysis of the observed water level at lake Buiten-IJ is performed by means of figure 5 (high water) and figure 6 (low water).

Figure 5: Analysis of high water level observations at lake Buiten-IJ

Figure 6: Analysis of low water level observations at lake Buiten-IJ.
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

In table 6 the characteristics of extreme locking levels at Schellingwoude lock complex are listed. During the exceeding of extreme locking levels the locking process is aborted for all navigation.

<table>
<thead>
<tr>
<th>Reference level</th>
<th>Water level [24]</th>
<th>Return period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest locking level (HLL)</td>
<td>NAP +0.70 m</td>
<td>&lt; 1/ 10,000 year</td>
</tr>
<tr>
<td>Lowest locking level (LLL)</td>
<td>NAP -0.70 m</td>
<td>1/ 0.2 year</td>
</tr>
</tbody>
</table>

Assuming a normative storm duration of 24 hours the maximum non-operational time of the lock complex as a result of an extreme low water level is set to be 5 days per year. The low probability of extreme high locking levels aborting the locking process is expected to have no effect on the yearly operational time.

3.2.3. **Dutch National Water Plan**

The Dutch government is aware of the ongoing climate change and the effect on the delta system in the Netherlands. In 2009 a Delta-committee was appointed to investigate the optimal response of the Dutch delta environment to adapt to these changes. The results of this committee are reported in the Dutch Delta Plan 2009. Many outcomes of this report are directly adopted in the Dutch National Water Plan (DNWP), approved by the Dutch Government. In this plan specific area-related policies with respect to the adaptation towards climate changes are developed. In figure 7 the structure plan on lake Buiten-IJ / Markermeer is added. In the DNWP aspects in relation to lake Buiten-IJ / Markermeer are distinguished that possibly affect the functional demands regarding water retention.

![Figure 7: Structure plan of lake Buiten-IJ/Markermeer [36].](image-url)
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

The first aspect in the DNWP influencing the locking process is the possible increase of the upper target water level of lake Markermeer. An increase of the water levels with 0.30m is proposed in case safety conditions can be guaranteed. This plan will cause a larger water level difference at the Schellingwoude lock complex leading to a longer operating time of the locking process. This will lead to an increase of passage time for all navigation. Also the probability of exceedence of the Highest Lock Level (HLL) is expected to increase. The return period is expected to decrease from less than 1/10,000 year to 1/50 year. On the other hand the probability of exceedence of the Lowest Lock Level (LLL) is expected to decrease from 1/0.2 year to 1/3 year. In total this will lead to a less frequent occurrence of abortion of the locking process. Less frequent abortion of the locking process increases the available operational time to handle navigation at the lock complex. A second aspect in the DNWP is change of approach towards the probability of failure of the flood defence system in the Netherlands. In the current situation the failure of the flood defence system is related to risk of exceedence of design frequency. In the future situation the failure of the flood defence system is directly related to risk of flooding. The effect of this approach on the Schellingwoude lock complex is not investigated in this study. It is expected that the functional requirements as listed in the paragraph on the flood defence system will increase. The last aspect in the DNWP is the rejection of the plan to construct a dam creating an extra compartment disconnecting Lake IJmeer with lake Markermeer (figure 8). This plan was proposed to enhance the construction of housing outside existing flood defence system. This plan also made way for a direct water based transport connection between Amsterdam Central Station and Almere without the water retaining function of the Schellingwoude lock complex. This plan was rejected because of the large probability of fluctuations of the water level in Amsterdam, due to the effect of setup and setdown of water from lake IJmeer and connecting lakes.

3.3. Environmental function

The environmental function of the Schellingwoude lock complex includes the physical barrier between two separate water systems preventing propagation of:

- Pollution;
- Siltation;
- Salt intrusion.

3.3.1. Pollution

Pollution may be caused due to a vessel-collision or accidental industrial spillages in the Amsterdam port area, resulting in harmful concentrations of dangerous cargo.
such as oil, gasoline, chemical fluids in surrounding waters. Depending on speed of the dissolving or dispersion process of the polluting material, the locking operations can be stopped to prevent the pollution reaching into lake Markermeer. This lake is an important ecological habitat for flora and fauna. A large part of lake Markermeer has been designated as Natura 2000 area. Natura 2000 is an ecological network of protected areas in the territory of the European Union. The probability of pollution is expected to be less than the design frequency of the lock complex. The safety margin regarding the reliability in closing the gates of the lock complex is expected to be sufficient.

3.3.2. Siltation
The original motivation to construct the Schellingwoude lock complex was to prevent the siltation of the port of Amsterdam. Nowadays the lock complex still prevents the transport of water with a high concentration of silt from lake Markermeer into the NZK. The volume of siltation as a result of the locking process is expected to be minimal. Therefore the constraint imposed by siltation is neglected.

3.3.3. Salt intrusion
Due to the locking operations at the IJmuiden lock complex located at the western side of the NZK at the connection with the North sea, salt intrusion is observed at lake Binnen-IJ. The Schellingwoude lock complex prevents mixing of brackish water from lake Binnen-IJ with the fresh water at lake Buiten-IJ. Although salt intrusion cannot be completely prevented, the separation of these different water quality aspects forms an environmental precondition at the Schellingwoude lock complex. The amount of salt intrusion is proportional to the head difference and the dimensions of the lock chamber. Since the density of salt water is higher than the density of fresh water, the salinity at lake Buiten-IJ is constantly monitored at a depth of NAP -2.80m. If possible, water is sluiced in the direction of lake Binnen-IJ to reduce the salinity at lake Buiten-IJ. Due to the variation of target water during winter and summer period, the salinity fluctuated through the year. During winter period the salinity is higher due to the equality of target water levels in this period. Extreme volumes of salt intrusion can be prevented by additional measures without influencing the locking process, i.e. bubble screen.
4  Lock operation system

Chapter 4 focuses on the lock operation system at the Schellingwoude lock complex. Detailed information on the system variables provides insight in possible optimization of the passage of fast ferry navigation within the lock operation system.

4.1.  General

The lock operation system can be considered as a system describing supply and demand. The supply of lock capacity is determined by the physical layout and operational management at the lock complex. These values depend on the functional demand related to the lock complex. The traffic intensity demanding capacity is determined by the volume and arrival pattern of navigation passing the lock complex. The relation between variables in the lock operation system is illustrated in figure 9. Specified information on the values and variables is described in the following paragraphs.

<table>
<thead>
<tr>
<th>System: Lock operation system Schellingwoude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
</tr>
<tr>
<td>Value</td>
</tr>
<tr>
<td>Variables</td>
</tr>
<tr>
<td>Value</td>
</tr>
<tr>
<td>Reference</td>
</tr>
<tr>
<td>Data</td>
</tr>
</tbody>
</table>

Figure 9: Overview lock operation system.
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

With respect to traffic intensity global historical data on navigation at the Schellingwoude lock complex and the classification system of vessels by Rijkswaterstaat are added. Detailed information on the volume and arrival pattern of navigation passing the lock complex is described in the normative navigation scenarios (Chapter 6) as part of the performance analysis elaborated in this research.

4.2. Locking process

The locking process is considered to be a continuous process of coupled locking cycles. From the point of view of navigation the performance of the locking process is indicated by the passage time of vessels in the queue to be locked. The lock operator defines the performance of the locking process by the occupancy of the various lock chambers. Since lock operators serve navigation during the lock operation process the interests of navigation is prioritized above the interests of lock operators. This is way the passage time is set to be the determining assessment criterion on the performance analysis part of this research.

4.2.1. Locking cycle

The Schellingwoude lock complex provides locking of vessels sailing in two directions (East and West). This implies two way traffic. The locking cycle handling two-way traffic differs from a one-way locking cycle, since the locking duration concerns both upstream and downstream traffic. The time to complete an entire locking cycle ($T_C$) can be written as follows:

$$T_C = T_{d(up)} + T_{d(down)}$$  \hspace{1cm} (1)

The locking duration in upstream direction ($T_{d(up)}$) and the locking duration in the downstream direction ($T_{d(down)}$) can both be subdivided into the total entry time ($T_i$), the lock operation time ($T_b$) and the total exit time ($T_u$):

$$T_d = T_i + T_b + T_u$$  \hspace{1cm} (2)

The entry time $T_i$ consists of two elements, being the switch/loop time ($t_{switch}$) and the sum of the entry headways ($\sum t_{in}$). The switch/loop time is defined as the time that elapses between the moment that the last vessel leaves the lock chamber and the moment the first vessel enters the lock chamber. In this case the moment of lock entry is defined as the moment that the stern of the vessel passes the lock sill, and the moment of leaving the lock as the moment that the stern of the vessel once again passes the lock sill, but in the other direction. The summation of the entry following times should therefore be taken over $(n-1)$ vessels, where $n$ is the total number of vessels entering the lock chamber. The first vessel and the time taken to get the vessels moving are included in the switch/loop time.

The lock operating time ($T_b$) can also be subdivided in various elements. The operating time starts when the last vessel entering is located within the lock chamber. The operating time is equal to the sum of the time required to close the gates ($T_{gates, close}$), the time required to fill/empty the lock chamber ($T_{chamber}$) and the time required to open the gates ($T_{gates, open}$). From observation it appears that the
leaving time ($t_{out}$) of the first vessel does not differ significantly from the leaving time of the following vessels. The total leaving time $T_u$ is therefore calculated as the sum of all vessels leaving times ($n$). From the considerations above, the following formula can be derived:

$$T_C = (t_{switch} + \sum t_{in} + T_{gates, close} + T_{chamber} + T_{gates, open} + \sum t_{out})_{upstream} +$$

$$(t_{switch} + \sum t_{in} + T_{gates, close} + T_{chamber} + T_{gates, open} + \sum t_{out})_{downstream}$$

In figure 10 an overview of parameters in equation 3 contributing to the lock cycle time is added.

![Figure 10: Elements contributing to the lock cycle time [19].](image)

**4.2.2. Passage time**

The passage time is a quantitative value displaying the performance of the lock operation system. The definitions of variables related to the passage time of individual vessels are described in table 7. The values of these variables are determined in the performance analysis to provide specific information on optimizing the passage of a fast ferry.

**Table 7: Explanation of definitions related to passage time.**

<table>
<thead>
<tr>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passage time</td>
<td>The time needed for an individual vessel to pass a lock complex (i.e. one lock chamber), being the sum of the:</td>
</tr>
<tr>
<td></td>
<td>- waiting time;</td>
</tr>
<tr>
<td></td>
<td>- locking time;</td>
</tr>
<tr>
<td></td>
<td>- demurrage time.</td>
</tr>
<tr>
<td>Waiting time</td>
<td>The waiting time starts when a vessel arrives at the lock complex and moors at the positioning area in front of the lock chamber, and it ends when the locking time or demurrage time starts (the time spent on sailing into the lock chamber is part of the waiting time).</td>
</tr>
</tbody>
</table>
The locking time starts when all vessels are inside the lock chamber and the gates at the entrance side start to close, and it ends when the stern of the vessel passes the gates at the exit side of the lock chamber (the time spent on sailing out of the lock chamber is part of the locking time).

The demurrage time starts when the gates at the entrance side of the lock chamber close in front of the waiting vessel, and it ends when the locking time of the vessel starts (when it is allowed for lockage).

The total waiting time is defined as the sum of the: waiting time; demurrage time.

The operation time is defined, being the time needed to open and close the gates at the entrance and exit side of the lock chamber including the time involved in leveling the water surface inside the lock chamber.

The passage time is dependent on the ratio between traffic intensity (I) and lock capacity (C). The traffic intensity is related to the volume and arrival pattern of all navigation passing a lock complex. The capacity is related to the physical layout and traffic management system applied at the lock complex. The number of locks in the physical layout is the most important factor influencing capacity. An increase of the I/C-value implies a proportional increase in passage time of navigation. The I/C-values of all lock structures in the Netherlands are checked on a regular basis by Rijkswaterstaat. Lock structures with a high I/C-value are considered to be a bottleneck on main fairway routes in the Netherlands preventing efficient traffic handling. Failing to meet the standards for the maximum average total waiting time, often leads to a sharp increase in the number of demurrages. From this perspective a premature increase of traffic capacity limits the total waiting time [29]. From latest research done by Rijkswaterstaat it can be derived that the existing Schellingwoude lock complex, consisting of four lock chambers, is regarded to have sufficient capacity serving the volume of commercial and recreational navigation in the current situation and future scenarios [37].

### 4.3. Supply: Lock capacity

The lock capacity is directly related to the physical layout and the operational management system applied at the navigation lock complex. The operational capacity is defined as the maximum number of vessels that can pass a lock per unit of time, taking into account safety margins and acceptable waiting times (service level). The minimum degree of service level is recorded within the target conditions related to capacity, i.e. safety margins related to dangerous cargo. These target conditions are recorded in the Richtlijnen Vaarwege 2005 published by Rijkswaterstaat and are discussed in paragraph 7.2.1 (Commercial navigation) and 7.2.2 (Recreational navigation).

If a lock chamber is constantly filled to maximum capacity over a longer period then the lock capacity can be determined as an average of that amount. The traffic capacity of a lock can be described as follows:
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The traffic capacity of a lock is the maximum quantity of traffic from both directions, expressed in numbers of vessels, dead-weight capacity or otherwise, that can be locked through under the prevalent conditions per time unit if the lock operators work continuously [18].

In general the capacity of a lock is expressed as the number of vessels per hour ($C_s$) or the tonnes of carrying capacity per hour ($C_T$). Since we focus on the Schellingwoude lock complex providing the lockage of two-way traffic the following comparisons apply:

\[
C_s = \frac{2 \cdot n_{max}}{T_C} \quad \text{[vessels/time unit]} \quad (4)
\]

\[
C_T = C_s \cdot T_s \quad \text{[tonnes carrying capacity/time unit]} \quad (5)
\]

As a result of expressing the lock capacity with the variables above, the lock capacity also depends on characteristic of navigation passing the lock complex. These characteristics include fleet composition and the presence of vessels transporting dangerous cargos. The factors influencing the traffic intensity are discussed in paragraph 4.6.

4.3.1. Physical layout
The physical layout of a lock complex is determined by the functional demands. These demands are related to nautical, hydraulic and environmental aspects imposed by the surrounding area. The functional demands can be translated to three areas within the design of the physical layout of the lock complex. These areas are the outer port, guide jetty and lock chamber [28]. In figure 11 a schematized overview of these areas is displayed.

The Schellingwoude lock complex consists of several hydraulic structures of which the Oranjesluiizen and the Prins Willem-Alexandersluis serve navigational purposes. The Oranjesluiizen consist of three separate lock chambers. In table 8 an overview of the lock chamber specifications of the Schellingwoude lock complex are listed.
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

Table 8: Overview lock chamber specifications [15].

<table>
<thead>
<tr>
<th>#</th>
<th>Description</th>
<th>Dimensions lock chamber ($L_k \times W$)</th>
<th>Entrance depth</th>
<th>Dimensions design vessel</th>
<th>Normative allowable vessel class$^1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Northern lock chamber</td>
<td>72.8 m x 14.0 m</td>
<td>NAP -4.5 m</td>
<td>70.0 m x 13.0 m</td>
<td>CEMT-class III</td>
</tr>
<tr>
<td>2</td>
<td>Middle lock chamber</td>
<td>95.2 m x 18.0 m</td>
<td>NAP -4.5 m</td>
<td>90.0 m x 17.0 m</td>
<td>CEMT-class IV</td>
</tr>
<tr>
<td>3</td>
<td>Southern lock chamber</td>
<td>72.8 m x 14.0 m</td>
<td>NAP -4.5 m</td>
<td>70.0 m x 13.0 m</td>
<td>CEMT-class III</td>
</tr>
<tr>
<td>4</td>
<td>PWA lock chamber</td>
<td>200.0 m x 24.0 m</td>
<td>NAP -4.7 m</td>
<td>197.0 m x 23.7 m</td>
<td>CEMT-class VIb</td>
</tr>
</tbody>
</table>

The northern lock chamber is commonly used by recreational navigation. The other lock chambers serve commercial navigation. During increased recreational navigation the middle lock chamber is also used to serve recreational navigation. In figure 12 an overview of the existing physical layout of the Schellingwoude lock complex is added. All lock chambers handle traffic from both directions.

Figure 12: Existing physical layout of the Schellingwoude lock complex.

$^1$ Additional information on the indication of the normative allowable vessel class is given in paragraph 4.5.2.
4.3.2. **Operational management**

The operational management system applied at the lock complex is an important variable determining capacity. Operational management is applied to serve the nautical function of the lock complex and focuses on the interaction between the lock operator and the captains of individual vessels. Optimizing the interaction between the lock operator and the captains of individual vessels, including fast ferries, may lead to a decrease of passage time. This paragraph focuses on the operational management of an onsite operated navigation lock handling mainly commercial navigation, such as the Schellingwoude lock complex.

The flowchart describing the general operational management can be subdivided into the following processes [29]:

A. Notification
B. Data transfer
C. Instructions
D. Operation of the lock chamber
E. Vessel movements

In practice the process of notification, data transfer and instructions are executed during the physical process of arrival. Optimizing the processes of notification, data transfer and instructions without changing the general operational management is expected to have little effect. The physical processes are expressed by the definitions related to passage time as discussed in paragraph 4.2.2. The detailed flowchart describing the general operational management of the locking process is added in APPENDIX 2.

### 4.4. Variables influencing capacity

This paragraph describes the variables influencing the locking cycle and their effect on the lock capacity of the Schellingwoude lock complex. The influence of these variables is based on theory and practical considerations and are listed in order of their effect on capacity. The quantitative influence of significant variables on the lock capacity is illustrated by the sensitivity analysis in paragraph 7.2.

#### 4.4.1. Lock chamber

Regarding the influence of the lock chamber on the capacity, the following variables are relevant:

- Number of lock chambers;
- Lock chamber dimensions.

Number of lock chambers $\uparrow \rightarrow$ Capacity $\uparrow$

A lock chamber can be considered as a service point for navigation passing the Schellingwoude lock complex. Additional service installation points increase the volume of navigation that can be served. In this research the effect of an additional lock chamber at the Schellingwoude lock complex on the total lock capacity is investigated.
Lock chamber dimensions $\uparrow \rightarrow$ Capacity $\uparrow$

The lock chamber dimensions determine the dimensions of the normative vessels allowed to pass the lock complex or the number of vessels that can enter the lock chamber during a single lockage. Although a large lock chamber takes more time to level, an increase in lock chamber dimensions results in an increase in lock capacity. An extra set of gates can be installed inside the lock chamber to avoid emptying or filling a lock chamber that is only partially filled with vessels. This reduces the amount of water to be released and therefore saves operation time. This leads to an increase of the lock capacity.

4.4.2. Hydraulic conditions

Hydraulic conditions at the Schellingwoude lock complex influence the lock capacity as a result of:

- Water level differences;
- Extreme wave conditions.

Water level differences $\uparrow \rightarrow$ Capacity $\downarrow$

The water level difference between lake Buiten-IJ and lake Binnen-IJ is considered to be very small (0.20 m) during the summer period. During the winter period there is no water level difference. The water level at lake Binnen-IJ is considered to be constant. At lake Buiten-IJ the water level fluctuates due to wind set-up and wind set-down. This effect creates water level fluctuations in the order of 0.50 to 1.50 m. Given the efficiency of the filling and emptying system it takes a certain time to adjust the level of the water within the lock chamber to the required outside water level. The larger the water level difference, the smaller the overall lock capacity and vice versa.

Frequency extreme wave conditions $\uparrow \rightarrow$ Capacity $\downarrow$

Extreme wave conditions due to high wind speeds can result in intolerable conditions regarding the nautical safety. In case of extreme wave heights the probability of a vessel colliding with the lock sill increases. Careful maneuvering decreases the probability of collision, but also takes more time. This has a negative effect on the capacity.

4.4.3. Inspection and maintenance activities

Inspection and maintenance activities $\uparrow \rightarrow$ Capacity $\downarrow$

Inspection and maintenance activities obstruct the effective use of the lock chamber. This obstruction can be related to time and space. Both obstructions lead to an immediate decrease in lock capacity.
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4.4.4. **Type of gates**
In relation to the type of gates the following variables are relevant:
- Size;
- Possibility of operating under a head difference;
- Opening and closing times.

Size of lock gates $\rightarrow$ Capacity $\downarrow$

The type of gates determines the effective area of the lock chamber, since the type of gate determines the spreading of force towards the lock heads. Gates with large dimensions decrease the effective area of the lock chamber and therefore affect the lock capacity negatively.

Possibility of operating under a head difference $\rightarrow$ Capacity $\uparrow$

Another aspect of the type of gate on the lock capacity is the ability of the gate to be opened and closed during the existence of a head difference at the gate. In practice the gates at the Schellingwoude lock complex are opened and closed during a maximum head difference of approximately 0.30 m.

Opening and closing times $\rightarrow$ Capacity $\downarrow$

The time needed to open or close the gates of the lock is an important stage in the lock cycle process. Therefore the opening and closing times have a direct effect on the length of the lock cycle and also the lock capacity. The longer opening and closing times, the longer the lock cycle and the smaller the lock capacity. Given the dimensions of the lock, the time needed to open or close the gates is determined by the mechanical devices used. Cautiously, it can be assumed that a larger lock requires larger gates, which would require more time to open and close. At the Schellingwoude lock complex this is not a significant parameter to reduce the locking time, since the mechanical devices are recently renovated.

4.4.5. **Filling and emptying system**
The filling and emptying system of a lock complex involves:
- Operating speed;
- Water motion in the lock chamber.

Operating speed $\rightarrow$ Capacity $\downarrow$

The importance of the operating speed of the filling and emptying system of a lock chamber is depending on the water level difference under normative circumstances. Usually the filling and emptying system of locks with a large water level difference are designed to have a higher capacity than locks with a lower range of water level difference. This way the share of the filling and emptying time is balanced with the total lock cycle time. The low water level difference at the Schellingwoude lock complex, assuming target water levels, makes the influence of the filling and emptying system on the overall lock capacity to be very small. In practice the water
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Level difference (summer period) is often leveled by means of opening the gates, without using the operating speed of the filling and emptying system.

Water motion in the lock chamber ➕ Capacity ➖

As a result of the filling and emptying process within the lock chamber, hydraulic phenomena, i.e. translation waves, will induce vessel movements. This may lead to unexpected high mooring forces. For safety reasons the mooring forces should be limited, depending on vessel class. The influence of water motion in the lock chambers at the Schellingwoude lock complex is considered to be small.

4.4.6. Maneuvering and mooring aids

Maneuvering and mooring aids ➕ Capacity ➚

The stage of navigation waiting, sailing in, leveling and sailing out the lock speeds up with help of maneuvering and mooring aids. Consequently the length of the lock cycle may be significantly reduced by providing sufficient maneuvering and mooring aids. At the Schellingwoude lock complex additional quide jetties are present to separate the maneuvering recreational navigation from commercial navigation. Effective use of maneuvering and mooring aids at the Schellingwoude lock complex can decrease the time involved in approaching and entering the lock complex of all navigation. Examples of the innovative mooring aids are vacuum pads and magnetic mooring systems.
4.5. Demand: Traffic intensity

The traffic intensity is expressed by the number of vessels that actually pass the Schellingwoude lock complex per unit of time. This number is also considered to be equal to the traffic demand at the lock complex. These values are derived from historical data on the number of vessels passing the Schellingwoude lock complex in previous years. This information is specified towards the prevailing vessel classification systems.

4.5.1. Historical data

The characteristics of navigation sailing on Dutch inland fairways is constantly monitored. Monitoring is done by Rijkswaterstaat, using the IVS-90 system (Information and Tracking System). The IVS-90 system is an information and tracking system used to identify commercial and recreational vessels and their cargo on Dutch inland fairways. The input of this system is registered at important fairway sections, i.e. locks. Important characteristic on navigation is information related to volume and arrival pattern. In figure 13 historical data on the volume of navigation passing the Schellingwoude lock complex is listed.

From figure 13 it can be derived that the total volume of navigation passing the Schellingwoude lock complex is recorded to be more than 100,000 vessels per year. This makes the Schellingwoude lock complex to be the lock complex with the second largest navigation demand in the Netherlands. In the data of Rijkswaterstaat multiple navigation types passing the Schellingwoude lock complex are distinguished. The northern lock chamber is commonly used by recreational navigation [24]. In figure 14 historical data on the fluctuations of navigation volume at the Schellingwoude lock complex throughout 2009 are displayed. Historical data on traffic intensity of the year 2009 show the most recent
available information on traffic intensity at the Schellingwoude lock complex. From this figure it can be concluded that the monthly volume of recreational navigation ranges between 200 vessels and 3,200 vessels. August is determined to be the normative month referring to the traffic intensity of commercial and recreational navigation. Although fast ferry navigation is expected to experience a decreased transport demand during August the performance analysis conducted in this research a traffic intensity scenario equal to August is applied to investigate the feasibility during extreme conditions. Next to the volume of recreational navigation being above average also the total entrance and leaving time of all recreational vessels during one lockage is increased.

![Figure 14: Yearly fluctuations in volume of navigation 2009](image)

The decreased volume of commercial navigation in September 2009 results from a large decrease in volume of navigation passing the PWA-lock chamber. This effect is due to maintenance and repair activities at sliding gates at the PWA-lock chamber. In chapter 6 various navigation scenarios are identified to measure the effect of traffic intensity on the performance of the lock operation system.

4.5.2. **Vessel classification**

The dimensions of individual vessels passing a lock complex are an important factor influencing the lock capacity. A classification system of vessel types describes the variety of vessels part of the IWT fleet. The classification of inland vessel types is introduced by the Conférence Européenne des Ministres de Transport (CEMT), to tune the accessibility of fairways throughout Europe. In the Netherlands an alternative classification method is introduced by Rijkswaterstaat to indicate the volume of cargo transported on inland waterways. This classification method is also referred to as the RWS/CBS-classification and links vessel dimensions with an average cargo transport capacity. This classification system is also introduced to
keep up with the trend of increasing vessel dimensions of inland navigation outside the range of vessels prescribed in the CEMT-classification. In this research a combination of the CEMT-classification system and the RWS/CBS-classification system is used, since the available historical data on vessel passages at the Schellingwoude lock complex is classified according the RWS/CBS-classification and the elaboration of the performance analysis is performed according the CEMT-classification. An overview of the relation between these classification systems is listed in APPENDIX 3.

4.6. Variables influencing intensity

This paragraph focuses on the variables of navigation influencing the traffic intensity in the lock operation system. These variables are listed in order of their influence on intensity.

4.6.1. Volume of navigation

Volume of navigation from different vessel classes $\rightarrow$ Intensity $\uparrow$

Globally, vessels from different vessel classes are distinguished based on vessel dimensions. This characteristic determines the accessibility of waterways and cargo transport capacity per vessel. A great variety of vessels from different vessel classes increases the need for additional lock chambers with various dimensions in order to meet the nautical demands associated with the lock complex. An increase of volume of navigation is directly connected with an increase of traffic intensity.

Volume of navigation with increased vessel dimensions $\rightarrow$ Intensity $\uparrow$

Due to an increase of vessel dimensions the intensity of navigation increases. Increases vessel dimensions lead to a less effective degree of filling of available the lock chamber space. Assuming a constant lock capacity an increase of vessel dimensions leads to an decrease in terms of number of vessels. In terms of transported cargo the intensity expressed in tonnage is expected to increase, due to an increase of vessel dimensions.

Volume of dangerous cargoes and special transports $\rightarrow$ Intensity $\uparrow$

The transport of dangerous cargo or special transports by vessels generally reduces the lock capacity because of safety requirements. In the Port of Amsterdam many port activities are related to dangerous cargoes influencing the relative volume of dedicated vessel types passing the Schellingwoude lock complex. Generally other vessels are not allowed within a certain safety zone around the considered vessel or transport, which effectively prohibits entrance of more than one vessel in the lock chamber.
4.6.2.   Arrival pattern of navigation

Monthly variation of recreational navigation $\rightarrow$ Intensity $\uparrow$

From historical data it is derived that the arrival pattern of recreational navigation during the summer period differs from the winter period. Especially August shows a large increase in volume of navigation passing the Schellingwoude lock complex above average. The monthly variation of recreational navigation has a significant influence on the traffic intensity within the lock operation process. In order to make a conservative estimation on the feasibility of the proposed water based public transport connection the monthly variation of recreational navigation is set to August for each navigation scenario applied in the performance analysis.

Hourly variation of commercial and recreational navigation $\rightarrow$ Intensity $\uparrow$

The arrival pattern of commercial and recreational navigation at the Schellingwoude lock complex during rush hour is different from the arrival pattern recorded during the afternoon. This variation is mainly due to the increased volume of recreational navigation during the afternoon and in the weekend. Another aspect is the decrease in volume of commercial navigation during the weekend. Regarding fast ferry navigation driven by commuter related passenger transport demand the hourly average passage time of navigation at the Schellingwoude lock complex is expected to vary following from the hourly variation of commercial and recreational navigation throughout the day. This factor is further investigated in the sensitivity analysis in paragraph 7.3.4.

4.6.3.   Heterogeneity of the fleet

Heterogeneity of the fleet $\rightarrow$ Intensity $\uparrow$

The Schellingwoude lock complex handles a great variety of vessel types as part of a fleet of different navigation types. The vessels being part of the commercial and recreational navigation fleet are separated during the lock operations to increase the lock capacity during high traffic intensity. This also serves safety requirements, due to variety of vessel dimensions. During low traffic intensity the heterogeneity of fleet influences the number of lock chamber to be used for the lockage of the equal volume of navigation. The PWA-lock chamber is used only by commercial navigation, while the northern lock chamber is mainly used by recreational navigation. During the summer period when the volume of recreational navigation is above average, the middle lock chamber is also reserved for recreational vessels.
4.7. Conclusion

The lock operation system is described by the process of supply and demand. The passage time is the quantitative value displaying the balance between these variables. The passage time is defined as the time needed for an individual vessel to pass a lock complex (i.e. one lock chamber), being the sum of the:

- waiting time;
- locking time;
- demurrage time.

Supply is delivered by the physical layout and the operational management at the lock complex. The number of lock chambers is the most significant factor influencing capacity. Other factors influence capacity in a lesser degree, but can be significant in optimizing the passage of a fast ferry. The exact effect of factors influencing capacity is further investigated in the sensitivity analysis in paragraph 7.2.

The demand in the lock operation system is generated by navigation. The characteristics of navigation are defined by the volume and arrival pattern of vessels originating from varying vessel classes. The Schellingwoude lock complex is the second busiest lock complex in the Netherlands handling a traffic intensity of more than 100,000 vessels per year. Especially during the summer period the number of recreational vessels adds largely to the total yearly volume. Rijkswaterstaat reports that the existing four lock chambers carry sufficient capacity to handle the current navigation and future navigation based on economic forecasts. The addition of fast ferry navigation to the existing fleet van navigation is an important aspect in this study and is expected to have a large impact on the passage time of commercial and recreational navigation. Based on the previous attempts to exploit a feasible water based public transport connection passing the Schellingwoude lock complex it is concluded that the existing lock operation process is not suitable to guarantee the average passage time of fast ferry navigation to be within the target conditions associated with water based public transport. This conclusion is supported by results of the performance analysis described in chapter 7. The discrepancy between the performance of the existing lock operation process with introduction of fast ferry navigation and the target conditions associated with water based public transport are recorded to be in the order of 15 minutes. These results display the need and necessity on optimizing the passage of fast ferry navigation at the Schellingwoude lock complex.

Part 2 of this report provides specific information on the lock system alternatives and navigation scenarios applied during the actual feasibility analysis.
PART 2: Feasibility study

Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex
5 Lock system alternatives

This chapter describes the various lock system alternatives examined to analyse their effect on the performance of the lock operation system. From a range of options only a limited number of alternatives are elaborated to prevent needless research. The result of the performance analysis of the various lock system alternatives is described in paragraph 7.4.

5.1. Alternative 0 – Existing lock complex

In order to compare proposed lock system alternatives with the current situation Alternative 0 is set to be the lock complex as it is present today. This involves the physical layout described in paragraph 4.3.1 in combination with the traffic management system described in paragraph 4.3.2. Anticipating on the results of alternative 0 in combination with the normative traffic intensity scenarios it can be concluded that the average passage time of fast ferry navigation in the existing lock complex is outside the target conditions associated with water based public transport. The results also show a large distribution of passage times indicating a small degree of reliability of the average passage time. These results ask for alternatives providing the optimization of the passage of fast ferry navigation at the Schellingwoude lock complex.

5.2. Options

In order to optimize the passage of fast ferry navigation at the Schellingwoude lock complex the passage time of fast ferry navigation needs to decreased. This is done by increasing the existing lock capacity or to change the order of lockage of individual vessels. Possible options are therefore related to the physical layout of the lock complex and the traffic management system applied. Alternatives fix the capacity of the lock operation system. Globally two options are investigated:

- Option 1 – Traffic management measures;
- Option 2 – Physical adaptation of layout.

5.2.1. Option 1 – Traffic management measures

This option describes measures related to the traffic management system in order to increase the capacity of the existing lock complex. This does not involve any physical adaptations of the existing lock complex. Therefore no construction costs are associated with alternatives derived from this option. To optimize the passage time of fast ferry navigation at the Schellingwoude lock complex multiple traffic management measures are examined.

Priority arrangement – Within a priority arrangement the priority of fast ferry navigation during the locking process is set above commercial and recreational navigation. A priority arrangement is only expected to decrease the passage time of fast ferry navigation at expense of commercial and recreational navigation. In order determine the exact disadvantage of commercial and recreational navigation following from a priority arrangement for fast ferry navigation this option is further elaborated in alternative 1a. In order to limit the expected increase of the average passage time of commercial and recreational navigation a priority arrangement is
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

also combined with a separate locking method. This alternative is expected to decrease the average passage time of commercial and recreational navigation, due to an optimized lock chamber occupancy. This alternative is further elaborated as alternative 1b. Additional legal aspects of these alternatives are described in paragraph 5.3.

Reservation – Reservation of an existing lock chamber can be considered a drastic measure following from a priority arrangement. This option can also be examined to determine if one lock chamber carries sufficient capacity to handle all daily fast ferry navigation. If not, a second existing lock chamber can be reserved for fast ferry navigation. These options are further investigated being alternative 2a and 2b. Additional aspects of these alternatives are described in paragraph 5.4.

Changing chamber priority – Current operational management assigns the present lock chambers to all passing vessels based on the dimensions of the lock chamber in relation to the vessel dimensions. Exceptions have been made to separate commercial navigation from recreational navigation. This principle enhances the overall safety at the lock complex. The chamber priority is related to the assessment of arriving vessels to be locked together or separated from vessels already assigned to a lock chamber. This assessment can be made based on the:
- available area in the lock chamber (absolute space);
- degree of filling (relative space), and;
- availability of other lock chambers.

To prevent the number of lockage’s during increased traffic intensity the chamber priority is often based on the availability of space (absolute space). During low traffic intensity the effect of the chamber priority is more significant, but in practice the lock operators manually optimize the chamber priority based on additional vessel information and changing sailing conditions. This option is not further investigated, since the normative navigation scenarios involve increased traffic intensity.

Changing locking method – The locking method refers to the consideration of separate or mixed locking strategy. A mixed locking strategy is commonly used to make sure that each vessel is locked in the order of arrival at the lock complex. Especially during high traffic intensity a mixed locking method is considered to be best practical approach, since designation of a lock chamber is done manually by the lock operators. A separate locking strategy refers to a placement of vessels inside the lock chamber based on vessel category. This distinction is made to minimize the space inside the lock chamber lost to safety margins between vessels from different categories. During a mixed locking strategy safety margins between vessels creates a decrease lock chamber utilization compared to a separate locking method. In case of high traffic intensity separation of vessel from different categories is expected to result in a strong variation in waiting times of specific navigation types. Navigation types consisting of vessels with the same category i.e. recreational navigation, are expected to benefit from this locking method. This effect is enlarged in case of a large volume of recreational navigation compared to the total volume of navigation passing the lock complex. Although a separate locking method during high traffic intensity might lead to practical limitations the effect of separate locking method is investigated in combination with a priority arrangement for fast
ferry navigation. This traffic management related measure further elaborated being alternative 1b.

**Changing locking regime** – A locking regime fixes the performance of the lock operation system by setting minimal demands related to the chamber utilization. Also a schedule for periodical locking can be implemented. This option provides the possibility to tune the performance of separate lock chambers. Since the lock operation system at the Schellingwoude lock complex consists of four lock chambers the overall performance is given a higher priority than the performance of separate lock chambers. A locking regime is expected to decrease the overall performance of the lock operation system as a result of the varying traffic intensity. This option is therefore not further elaborated as an alternative.

5.2.2. **Option 2 – Physical adaptation of layout**

Increasing lock capacity can be done by physical adaptation of the existing layout of the Schellingwoude lock complex. Alternatives related to this option involve large construction costs and show therefore less potential than traffic management related measures. Next to fast ferry navigation, physical adaptation of the lock complex can provide additional capacity regarding future trends on IWT in general. The construction costs of additional capacity can therefore be shared by all stakeholders benefitting from a decrease of passage time at the Schellingwoude lock complex.

**Adaptation of existing lock chambers** – Adaptation of the existing lock chambers involves type of gates and the filling and emptying system as stated in paragraph 4.4.4 and 4.4.5. Their quantitative effect on capacity is examined in the sensitivity analysis as part of the performance analysis. This option is therefore not further elaborated as an alternative.

**Additional lock chamber** – Since the number of lock chambers is the largest factor influencing capacity, an additional lock chamber is the most rigorous way to increase the lock capacity. An additional lock chamber can be designed to handle fast ferry navigation only or can be designed to serve all types of navigation able to pass the lock chamber. In order to measure the range of effect of an additional lock chamber, two different lock chambers dimensions are examined. One carrying minimal dimensions handling fast ferry navigation and a lock chamber handling vessels up to CEMT-class VIb. Additional aspects of these alternatives are stated in paragraph 5.6.

**Additional innovative structure** – Besides the common concept of lock chamber the addition of an innovative structure handling fast ferry navigation is investigated. During the locking process all navigation, including fast ferry navigation, are bounded by passage time. The distance covered during the locking process often is limited to the distance between the ends of the guiding jetties at both sides of the lock complex. This implies a limited average velocity of vessels during the locking process. The design of the innovative structure in this option is intended to increase the average velocity of fast ferry navigation during the locking process. No other vessels are allowed to use this structure. Additional design aspects of this alternative are stated in paragraph 5.7.
5.3. **Alternative 1a/1b – Priority arrangement**

A priority arrangement for fast ferry navigation is in place to decrease the waiting time of fast ferry navigation at the lock complex. A priority is applied at the northern, middle and southern lock chambers of the Schellingwoude lock complex. The priority arrangement is not applied at the PWA-lock chamber, since the characteristics of this lock chamber do not provide the possibility to decrease the average passage time below the target condition associated with fast ferry navigation. This is due to the large opening and closing time of the sliding gates at the PWA-lock chamber. This approach differs from alternative 0, since a priority arrangement does not imply a locking procedure in order of arrival time at the lock complex. Existing legislation does not allow priority arrangements regarding any vessel types, except vessels of the competent authority. This alternative should identify to what extent other navigation types are disadvantaged by this traffic management related measure. This lock operation process is recorded in alternative 1a.

Due to the large increase of traffic intensity following from the introduction of fast ferry navigation, a priority arrangement is expected to result in a large increase of the average passage time of the conventional fleet passing the Schellingwoude lock complex. In order to limit the increase of the average passage time of the conventional fleet a priority arrangement is applied in combination with a separate locking method. At the northern, middle and southern lock chamber. The average passage time of recreational navigation, mainly consisting of vessels from the same vessel category, is expected to decrease. Although in practice a separated locking method during high traffic intensity is hard to maintain, this lock operation process is referred to as alternative 1b. A separate locking method is expected to create large variations in the passage time of individual vessels conflicting with the legal obligations related to the order of lockage based on the order of arrival at the lock complex.

5.4. **Alternative 2a / 2b – Reservation**

Alternative 2 is derived from alternative 1 except that no other types of navigation are allowed to use the lock chamber designated to fast ferry navigation. To optimize the separation of fast ferry navigation, this type of navigation is designated to a fixed lock chamber. This procedure can also be regarded as a reservation of a lock chamber. In alternative 2a the southern lock chamber is reserved for fast ferry navigation and not accessible for commercial or recreational navigation. The southern lock chamber is chosen since this lock chamber carries the minimum dimensions providing the passage of the design vessel of fast ferry navigation adopted in this research. Reservation of the southern lock chamber also prevents the redirection of recreational navigation mainly passing via the northern lock chamber. The passage of fast ferry navigation at the southern lock chamber separates the recreational navigation from the fast ferry navigation, improving safety conditions at the lock complex.

Depending on the results of alternative 2a the reservation of two lock chambers is recorded by alternative 2b. In this case the southern and middle lock chamber are reserved for fast ferry navigation. These lock chambers are chosen since the location of these lock chamber forces a complete separation of commercial, recreational and fast ferry navigation. Commercial navigation is supposed to pass
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

the Schellingwoude lock complex via the PWA-lock chamber. Recreational navigation is supposed to pass via the northern lock chamber. Complete separation of navigation enhances nautical safety conditions at the lock complex.

5.5. **Alternative 3 – Priority arrangement & reservation**

In case the reservation of one lock chamber during a 15 minute timetable is not sufficient to meet the target conditions associated with fast ferry navigation, the combination of a priority arrangement and reservation of a lock chamber is investigated. This combination is expected to minimize the waiting of vessels from one direction using the reserved lock chamber. In this alternative the southern lock chamber is reserved for fast ferry navigation. Fast ferries from the opposite direction are expected be prioritized at the northern and middle lock chamber. The effective management related measure per direction can be determined based on the largest transport demand during rush hour. Reservation of a lock chamber is expected to show less variability to passage time in relation to priority arrangement. This measure is therefore preferred in the direction of the largest transport demand.

5.6. **Alternative 4a / 4b – Additional lock chamber**

Unlike previous alternatives, alternative 4 describes physical adaptation of the existing lock complex. An additional lock chamber is intended to increase the lock capacity affecting the passage time of all navigation. In order to minimize the construction costs an additional lock chamber with minimal dimensions serving fast ferry navigation is investigated (Alternative 4a). This lock chamber is able to handle one normative vessel per lockage and is therefore only assessable for fast ferry navigation. The characteristics of the additional minimal lock chamber are based on the governing vessel characteristics for fast ferry navigation as stated in paragraph 6.4. Regarding the variety of possible normative vessels serving water based public transport, extra margins on the minimal lock chamber dimensions are accounted.

Future scenarios on traffic intensity near the Schellingwoude lock complex show an overall increase of vessel dimensions. Although the existing lock complex is expected to carry sufficient capacity serving future commercial navigation an additional CEMT-class VIb lock chamber is investigated (alternative 4b). This alternative is investigated to compensate for the additional passage time of commercial navigation following from the addition of fast ferry navigation at the Schellingwoude lock complex. The additional lock chamber is only accessible for commercial navigation. Within this alternative the middle and southern lock chamber are reserved for fast ferry navigation. The northern lock chamber used by recreational navigation. The characteristics of the additional lock chambers applied in alternative 4a and 4b are listed in table 9.
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

Table 9: Characteristics of additional lock chambers.

<table>
<thead>
<tr>
<th>#</th>
<th>Description</th>
<th>Dimensions lock chamber (L x W)</th>
<th>Entrance depth</th>
<th>Dimensions design vessel</th>
<th>Normative allowable vessel class</th>
</tr>
</thead>
<tbody>
<tr>
<td>4a</td>
<td>Additional minimal lock chamber</td>
<td>40.0 m x 7.5 m</td>
<td>NAP -3.1 m</td>
<td>27.6 m x 6.7 m</td>
<td>Fast ferry navigation</td>
</tr>
<tr>
<td>4b</td>
<td>Additional CEMT-class VIb lock chamber</td>
<td>200.0 m x 24.0 m</td>
<td>NAP -4.7 m</td>
<td>197.0 m x 23.7 m</td>
<td>CEMT-class VIb</td>
</tr>
</tbody>
</table>

Integration of an additional lock chamber complex within the existing lock complex involves free space at the connecting levees. Also the design of the outer port at both sides of the lock complex serving nautical safety purposes needs to be integrated. The limited navigation space and the presence of living boats the at the surrounding waters ask for an integral joining of outer port of all existing lock chambers. In figure 15 available locations of the additional lock chambers are identified.

Figure 15: Location of additional lock chambers.
5.7. **Alternative 5 – Additional innovative structure**

Alternative 5 describes the existing lock complex in combination with an additional innovative structure dedicated to the passage of fast ferry navigation. Therefore the locking process of commercial and recreational navigation is not affected by this alternative. The layout of the innovative structure is designed to increase the average velocity during the passage of the Schellingwoude lock complex. The design of the structure is strongly related to an ‘ordinary’ lock chamber, but distinguished by an increased lock chamber length. The length of the lock chamber is determined by the condition that the fast ferry does not need to make fast during the stage of leveling. The sailing velocity in the lock chamber is assumed to be 12 km/h. During the stage of sailing inside the lock chamber the closing of the entrance gates, leveling of water difference and opening of the exit gates is done simultaneously. Assuming a gate opening and closing time of 1.75 minutes a minimal lock chamber length of 700 m is required. In this calculation the time involved in leveling is considered to be none. This assumption is based on a minimal water level difference in which the gates can be controlled during a head difference. During the summer period when the target water level head is 0.20 m, a translatory wave as a result of opening the gates under a head difference propagates inside the lock chamber. The translatory wave forms the transition between the target water levels propagating is from East to West depending on the direction of locking process. As a result of translatory waves and the large dimensions of the lock chamber, the total water loss is expected to be higher than conventional lock chambers. The storage area of lake Binnen-IJ, NZK and ARK is expected to carry sufficient capacity to prevent large water levels fluctuation following from the additional water loss. Due to the fact that at least one set of gates is closed during the locking process, no free gravitational flow from lake Buiten-IJ towards lake Binnen-IJ will occur. Within this concept the flood defense system protecting dike ring area 44 is always closed. In order to prevent an increase of salinity due to the additional water loss, bubble screens can be installed. The physical elaboration of the design is represented in figure 16.

![Figure 16: Physical elaboration of alternative 5.](image-url)
The innovative structure intended to provide a safe and fast passage of fast ferry navigation is situated south of the PWA-lock chamber. The design of the northern lock chamber wall consists of a large cofferdam. The southern lock chamber wall partially consists of the northern bank protection of the island of Zeeburg and a cofferdam.

5.8. Conclusion

The existing lock operation process is not suitable for the passage of fast ferry navigation within the target conditions associated with water based public transport. In order to optimize the passage of fast ferry navigation at the Schellingwoude lock complex eight lock system alternatives are derived from a list of options. These lock system alternatives are:

- Alternative 1a – Priority arrangement;
- Alternative 1b – Priority arrangement and separate locking method;
- Alternative 2a – Reservation of one lock chamber;
- Alternative 2b – Reservation of two lock chambers;
- Alternative 3 – Priority arrangement and reservation of one lock chamber;
- Alternative 4a – Additional minimal lock chamber;
- Alternative 4b – Additional CEMT-class Vlb lock chamber;
- Alternative 5 – Additional innovative structure.

The performance of these alternatives is analyzed in combination with various normative navigation scenarios described in the next chapter.
6 Navigation scenarios

Chapter 6 describes the normative navigation scenarios examined during the performance analysis of the lock operation system. A navigation scenario consists of the volume and arrival pattern of:

- Commercial navigation;
- Recreational navigation;
- Fast ferry navigation.

By describing the volume and arrival pattern of all navigation within the performance analysis the demand following from the traffic intensity is fixed.

6.1 General assumptions

The performance analysis requires relevant input data related to volume and arrival pattern of navigation. Navigation scenarios are distinguished to provide relevant characteristics of combinations of navigation types. In the volume of commercial navigation a distinction has been made between a short term (2012) and a midterm (2020) scenario. A short term scenario is chosen to analyze the results of the performance analysis with recent trends in IWT based extrapolation of recent historical data. A midterm scenario shows the potential of a future water based public transport connection passing the Schellingwoude lock complex regarding future accessibility of the planned housing at Almere in lake Markermeer. The volume of recreational navigation within the various navigation scenarios is set to be equal to the normative month (August). It is assumed that the navigation scenarios describing the average volume of recreational navigation are not relevant, since the legal obligations related to exploitation of fast ferry navigation consider an increased traffic intensity being a culpable delay towards shipping companies. An increased traffic intensity during the summer period is therefore directly related to the punctual performance of the water based transport connection. Although the commuter related transport demand is below average during August, the punctual performance conditions related to public transport must be guaranteed. During August the minimal service level of water based public transport is set to be a 30 min timetable. Focussing on additional passenger transport capacity also a 15 min timetable is applied in the performance analysis on optimizing the passage of fast ferry navigation. To verify the effect of monthly variation of traffic intensity of recreational navigation on the average passage time a sensitivity analysis is executed in paragraph 7.3.3. The arrival pattern of fast ferry navigation is recorded by a 30 and 15 min timetable. These timetables are applied during the complete duration of the performance analysis. The effect of hourly variations on traffic intensity of commercial and recreational navigation on the passage time of fast ferry navigation in and outside rush hour is further investigated in the sensitivity analysis in paragraph 7.3.4.

6.2 Commercial navigation

A significant throughput of cargo from and towards the hinterland of seaports is transported via IWT. Therefore commercial navigation adds a substantial contribution to the Dutch economy. In commercial navigation a distinction is made between cargo and non-cargo navigation. Next to vessel dimensions also the
volumes of these types of commercial navigation increase in a different rate. Cargo vessels up to CEMT-class VIb are allowed on the main navigation route passing the Schellingwoude lock complex.

6.2.1. Volume
The navigation volume is an important factor determining the traffic intensity of commercial navigation at the Schellingwoude lock complex. The volume of navigation in 2012 is based on historical data of 2006 to 2009 [14]. At the Schellingwoude lock complex also seagoing vessels are recorded. This vessel type is neglected during the performance analysis, due to the small volume of vessels per week in relation to the volume of inland navigation. The number of seagoing vessels is determined to be less than 1 vessel per week. Other than the limited line of sight of these vessels the maneuverability is expected to cause no disruptions in the lock operation process. The navigation volume in 2020 is based on a forecast of the expected navigation volumes. The forecast of the expected navigation volumes is derived from the WLO scenarios, which forms an important basis for planning policy of the Dutch government. The Global Economy (GE) scenario as set by the government accounts for a global increase of IWT and a shift in vessel dimensions and vessel categories [38]. It is forecasted that the volume of vessels below CEMT-class III will decrease and the volume of vessels of CEMT-class III and above will increase. The relative share of push barges and convoys is expected to increase in favor of motor vessels. The phenomena is attributed to the overall increase of loading capacity of cargo vessels. The fleet of non-cargo vessels is assumed to consist of an equal volume of service vessels and tugs. Directional information is derived from data of the NIS application of Rijkswaterstaat [12]. The volume of commercial navigation is listed in table 10. The exact volume of cargo and non-cargo vessels per scenario is added in APPENDIX 4.

Table 10: Volume of commercial navigation [12].

<table>
<thead>
<tr>
<th>Commercial navigation</th>
<th>Year</th>
<th>Volume per week</th>
<th>Vessel category (Cargo)</th>
<th>Vessel category (Non cargo)</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Motor vessel</td>
<td>Push barge</td>
<td>Convoy</td>
</tr>
<tr>
<td>Cargo</td>
<td>2012</td>
<td>630 vessels</td>
<td>89%</td>
<td>6%</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>2020</td>
<td>709 vessels</td>
<td>82%</td>
<td>11%</td>
<td>7%</td>
</tr>
<tr>
<td>Non cargo</td>
<td>2012</td>
<td>92 vessels</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>2020</td>
<td>110 vessels</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

6.2.2. Arrival pattern
The arrival pattern of commercial navigation in both directions is derived from the IVS-90 data of Rijkswaterstaat [12]. The arrival pattern of cargo and non-cargo vessels is assumed to be equal. Also the arrival pattern in 2012 and 2020 is assumed to be equal. The exact arrival pattern per direction is added in APPENDIX 5.
6.3. **Recreational navigation**

The large network of waterways in the Netherlands attracts a large volume of recreational navigation. On main navigation routes recreational navigation is mixed with commercial navigation. Especially during the period between April and October the volume of recreational navigation is above average. Large fluctuations in volume recreational navigation are an important factor determining local traffic intensity at the Schellingwoude lock complex. Due to a lack of data the recreational fleet is assumed to consist of an equal volume of motor- and sailing yachts.

6.3.1. **Volume**

Based on the historical data on the volume of passages at the Schellingwoude lock complex August is determined to be the normative month regarding the volume of recreational navigation. Directional information is derived from data of the NIS application of Rijkswaterstaat [12]. The volume of recreational navigation during the August (Normative month) and October is listed in table 11. The exact volume of recreational navigation per vessel type is added in APPENDIX 4.

<table>
<thead>
<tr>
<th>Month</th>
<th>Volume per week</th>
<th>Vessel type</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>August (Normative month)</td>
<td>2769 vessels</td>
<td>50%</td>
<td>51% 49%</td>
</tr>
<tr>
<td>October</td>
<td>707 vessels</td>
<td>50%</td>
<td>51% 49%</td>
</tr>
</tbody>
</table>

6.3.2. **Arrival pattern**

The arrival pattern of recreational navigation in both directions is derived from the IVS-90 data of Rijkswaterstaat [12]. The exact arrival pattern of recreational navigation per direction is added in APPENDIX 5.

6.4. **Fast ferry navigation**

The vital aspect in this research is the introduction of fast ferry navigation to the existing fleet of navigation passing the Schellingwoude lock complex. The increase of traffic intensity due to this additional navigation type is expected to be significant. This paragraph discusses important characteristics of fast ferry navigation.

6.4.1. **Governing vessel type**

From the recent history of modern water based transport in the Netherlands and operating fast ferry connections all over the world, an overview of suitable vessel types to perform the connection on the route between Amsterdam Central Station and Almere is listed in figure 17.
From recent history on water based public transport in the Netherlands it can be concluded that vessel type is an important factor determining the success of a connection. Based on the success factors described in paragraph 2.3 and the local boundary conditions on the route between Amsterdam Central Station and Almere, the normative vessel type is chosen to be a hydrofoil. The hydrofoil vessel type is considered to include the most effective combination of a high service velocity and low wash generation. This combination on the one hand corresponds with the asked high service velocity limiting the travel time crossing lake Buiten-IJ. On the other hand obligations related to the nuisance towards living boats and the limited strength of bank protections at lake Binnen-IJ limit the allowable generation of wash. Research based on fieldwork by Rijkswaterstaat on water movement generated by fast ferry shows that hydrofoil vessels generate less wash in comparison to catamaran type vessels [21]. An extensive assessment of the normative vessel type is not included in this research. The characteristics of the hydrofoil vessel used within this research are partially based on the characteristics of the vessel type performing the water based public transport connection between Amsterdam Central Station and Velsen. Although the design of these Ukraine-build vessels originates from the 70’s of the previous century these vessel are still performing according a tight 30 min timetable. Further research on the safety conditions and the emissions of the corresponding drive system of these vessels is not part of this study either. Accept for vessel dimensions it is expected that different design vessels of fast ferry navigation do not influence the outcome the performance analysis. The main vessel characteristics of the fast ferry navigation introduced in this study are listed in table 12.
### Table 12: Vessel characteristics of fast ferry navigation [22]

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel type</td>
<td>Hydrofoil</td>
</tr>
<tr>
<td>L.O.A.</td>
<td>27.62 m</td>
</tr>
<tr>
<td>Width</td>
<td>6.80 m</td>
</tr>
<tr>
<td>Draught (floating)</td>
<td>2.10 m</td>
</tr>
<tr>
<td>Draught (on wings)</td>
<td>1.20 m</td>
</tr>
<tr>
<td>Weight</td>
<td>29.8 tonnes</td>
</tr>
<tr>
<td>Loading capacity</td>
<td>79 passengers</td>
</tr>
<tr>
<td>Service velocity</td>
<td>50 – 60 km/h</td>
</tr>
<tr>
<td>Maximum velocity</td>
<td>65 km/h</td>
</tr>
<tr>
<td>Stopping distance</td>
<td>200 to 280 m</td>
</tr>
<tr>
<td>Stopping time</td>
<td>31 seconds</td>
</tr>
</tbody>
</table>

#### 6.4.2. Volume per week

The volume of fast ferry navigation per week is fixed by the arrival pattern. In case of fast ferry navigation the arrival pattern is expressed by a timetable. In reality the timetable will be adapted according to the hourly transport demand throughout the day. The volumes of fast ferry navigation resulting from the arrival pattern are listed in table 13.

<table>
<thead>
<tr>
<th>Time table</th>
<th>Volume per week</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 min</td>
<td>462 vessels</td>
<td>East: 50% West: 50%</td>
</tr>
<tr>
<td>15 min</td>
<td>917 vessels</td>
<td>East: 50% West: 50%</td>
</tr>
</tbody>
</table>

#### 6.4.3. Arrival pattern

In order to estimate the influence of the additional traffic demand at the Schellingwoude lock complex as a result of the introduction of fast ferry navigation, two possible arrival patterns are simulated. The arrival pattern of the fast ferry at the boundary of the lock operation system is characterized by a fixed interval and can be described by the same interval which is set in the timetable with respect to arrival and departure times at the stations. The timetables are applied on a daily cycle between 6:00h and 22:00h. In practice variations ranging up to 2 minutes in the exact arrival pattern will occur. These variations are included in the simulation model as described in paragraph 0. A 30 minute timetable is the minimal requirement for a water based public transport connection to serve as an additional competitive transport alternative on the route between Amsterdam Central Station and Almere. A 30 minute timetable is imposed at both boundaries of the lock operation system. During rush hour the transport demand is above the daily average. To keep up with an increase of transport demand during rush hour, a higher frequency of arrival and departure times of vessels on the route between Amsterdam Central Station and Almere is required. A 15 minute timetable doubles the transport capacity and increases the service level of the water based transport connection. As result of a 15 minute timetable of the fast ferry navigation, an increase of traffic intensity at the lock complex will be observed. This scenario is intended to investigate effect of an
increase in traffic intensity on the locking process. A 15 minute timetable is imposed at both boundaries of the lock operation system. To tune the approach of fast ferry navigation from both directions the arrival pattern is optimized by sequential approach of vessel from the direction West and East. The exact arrival pattern of fast ferry navigation in both scenarios is listed in APPENDIX 5.

6.5. Summary
A summary of the distinctive characteristics of relevant navigation scenarios being input data for the performance analysis is listed in table 14.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Volume commercial navigation</th>
<th>Arrival pattern fast ferry navigation</th>
<th>Volume per week [vessels]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[year]</td>
<td>[...] min timetable</td>
<td>Total</td>
</tr>
<tr>
<td>1</td>
<td>2012</td>
<td>30</td>
<td>3861</td>
</tr>
<tr>
<td>2</td>
<td>2012</td>
<td>15</td>
<td>4316</td>
</tr>
<tr>
<td>3</td>
<td>2020</td>
<td>30</td>
<td>3940</td>
</tr>
<tr>
<td>4</td>
<td>2020</td>
<td>15</td>
<td>4395</td>
</tr>
</tbody>
</table>

Table 14: Distinctive characteristics of relevant navigation scenarios.
## 7 Performance analysis

This chapter describes the approach and results of the performance analysis as part of the feasibility study towards optimizing the passage of fast ferry navigation.

### 7.1. Research approach

From the point of view of navigation the performance of the locking process is indicated by the average passage time of vessels in the queue to be locked. A reliable performance analysis requires an exact determination of the average passage time and 95% value of the passage time of individual vessels. A simulation run consists of a combination of an alternative and a navigation scenario. In figure 18 an overview of all runs part of the performance analysis is listed.

<table>
<thead>
<tr>
<th>Lock system alternative</th>
<th>Navigation scenario</th>
<th>Run</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing Situation (Validation)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternative 0 — Existing lock complex</td>
<td></td>
<td>Run 1, Run 2, Run 3, Run 4</td>
</tr>
<tr>
<td>Alternative 1 — Priority arrangement</td>
<td></td>
<td>Run 5, Run 6, Run 7, Run 8</td>
</tr>
<tr>
<td>Alternative 2a — Reservation of one lock chamber</td>
<td></td>
<td>Run 9, Run 10, Run 11, Run 12</td>
</tr>
<tr>
<td>Alternative 2b — Reservation of two lock chambers</td>
<td></td>
<td>Run 13, Run 14, Run 15, Run 16</td>
</tr>
<tr>
<td>Alternative 3 — Priority arrangement and reservation</td>
<td></td>
<td>Run 17, Run 18, Run 19, Run 20</td>
</tr>
<tr>
<td>Alternative 4a — Additional minimal lock chamber</td>
<td></td>
<td>Run 21, Run 22, Run 23, Run 24</td>
</tr>
<tr>
<td>Alternative 4b — Additional CEMT-class Vlb lock chamber</td>
<td></td>
<td>Run 25, Run 26, Run 27, Run 28</td>
</tr>
<tr>
<td>Alternative 5 — Additional innovative structure</td>
<td></td>
<td>Run 29, Run 30, Run 31, Run 32</td>
</tr>
</tbody>
</table>

![Figure 18: Overview of runs part of the performance analysis.](image-url)
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

For the calculation of passage times of individual vessels during the runs as listed above, multiple methods are available:

- Calculation on the basis knowledge and experience;
- Calculation on the basis of analytical approach;
- Calculation on the basis of simulation.

The calculation on the basis of simulation is preferred above other types of methods because of:

- the complexity of process involved in stochasticity;
- the large volume of navigation on a yearly basis;
- the examination of various lock system alternatives;
- the examination of various navigation scenarios.

Other aspects influencing this decision are restrictions with respect to the authors planning and costs.

7.1.1. Simulation model

The choice for the right simulation model is dependent on the functionality, availability, costs and reputation of a model. Regarding the assessment of the performance of the lock operation process, conducted within this research, the following criteria towards the simulation model are considered to be relevant:

- Process orientated description method;
- Capability to simulate a continuous process;
- Capability to simulate a multiple service installation (lock chambers).

The SIVAK Simulation package (Simulatiemodel voor de Verkeers-Afwikkeling bij Kunstwerken) can be used to determine reliable passage times of navigation handled at locks. SIVAK was developed by Rijkswaterstaat for dealing with navigation and road traffic at locks, constrictions and bridges situated in a network of waterways. It is intended as an advisory tool for waterway authorities in setting up plan studies and cost-benefit analyses. The model can be used to express changes in the use and design of the structure and changes in the requirements for waiting areas for both navigation and road traffic (in the case of moveable bridges). The upgrade of SIVAK towards SIVAK2 involves the possibility of expressing the arrival pattern of vessels into a fixed timetable next to the intensity based method of describing the arrival pattern of vessels within the model. This way the functionality of the SIVAK-model has increased and also makes it possible to apply the model during the simulation of ‘ordinary’ mixed flow navigation in combination with navigation sailing according a fixed timetable (i.e. water based public transport).

The SIVAK simulation model is based on the Prosim simulation language. A computer simulation language describes the operation of a simulation on a computer. The Prosim environment remains outside the field of observation of ‘ordinary’ users, since the user interface of these models provide the tools for the creation and management of the input files and analysis of the output files. During simulation the animation possibilities of the Prosim language are used for graphical reference of the simulation of the described process. The main features of the SIVAK2 simulation model are:
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

- the ability to describe continuous, stochastic processes;
- vessels are individual navigation participants with individual arrival pattern (based on intensities and/or timetables), sailing behaviour and dimensions;
- particularly useful for a large diversity in vessel dimensions and sailing behaviour;
- very suitable for lock complexes with more than one chamber.

Note:
The SIVAK2 simulation model is applied in this research to determine the capacity of various specific alternative lock operation systems, in combination with multiple scenarios. The verification and validation of the model (trial and error) is carried out to narrow the discrepancy between the interpretation of model response and the “real world”. It is noted that the human factors influencing the handling of navigation at a lock complex are not represented in the model. Therefore human errors and possible deviant behavior of vessels resulting in additional delays are not simulated.

7.1.2. Calibration
The SIVAK2 model is composed of various blocks, carrying physical and process-related properties of the components involved in the lock operation system. In APPENDIX 6 an overview of blocks in relation to the lock operation system is listed. With the upgrade from SIVAK to SIVAK2 the possibility of expressing the arrival pattern of according a fixed time schedule became available. This feature makes it possible to simulate the arrival pattern of fast ferry navigation according a 30 or 15 min timetable. Based on the experience of Rijkswaterstaat with the SIVAK2 model and these features, it is assumed the locking process simulated by the model is consistent with the locking process as performed at the Schellingwoude lock complex after introduction of fast ferry navigation.

7.1.3. Input data
The input data applied in the simulation runs executed during this research is based on the description of the process related properties in chapter 4. Additional relevant input data inserted in the system block of the SIVAK2 model is added in this paragraph.

Network
The capacity analysis as part of this study focuses on the passage navigation at the Schellingwoude lock complex, therefore the simulation of navigation on surrounding waterway sections is neglected. The purpose of the waterways sections within the system network is to guide the model generated navigation in node 1 and node 6, towards the lock complex (section 3-4) and to fulfil as a queuing area for waiting vessel at both sides at the lock complex. An overview of the system network applied within the simulation model is added in figure 19. It is noted that the arrows connecting the nodes do not imply one-way traffic.
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

The characteristics of the various waterway sections in the network are listed in table 15.

Table 15: Characteristics of waterway sections in the model network.

<table>
<thead>
<tr>
<th>Section</th>
<th>Type</th>
<th>Length</th>
<th>Max. velocity</th>
<th>Overtaking allowed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>Waterway</td>
<td>10.000 m</td>
<td>60 km/h</td>
<td>Yes</td>
</tr>
<tr>
<td>2-3</td>
<td>Outer port</td>
<td>200 m</td>
<td>12 km/h</td>
<td>No</td>
</tr>
<tr>
<td>3-4</td>
<td>Navigation lock</td>
<td>varying</td>
<td>-</td>
<td>No</td>
</tr>
<tr>
<td>4-5</td>
<td>Outer port</td>
<td>200 m</td>
<td>12 km/h</td>
<td>No</td>
</tr>
<tr>
<td>5-6</td>
<td>Waterway</td>
<td>10.000 m</td>
<td>60 km/h</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Length of runs

The duration of generation of a fleet composed of individual vessels is equal to the length of the simulation runs according to the arrival pattern set in the model. The length of runs per simulation scenario (n) affects the confidence interval of the output data of the simulation scenario. The minimal confidence interval is set to be 95%. In relation to this number a degree of accuracy must be set. The accuracy is considered to be higher than the tolerance involved in the variation arrival time of fast ferries approaching the lock complex, which is set to be 2 minutes. The accuracy is set to be 1 minute. The length of the simulation runs (n) is calculated, according to the following formula:

\[ n > \frac{Z^2 \sigma^2}{d^2} \]

In which:
- \( Z [-] \) = fractional confidence interval
- \( d [\text{min}] \) = accuracy
- \( \sigma [\text{min}] \) = standard deviation of passage time of all vessels during one run based on a SIVAK query

\(^2\) The length of the waterway sections 1-2 and 5-6 is based on the condition of variation of arrival moments of the fast ferry navigation at both sides of the lock complex (node 3 and 4). Assuming a service velocity ranging between 50 and 60 km/hr and an arithmetical sailing distance of 10,000 m, the arrival moments will vary in a range of 2 minutes around the fixed arrival pattern as recorded in the timetable.
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

Table 16: Simulated passage time in present situation (Average month).

<table>
<thead>
<tr>
<th>Week</th>
<th>Average passage time [min]</th>
<th>Deviation from average [min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1</td>
<td>24.13</td>
<td>-0.50</td>
</tr>
<tr>
<td>Week 2</td>
<td>26.08</td>
<td>1.45</td>
</tr>
<tr>
<td>Week 3</td>
<td>23.66</td>
<td>-0.97</td>
</tr>
<tr>
<td>Week 4</td>
<td>24.39</td>
<td>-0.24</td>
</tr>
<tr>
<td>Week 5</td>
<td>23.15</td>
<td>-1.48</td>
</tr>
<tr>
<td>Week 6</td>
<td>24.23</td>
<td>-0.40</td>
</tr>
<tr>
<td>Week 7</td>
<td>22.71</td>
<td>-1.92</td>
</tr>
<tr>
<td>Week 8</td>
<td>28.68</td>
<td>4.05</td>
</tr>
<tr>
<td>Average</td>
<td>24.63</td>
<td></td>
</tr>
</tbody>
</table>

In which:

$$Z = 1.96 \text{ [-]} \quad (95\% \text{ confidence interval})$$

$$d = 1 \text{ min}$$

$$\sigma = 1.43 \text{ min}$$

$$n = 7.88 \text{ week (calculated)}$$

$$n = 8 \text{ week (rounded)}$$

The duration of simulation is extended to period of 8 weeks. This duration also accounts for possible effects of warm-up time and irregularities in the generation of vessels at the system boundaries. A longer duration of simulation will result in a larger volume of data. The duration of simulation is therefore a trade-off between theoretical and practical considerations.

**Operation schedule**

All lock chambers are available for lockage between 6:00h and 22:00h. During night time the operation schedule of the lock chambers part of the Schellingwoude lock complex depends on the traffic demand. The PWA-lock chamber is also available from 22:00h to 6:00h. At night time during low traffic intensity only one of the Oranjesluizen is available for navigation. The designation of the lock chamber is based on the dimensions of the approaching vessel. The designated lock chamber is operated via an extended camera system making it possible to supervise the complete locking process during night time from one control building. Only one lock chamber at the time can be operated via camera, due to the limited capacity of a lock operator. The simulation model is not able to designate one particular lock chamber providing lockage without aborting the locking process at other lock chambers. In order to prevent extreme waiting times of vessels approaching before 6:00h the northern lock chamber is determined to be available at all times. Since fast ferry navigation sails between 6:00h and 22:00h the consequents of this input data on the results of the performance analysis is assumed to be minimal. The operation schedule applied in the simulation of the existing lock complex is listed in table 17.
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

Table 17: Characteristics of operation schedule.

<table>
<thead>
<tr>
<th>Lock chamber</th>
<th>Operation schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern lock chamber</td>
<td>Daily from 0:00h to 23:59h</td>
</tr>
<tr>
<td>Middle lock chamber</td>
<td>Daily from 6:00h to 22:00h</td>
</tr>
<tr>
<td>Southern lock chamber</td>
<td>Daily from 6:00h to 22:00h</td>
</tr>
<tr>
<td>PWA-lock chamber</td>
<td>Daily from 0:00h to 23:59h</td>
</tr>
</tbody>
</table>

Entering and leaving time of fast ferry navigation
The entering and leaving time is depending on the layout of the outer port on both side of the lock complex and the navigation class. The entering and leaving time of the conventional fleet of commercial and recreational navigation is based on data of Rijkswaterstaat on lock complexes with similar dimensions as included in the SIVAK2-model. The entering and leaving time of fast ferry navigation is based on the vessel with a similar dimensions. During maneuvering with a velocity below 12 km/h a hydrofoil vessel shows large similarity with conventional water displacing vessels. The exact entering and leaving times of fast ferry navigation are recorded in table 18.

Table 18: Entering and leaving times.

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Entering [min]</th>
<th>Leaving [min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.30</td>
<td>0.60</td>
<td>0.60</td>
</tr>
<tr>
<td>0.80</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>0.95</td>
<td>1.40</td>
<td>1.40</td>
</tr>
</tbody>
</table>

Gate opening and closing time
The opening and closing time of the gates have a direct influence on the lock cycle time. The values are based on the interview with the lock operators at the Schellingwoude lock complex [24]. No variation is assumed due to the high level of reliability of the gates following from the functional demands related to the flood defense system. The characteristics of the gates of the Schellingwoude lock complex are listed in table 19.

Table 19: Characteristics of gates.

<table>
<thead>
<tr>
<th>Lock chamber</th>
<th>Gate type</th>
<th>Opening time</th>
<th>Closing time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern lock chamber</td>
<td>Mitre gates</td>
<td>1.75 min</td>
<td>1.75 min</td>
</tr>
<tr>
<td>Middle lock chamber</td>
<td>Mitre gates</td>
<td>1.75 min</td>
<td>1.75 min</td>
</tr>
<tr>
<td>Southern lock chamber</td>
<td>Mitre gates</td>
<td>1.75 min</td>
<td>1.75 min</td>
</tr>
<tr>
<td>PWA-lock chamber</td>
<td>Sliding gates</td>
<td>3.00 min</td>
<td>3.00 min</td>
</tr>
</tbody>
</table>

Fleet
The input data concerning the fleet characteristics is set by adding a fleet share for every navigation type during each relevant scenario. The fleet consists of commercial, recreation and fast ferry navigation. Each navigation type is contained within a fleet share describing relevant information on the volume and arrival pattern of navigation as described in paragraph 6.1.
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

Water level
The water levels applied during the simulation of the lock operation process are based on the target water levels during the summer period. Further research on the effect of changing water levels differences on the average passage time of navigation is executed in the sensitivity analysis in paragraph 7.3.1. The characteristics of the target water level at surrounding waters during the summer period are listed in table 20.

<table>
<thead>
<tr>
<th>Water system</th>
<th>Target water level (summer period)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Binnen-IJ / NZK</td>
<td>NAP -0.40 m</td>
</tr>
<tr>
<td>Lake Buiten-IJ / Markermeer</td>
<td>NAP -0.20 m</td>
</tr>
</tbody>
</table>

7.1.4. Validation
The output of the data of the SIVAK2-model should characterize the performance of the lock operation system. This conclusion can be drawn from the validation of the model. During validation, the historical data on the average passage times of navigation passing the Schellingwoude lock complex are compared with the average passage time as a result of the model. A reliable validation involves corresponding input data related to navigation. The characteristics of navigation during the validation process are related to the normative month (August). In table 21 the recorded IVS90-data on the passage time of navigation from the NIS database [12] are compared with the results of the SIVAK model. This comparison only contains data on commercial navigation, since the IVS90 system does not registers the passage time of recreational navigation.

<table>
<thead>
<tr>
<th>Validation</th>
<th>aug-08 [min]</th>
<th>aug-09 [min]</th>
<th>aug-10 [min]</th>
<th>Model [min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern lock chamber</td>
<td>20.04</td>
<td>19.19</td>
<td>19.41</td>
<td>29.87</td>
</tr>
<tr>
<td>Middle lock chamber</td>
<td>22.08</td>
<td>21.80</td>
<td>22.11</td>
<td>14.66</td>
</tr>
<tr>
<td>Southern lock chamber</td>
<td>17.94</td>
<td>18.53</td>
<td>19.08</td>
<td>18.51</td>
</tr>
<tr>
<td>PWA lock chamber</td>
<td>24.81</td>
<td>26.08</td>
<td>29.47</td>
<td>21.94</td>
</tr>
<tr>
<td>Total weighted average</td>
<td>21.22</td>
<td>21.40</td>
<td>22.52</td>
<td>24.63</td>
</tr>
</tbody>
</table>

From table 21 it can be concluded that the total weighted average passage time of the model shows a large degree of similarity in relation to the historical data. The discrepancy between the model output and the historical data is approximately 2 minutes. Regarding the separate average passage time at the southern chamber the discrepancy is also acceptable. The separate average passage time of navigation at northern, middle and PWA lock chamber show a large deviation to the historical data in the order of 7 to 10 minutes. Deviations in the average passage time at these lock chambers are due to:

- a lack of recordings of recreational navigation into the IVS90 system;
- the manual input of data by lock operators into the IVS90 system;
- a difference in the transition on sailing time towards waiting time;
- practical considerations related to chamber priority.
Based on the total weighed average of the passage time of all lock chambers it is assumed that the results of the SIVAK2 simulation model characterize the performance of the lock operation system. The results of the performance analysis should be reviewed with the understanding of irregular lock chamber designation leading to a possible deviation of average passage time per lock chamber. The output of the model is displayed based on navigation type referring to the requirements as stated in the following paragraph.

7.2. Requirements
Conclusions on the performance of the various alternatives are drawn based on the requirements associated with the multiple navigation types passing the Schellingwoude lock complex. The requirements are related to the target conditions on the duration and reliability of the average passage at the Schellingwoude lock complex.

7.2.1. Commercial navigation
The average total waiting time during the normative month should not exceed 30 minutes [33]. The target passage time of commercial navigation at the Schellingwoude lock complex is set to be 45 minutes [12]. The reliability of the minimum target conditions is determined to be 95%.

7.2.2. Recreational navigation
The maximum total waiting time should not exceed 1 hour on the tenth busiest day of the year. In practice this condition is applied to the normative month [33]. The reliability of this target condition is set to be 95%.

7.2.3. Fast ferry navigation
The target conditions concerning the passage of fast ferry navigation are derived from the legal conditions commonly applied in the public transport sector. The average passage time under normative circumstances should not exceed 8 minutes. This figure is based on the travel time analysis in relation to competitive transport modes on the preferred route. Regarding deviations of the average passage time the 95% confidence interval should not exceed 15.0 minutes.

7.3. Sensitivity analysis
A sensitivity analysis is executed to estimate the absolute influence of specific factors as described in paragraph 4.4 on the performance of the lock operation system. The choice of these factors is based on the likelihood and expected degree of influence on the average passage time. The navigation scenario applied during the sensitivity analysis equals the current navigation as used during the validation of the model. This implies both commercial and recreational navigation, without fast ferry navigation. A exception is made in the sensitivity analysis on the hourly variations in traffic intensity of commercial and recreational navigation affecting the average passage time of fast ferry navigation in and outside rush hour. The results of the sensitivity analysis are listed per factor.
7.3.1. Water level differences
During the performance analysis the water level of lake Buiten-IJ is set to be NAP - 0.40m (summer target level). Within the sensitivity analysis the influence of various water levels at lake Buiten-IJ is recorded. The results of the sensitivity analysis regarding the water level difference are displayed in figure 20.

![Figure 20: Absolute influence water level lake Buiten-IJ.](image)

From this figure we can derive that the influence of extreme locking levels is significant. Especially the highest locking level (HLL) results in a large increase of the average passage time. During the winter period when the target water level of lake Buiten-IJ equals lake Binnen-IJ the average passage time of commercial and recreational navigation is recorded to 21.63 minutes. From this value we can derive that the average emptying and filling time during a 0.40 m water difference at all lock chambers equals approximately 3.00 minutes.

7.3.2. Opening and closing time gates
The opening and closing time of the gates at the northern, middle and southern lock chamber is set to be 1.75 minutes. In order to quantify the influence of the opening and closing times multiple values are investigated. The opening and closing time of the gates at the PWA-lock chamber remains 3.00 minutes, since the PWA-lock chamber is not optimized for the passage of fast ferry navigation. The results of the sensitivity analysis regarding the opening and closing time of the gates at the northern, middle and southern lock chamber are displayed in figure 21.
From the results we can conclude that an absolute increase of opening and closing time results in an absolute increase to the total average passage equal to 3 times this amount. This effect is due to the fact that the stage of opening and closing occurs two times in the locking process per vessel. Next to that an increase of waiting time leads to a total increase of approximately 3 times the original absolute increase of opening and closing time.

7.3.3. **Monthly variations in traffic intensity of recreational navigation**

During all navigation scenarios part of the performance analysis the traffic intensity of recreational navigation is set to be equal to the normative month (August). These conditions are decisive regarding the technical feasibility on optimizing the passage of fast ferry navigation. In order to demonstrate the qualitative impact of the traffic intensity of recreational navigation on the average passage time the volume of recreational navigation is decreased. The traffic intensity of recreational navigation as set during this sensitivity analysis is based on the volumes recorded during October and December in 2009. The results of the sensitivity analysis are displayed in figure 22.
From these results it can be concluded that the influence of traffic intensity of recreational navigation on the average passage time of all navigation is significant. Simulation shows that an average traffic intensity (October) and a minimal traffic intensity (December) of recreational navigation result in a minimal average passage time of approximately 15 minutes. The average passage time of commercial and recreational navigation during the normative month (August) increases with approximately 10 minutes compared to the non-normative months throughout the rest of the year.

### 7.3.4. Hourly variations in traffic intensity in and outside rush hour

In the navigation scenarios applied in the performance analysis a distinction has been made in the arrival pattern of fast ferry navigation. The arrival pattern is expressed by a fixed timetable determining the number of departing and arriving vessels per hour. This number is of great influence on the transport capacity expressed by the number of passengers per hour. During rush hour the transport demand of commuter related passenger transport is above average demanding a more frequent departure and arrival frequency. In order to quantify the effect of hourly variations in traffic intensity in and outside rush hour on the performance of fast ferry navigation a sensitivity analysis is executed. The results are recorded in figure 23. The recordings are derived from multiple specific time frames on the same midweek day during a complete simulation run.
From these results we can conclude that the passage time of fast ferry navigation strongly depends on the daily arrival pattern of commercial and recreational navigation. The number of passages of the conventional fleet at the Schellingwoude lock complex is above average from 12:00 AM to 18.00 PM. This results in an increase of passage time of individual fast ferries. The passage time of fast ferries during a 15 min timetable is on average 4 minutes longer compared to a 30 min times table. The results also show that the existing arrival pattern of commercial and recreational navigation allow for additional transport capacity of fast ferry navigation during the morning rush hour. In the morning the passage time of fast ferry navigation during a 15 min timetable is within the target conditions. During the evening rush hour the arrival pattern of commercial and recreational navigation does not allow fast ferry navigation to be within target conditions. Based on the sensitivity analysis it is concluded that tuning the daily arrival pattern of commercial and recreational navigation on the demanded transport capacity of fast ferry navigation increases the reliability of passage time of individual fast ferries.
7.4. Results

In the following paragraphs the result of the performance analysis is summarized. The summary involves the average passage time of all navigation simulated within the model. Detailed information on the distribution (95% confidence band) of the passage time and the values of variables determining passage time are added in APPENDIX 7.

7.4.1. Present situation

The average passage time of commercial and recreational navigation in the present situation is investigated to serve as a reference situation with respect to the expected increase of average passage time after introducing fast ferry navigation to the existing lock operation process. This reference is made for the current volume of navigation (2012) as well as for the future volume of navigation (2020). A summary of the results of simulating the existing situation is added in table 22.

Table 22: Average passage time within the existing situation.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Target</th>
<th>Current navigation</th>
<th>Future navigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume commercial navigation</td>
<td>2012</td>
<td>August</td>
<td>2020</td>
</tr>
<tr>
<td>Normative month</td>
<td>[min]</td>
<td>[min]</td>
<td>[min]</td>
</tr>
<tr>
<td>Commercial navigation</td>
<td>45.00</td>
<td>18.36</td>
<td>19.28</td>
</tr>
<tr>
<td>Recreational navigation</td>
<td>60.00</td>
<td>26.17</td>
<td>26.44</td>
</tr>
<tr>
<td>All navigation</td>
<td>-</td>
<td>24.63</td>
<td>24.80</td>
</tr>
</tbody>
</table>

From the results it is concluded that the average passage time of commercial and recreational navigation is well within the target conditions as recorded within the guideline. These results also confirm the conclusions of Rijkswaterstaat on the capacity of the existing Schellingwoude lock complex. Regarding the future situation a minor decrease of passage time is noted. This effect is attributed to the overall increase of loading capacity of cargo vessels. Simulation shows that these vessels are more frequently using the PWA-lock chamber carrying sufficient capacity to lock multiple vessels of the CEMT III class or higher during one lockage. This strategy matches the locking preference based on the degree of filling.

7.4.2. Alternative 0 – Existing lock complex

In alternative 0 fast ferry navigation is introduced next to the conventional fleet of commercial and recreational navigation. Fast ferry navigation is allowed to use the northern, middle and southern lock chamber without additional traffic management related measures. A summary of the results of simulating alternative 0 is added in table 23.
Table 23: Average passage time Alternative 0.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Target</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume commercial navigation</td>
<td>2012</td>
<td>30 min timetable</td>
<td>2012</td>
<td>15 min timetable</td>
<td>2020</td>
</tr>
<tr>
<td>Arrival pattern</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fast ferry navigation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial navigation</td>
<td>45.00</td>
<td>19.32</td>
<td>18.79</td>
<td>19.55</td>
<td>24.23</td>
</tr>
<tr>
<td>Recreational navigation</td>
<td>60.00</td>
<td>27.20</td>
<td>29.05</td>
<td>27.32</td>
<td>26.60</td>
</tr>
<tr>
<td>Fast ferry navigation</td>
<td>8.00</td>
<td>21.30</td>
<td>23.91</td>
<td>22.81</td>
<td>25.20</td>
</tr>
<tr>
<td>All navigation</td>
<td>-</td>
<td>25.07</td>
<td>26.29</td>
<td>25.23</td>
<td>25.88</td>
</tr>
</tbody>
</table>

From the results it is concluded that the introduction of fast ferry navigation within the existing lock operation process influences all navigation passing the Schellingwoude lock complex. The performance of the existing lock complex, without additional traffic management measures, is not sufficient to meet the target conditions associated with fast ferry navigation. The average passage time of commercial navigation during scenario 1, 2 and 3 shows a minor increase in the order of 1 minute compared to the present situation. This effect is attributed to the introduction of fast ferry fast ferry navigation adding minimal waiting time to commercial navigation. In 2020 the passage time of commercial navigation in combination with fast ferry navigation performing a 15 min timetable shows an increase in the order of 5 minutes. Recreational navigation also shows a minor increase of the average passage time in the order of 1 minute during a 30 min timetable and almost 4 minutes during a 15 min timetable. This is caused by the fact that fast ferry navigation is allowed to use the only lock chamber which is also accessible for recreational navigation. In 2020 the average passage time of recreational navigation equals the present situation. Due to the autonomous growth of commercial vessel dimensions more lock capacity becomes available for smaller recreational vessels. The average passage time of commercial and recreational navigation during all scenarios are still within the target conditions.

7.4.3. Alternative 1a – Priority arrangement

In order to optimize the passage time of fast ferry navigation a priority arrangement is introduced to make sure that individual fast ferries are prioritized in the order of lockage above recreational and commercial navigation. This way fast ferry navigation is guaranteed to be served with the first lockage in the same direction after arrival at the lock complex. Within priority arrangement the order of vessels entering the specific lock chamber is reshuffled prioritizing fast ferry navigation above other vessels in the queue. This reshuffling process can only be done in before the first original vessel enters the lock chamber. After this stage the order of entering the lock chamber is fixed. It is noted that other navigation is allowed to be locked during the same lockage as fast ferry navigation. The dimensions of individual fast ferries including safety margins in comparison to the lock chamber dimensions limit the number of additional vessels to be locked together with individual fast ferries. A priority arrangement is applied at the northern, middle and
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

A summary of the results of simulating alternative 1a is added in table 24.

Table 24: Average passage time Alternative 1a.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Target</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume commercial navigation</td>
<td>2012</td>
<td>16.14</td>
<td>17.28</td>
<td>18.56</td>
<td>18.99</td>
</tr>
<tr>
<td>Arrival pattern</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fast ferry navigation</td>
<td>30 min</td>
<td>15 min</td>
<td>30 min</td>
<td>15 min</td>
<td></td>
</tr>
<tr>
<td></td>
<td>timetable</td>
<td>timetable</td>
<td>timetable</td>
<td>timetable</td>
<td></td>
</tr>
<tr>
<td>Commercial navigation</td>
<td>45.00</td>
<td>17.28</td>
<td>18.56</td>
<td>18.99</td>
<td></td>
</tr>
<tr>
<td>Recreational navigation</td>
<td>60.00</td>
<td>86.61</td>
<td>73.27</td>
<td>83.56</td>
<td></td>
</tr>
<tr>
<td>Fast ferry navigation</td>
<td>8.00</td>
<td>10.87</td>
<td>9.45</td>
<td>10.21</td>
<td></td>
</tr>
<tr>
<td>All navigation</td>
<td>-</td>
<td>57.56</td>
<td>59.44</td>
<td>54.91</td>
<td>56.88</td>
</tr>
</tbody>
</table>

A priority arrangement leads to a significant decrease of the average passage time of fast ferry navigation. The upper 95% confidence interval of the passage time of fast ferry navigation is within the target conditions associated with water based public transport. The average passage time of commercial navigation equals the present situation. This result is due to the fact that commercial navigation is allowed to use the PWA-lock chamber in case of increased waiting time at the middle and southern lock chamber. The PWA-lock chamber carries sufficient capacity serve the additional traffic intensity without an increase of the average passage time.

Recreational navigation on the other hand shows a large increase in average passage time. This value is significantly higher compared to the present situation and also has increased above the prescribed target conditions. The main reason for the significant increase in passage time of recreational navigation is caused by additional demurrage time of recreational vessels. The number of demurraging recreational vessels shows an increase due to the fact that these vessels are obliged to give priority to approaching fast ferries.

7.4.4. Alternative 1b – Priority arrangement and separate locking method

Alternative 1b describes a combination of a priority arrangement for fast ferry navigation and a separated locking method. Both traffic management related measures are applied at the northern, middle and southern lock chamber. This alternative is intended to decrease the average passage time of recreational navigation as displayed by alternative 1a. By introducing a separated locking method the average passage time of recreational navigation is expected to decrease following from a higher lock chamber utilization per lockage. A summary of the results of simulating alternative 1a is added in table 25.
Table 25: Average passage time Alternative 1b.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Target</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>[min]</td>
<td>[min]</td>
<td>[min]</td>
<td>[min]</td>
</tr>
<tr>
<td>Volume commercial navigation</td>
<td>2012</td>
<td>30 min</td>
<td>15 min</td>
<td>30 min</td>
<td>15 min</td>
</tr>
<tr>
<td>Arrival pattern</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fast ferry navigation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial navigation</td>
<td>45.00</td>
<td>19.94</td>
<td>17.35</td>
<td>19.83</td>
<td>21.75</td>
</tr>
<tr>
<td>Recreational navigation</td>
<td>60.00</td>
<td>17.13</td>
<td>17.24</td>
<td>17.79</td>
<td>17.22</td>
</tr>
<tr>
<td>Fast ferry navigation</td>
<td>8.00</td>
<td>10.12</td>
<td>10.87</td>
<td>10.19</td>
<td>10.53</td>
</tr>
<tr>
<td>All navigation</td>
<td>-</td>
<td>16.46</td>
<td>15.94</td>
<td>17.34</td>
<td>16.68</td>
</tr>
</tbody>
</table>

Application of a priority arrangement in combination with a separated locking method leads to a significant decrease of the average passage time of fast ferry navigation equal to the results displayed by alternative 1a. The upper 95% confidence interval of the passage time of fast ferry navigation is within the target conditions associated with water based public transport. The results also show a sharp decrease of the average passage time of recreational navigation compared to alternative 1a. The results even shows a decrease referring to the present situation in the order of 10 minutes. From these results it is concluded that the separate locking method contributes to a significant increase of the available lock capacity available for recreational navigation passing the Schellingwoude lock complex. The additional capacity is made available due to the higher utilization of lock chambers available for recreational navigation. The separate locking method limits the space inside the lock chamber lost to safety margins between vessel from different vessel categories. This aspect especially contributed to the available lock capacity of the middle lock chamber in which all navigation types are allowed. The impact of a priority arrangement of fast ferry navigation is not affected by the separate locking method, because the locking method only applies to an alternative location of vessels inside the lock chamber and not to the order of vessels entering the lock chamber. As described before it is noted that the application of a separated locking method resulting in the average passage time as listed in table 25 is unlikely to be established in practice. This is due to the high traffic intensity of recreational navigation during the normative month and additional time involved in optimizing the lock chamber utilization. In practice the additional time involved in the maneuvering of recreational vessels does not leads to a significant decrease of passage time as displayed by SIVAK2.

7.4.5. Alternative 2a – Reservation of one lock chamber

Reservation of one lock chamber used to serve fast ferry navigation is considered to be an extensive measure on optimizing the passage of fast ferry navigation referring to a priority arrangement. During this alternative the southern lock chamber is reserved for fast ferry navigation only. Fast ferry navigation is not allowed to use the northern and middle lock chamber. A summary of the results of simulating alternative 2a is added in table 26.
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

Table 26: Average passage time Alternative 2a.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Target</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume commercial navigation</td>
<td></td>
<td>2012</td>
<td>2012</td>
<td>2020</td>
<td>2020</td>
</tr>
<tr>
<td>Arrival pattern</td>
<td></td>
<td>30 min timetable</td>
<td>15 min timetable</td>
<td>30 min timetable</td>
<td>15 min timetable</td>
</tr>
<tr>
<td>fast ferry navigation</td>
<td></td>
<td>[min]</td>
<td>[min]</td>
<td>[min]</td>
<td>[min]</td>
</tr>
<tr>
<td>Commercial navigation</td>
<td>45.00</td>
<td>19.23</td>
<td>19.11</td>
<td>20.04</td>
<td>26.19</td>
</tr>
<tr>
<td>Recreational navigation</td>
<td>60.00</td>
<td>36.02</td>
<td>36.55</td>
<td>34.91</td>
<td>30.28</td>
</tr>
<tr>
<td>Fast ferry navigation</td>
<td>8.00</td>
<td>7.92</td>
<td>13.29</td>
<td>8.14</td>
<td>13.40</td>
</tr>
<tr>
<td>All navigation</td>
<td>-</td>
<td>29.66</td>
<td>28.84</td>
<td>28.84</td>
<td>28.82</td>
</tr>
</tbody>
</table>

The reservation of the southern lock chamber for fast ferry navigation leads to an decrease of the average passage time of fast ferry navigation. The passage time of fast ferry navigation performing a 30 min timetable is considered to be within the target condition associated with water based public transport. During a 15 min timetable the passage time will increase to 5 minutes above the target level as a result of the limited time between the sequential arrival of individual fast ferries from both directions. This process is further elaborated in figure 25 in which the progress of the lockage in time is illustrated. It shows that the waiting time of approaching fast ferries increases due to the fact that the total lock cycle time \( T_c \) is higher than the headway between two approaching fast ferries \( \Delta t_{ff} \) from the same direction. These conditions result in a bi-modal variation of the passage time of fast ferry navigation as displayed in figure 24. The capacity of one lock chamber therefore proves to be insufficient to serve fast ferry navigation performing a 15 min timetable. This is the reason why the reservation of a second additional lock chamber is further elaborated as alternative 2b. Compared to alternative 0 the average passage time of commercial navigation shows no significant increase. From this it is concluded that the largest volume of commercial navigation is diverted to the middle and PWA-lock chamber. The average passage time of recreational navigation during all scenarios shows an increase in the order of 7 minutes. This effect is attributed to the additional commercial vessels which are locked via the middle lock chamber which in August also is accessible for recreational navigation. The average passage time of commercial and recreational navigation are still within the target conditions.

Figure 24: Variation in passage time of fast ferry navigation scenario #2.
Figure 25: Progress of lockage of fast ferry navigation during alternative 2a.
7.4.6. **Alternative 2b – Reservation of two lock chambers**

Alternative 2b focuses on the reservation of two lock chambers. In this case the southern and middle lock chamber are reserved for fast ferry navigation. All commercial navigation is supposed to pass the Schellingwoude lock complex via the PWA-lock chamber. A summary of the result of simulating alternative 2b is added in table 27.

Table 27: Average passage time Alternative 2b.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Target</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume commercial navigation</td>
<td>2012</td>
<td>2012</td>
<td>2020</td>
<td>2020</td>
<td></td>
</tr>
<tr>
<td>Arrival pattern</td>
<td>30 min timetable</td>
<td>15 min timetable</td>
<td>30 min timetable</td>
<td>15 min timetable</td>
<td></td>
</tr>
<tr>
<td>fast ferry navigation</td>
<td>45.00</td>
<td>31.56</td>
<td>29.75</td>
<td>40.63</td>
<td>38.89</td>
</tr>
<tr>
<td>Commercial navigation</td>
<td>60.00</td>
<td>71.64</td>
<td>73.90</td>
<td>71.91</td>
<td>78.96</td>
</tr>
<tr>
<td>Recreational navigation</td>
<td>8.00</td>
<td>8.34</td>
<td>13.26 (7.92)</td>
<td>8.17</td>
<td>12.99 (8.14)</td>
</tr>
<tr>
<td>Fast ferry navigation</td>
<td>-</td>
<td>56.90</td>
<td>54.03</td>
<td>58.30</td>
<td>58.25</td>
</tr>
<tr>
<td>All navigation</td>
<td>-</td>
<td>56.90</td>
<td>54.03</td>
<td>58.30</td>
<td>58.25</td>
</tr>
</tbody>
</table>

The reservation of the middle and southern lock chamber by fast ferry navigation leads to a significant decrease of passage time of fast ferry navigation with respect to alternative 0. The performance of fast ferry navigation equals approximately the result displayed by alternative 2a. This effect can be partially explained by the variation of arrival time of fast ferry navigation at the lock complex as a result of delays following from the sailing stages. Another factor influencing the average passage time of fast ferry navigation is the initial availability of the reserved lock chambers during the start of the simulation period. The initial conditions might lead to the phenomena of the availability of lock chambers to be in anti-phase with the arrival pattern of fast ferry navigation at both sides of the lock complex. These processes do not justify the average passage time of fast ferry navigation during all scenarios to be equal to alternative 2a, since the inter arrival time of fast ferry navigation is larger than the average passage time. This is the main reason why the possible anti-phase between the availability of reserved lock chambers and the arrival pattern of fast ferry navigation at the start is expected to die in a short period of time. From analytical approach is can be concluded that the I/C value of alternative 2a in combination with scenario #1 or #3 should equal alternative 2b in combination with scenario #2 or #4. In both cases one reserved lock chamber serves one per ferry 30 minutes. Equality in I/C value should lead to an average passage time in the same order. This is not the case. Therefore the results regarding fast ferry navigation performing a 15 min timetable (Scenario #2 and #4) are assumed to be equal to the result displayed by alternative 2a during scenario #1 and #3.

The average passage time of commercial navigation shows an increase in the order of 10 minutes in 2012 and 15 to 20 minutes in 2020. During all scenarios the average passage time of commercial navigation is still within target conditions. The increase is caused by the fact that less lock chambers are available for commercial
navigation. During all scenarios the average passage time of recreational navigation increase in the order of 35 minutes compared to alternative 0. The average passage time of recreational navigation therefore increases outside the target conditions.

7.4.7. **Alternative 3 – Priority arrangement and reservation of one lock chamber**

From the previous alternatives it is known that especially during a 15 min timetable the performance of the lock operation system lacks capacity. Alternative 3 is considered to be a combination of alternative 1 and 2a. This combination is investigated to decrease to average passage time of fast ferry navigation during all scenarios especially during fast ferry navigation performing a 15 min timetable. This alternative is also expected to prevent a large increase of average passage time of commercial and recreational navigation as displayed by alternative 2b. A summary of the results of simulating alternative 3 is added in table 28.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Target</th>
<th>#1 [min]</th>
<th>#2 [min]</th>
<th>#3 [min]</th>
<th>#4 [min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume commercial navigation</td>
<td></td>
<td>2012</td>
<td>2012</td>
<td>2020</td>
<td>2020</td>
</tr>
<tr>
<td>Arrival pattern</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fast ferry navigation</td>
<td></td>
<td>30 min</td>
<td>15 min</td>
<td>30 min</td>
<td>15 min</td>
</tr>
<tr>
<td></td>
<td></td>
<td>timetable</td>
<td>timetable</td>
<td>timetable</td>
<td>timetable</td>
</tr>
<tr>
<td>Commercial navigation</td>
<td>45.00</td>
<td>17.74</td>
<td>18.56</td>
<td>19.05</td>
<td>21.43</td>
</tr>
<tr>
<td>Recreational navigation</td>
<td>60.00</td>
<td>72.27</td>
<td>75.93</td>
<td>78.30</td>
<td>82.50</td>
</tr>
<tr>
<td>Fast ferry navigation</td>
<td>8.00</td>
<td>8.79</td>
<td>9.84</td>
<td>8.64</td>
<td>9.72</td>
</tr>
<tr>
<td>All navigation</td>
<td>-</td>
<td>54.86</td>
<td>52.76</td>
<td>58.36</td>
<td>56.57</td>
</tr>
</tbody>
</table>

Compared to alternative 0 a combination of a priority arrangement and the reservation of one lock chamber results in a significant decrease of the average passage time of fast ferry navigation performing a 30 as well as a 15 min timetable. The 95% confidence interval of the recorded variation in passage time is within the target conditions associated with water based public transport. Approximately 50% of all fast ferry navigation is recorded to pass the lock complex via the reserved southern lock chamber. This observation shows that the combination of reservation of one lock chamber and a priority arrangement helps to decrease the passage time of commercial navigation in comparison alternative 2b in the order of 10 minutes. This phenomena is attributed to the difference between a priority arrangement and complete reservation of a lock chamber. Nevertheless the average passage time of recreational navigation during all scenarios is still not within the prescribed target conditions.

7.4.8. **Alternative 4a – Additional minimum lock chamber**

In alternative 4a an additional lock chamber with minimal dimensions dedicated to fast ferry navigation is added. The total number of lock chambers becomes five. The additional lock chamber is reserved for fast ferry navigation only. The fast ferries are allowed to use the existing northern, middle and southern lock chamber. There is no traffic management related measure involved during the locking process at the
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

existing lock chambers. A summary of the results of simulating alternative 4a is added in table 29.

Table 29: Average passage time Alternative 4a.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Target</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume commercial navigation</td>
<td>2012</td>
<td>2012</td>
<td>2020</td>
<td>2020</td>
<td></td>
</tr>
<tr>
<td>Arrival pattern</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fast ferry navigation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[min]</td>
<td>[min]</td>
<td>[min]</td>
<td>[min]</td>
<td>[min]</td>
<td>[min]</td>
</tr>
<tr>
<td>Commercial navigation</td>
<td>45.00</td>
<td>16.06</td>
<td>16.86</td>
<td>20.12</td>
<td>19.60</td>
</tr>
<tr>
<td>Recreational navigation</td>
<td>60.00</td>
<td>35.80</td>
<td>35.41</td>
<td>35.07</td>
<td>34.68</td>
</tr>
<tr>
<td>Fast ferry navigation</td>
<td>8.00</td>
<td>9.79</td>
<td>17.54</td>
<td>7.85</td>
<td>13.30</td>
</tr>
<tr>
<td>All navigation</td>
<td>-</td>
<td>29.15</td>
<td>28.64</td>
<td>28.94</td>
<td>27.58</td>
</tr>
</tbody>
</table>

An additional lock chamber with minimal dimensions serving fast ferry navigation, without additional traffic management measures, will lead to a decrease of the passage time of all navigation. This phenomena is supported by theory since additional locking capacity is made available by an additional service installation. During a 30 min timetable fast ferry navigation is expected to meet the required target condition. A 15 min timetable results in an increase of the average passage time outside the target conditions. From the registration of vessels per lock chamber it is concluded that a significant share of fast ferry navigation passes via the northern lock chamber, due to the limited capacity of the added minimal lock chamber. This phenomena leads to an increase of the average passage time of recreational navigation in the order of 9 minutes compared to the present situation. Regarding fast ferry navigation with a 15 min timetable even more fast ferries are passing via the northern lock chamber resulting in a strong increase (7 minutes) of the average passage time compared to a 30 min timetable. Referring to alternative 0 one can say that the optimization of the average passage time of fast ferry navigation with 12 minutes is reached at expense of an increase of the average passage time of recreational navigation in the order of 6 minutes. The lock operation process of the recreational fleet is still significantly affected during this alternative. Although the additional lock chamber is used efficiently (97% of fast ferry navigation passing via the additional lock chamber) the additional capacity following from the extra lock chamber with minimal dimensions does not balance with the required traffic demand. The average passage time of commercial navigation equals the present situation. Both the average passage time of commercial and recreational navigation are still within the target conditions.

7.4.9. **Alternative 4b – Additional CEMT-classVIb lock chamber**
The addition of a CEMT-class VIb lock chamber to the existing lock complex is recorded in alternative 4b. The additional lock chamber is only accessible for commercial navigation. The middle and southern lock chamber are reserved for fast ferry navigation. The northern lock chamber used by recreational navigation. A summary of the results of simulating alternative 4b is added in table 30.
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

Adding a CEMT-class VIb lock chamber to the existing look complex is proved to have little effect on the passage time of navigation on the short term. Regarding the short term scenarios the results of the performance analysis show large similarity to alternative 2b. During the midterm scenarios, the passage time of commercial navigation is positively affected by the additional locking capacity resulting in an increase of the average passage time in the order of Especially the large lock chamber dimensions serve the autonomous growth of vessel dimensions. This alternative also fails to meet the requirements regarding the target conditions related to fast ferry navigation during a 15 min timetable.

7.4.10. Alternative 5 – Additional innovative structure

Alternative 5 is considered to be an experimental solution to decrease the passage time of fast ferry navigation. The starting point of the design of this innovative structure is described in paragraph 5.7. A summary of the results of simulating alternative 5 is added in table 31.

The additional innovative structure has proven to have a positive effect on the passage time of all navigation. The innovative structure results in an average passage time of fast ferry navigation performing a 30 min timetable within the target conditions. This effect is similar to the construction of an additional minimal lock chamber. During a 15 min timetable the passage time of fast ferry navigation results in a large increase of passage time referring to alternative 4a. This effect is

---

**Table 30: Average passage time Alternative 4b.**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Target</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume commercial navigation</td>
<td>2012</td>
<td>2012</td>
<td>2020</td>
<td>2020</td>
<td></td>
</tr>
<tr>
<td>Arrival pattern</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fast ferry navigation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[min]</td>
<td></td>
<td>[min]</td>
<td>[min]</td>
<td>[min]</td>
<td></td>
</tr>
<tr>
<td>Commercial navigation</td>
<td>45.00</td>
<td>19.00</td>
<td>19.12</td>
<td>20.12</td>
<td>19.60</td>
</tr>
<tr>
<td>Recreational navigation</td>
<td>60.00</td>
<td>36.07</td>
<td>36.46</td>
<td>35.07</td>
<td>34.68</td>
</tr>
<tr>
<td>Fast ferry navigation</td>
<td>8.00</td>
<td>7.88</td>
<td>13.26</td>
<td>7.85</td>
<td>13.30</td>
</tr>
<tr>
<td>All navigation</td>
<td>-</td>
<td>29.65</td>
<td>28.78</td>
<td>28.94</td>
<td>27.58</td>
</tr>
</tbody>
</table>

**Table 31: Average passage time Alternative 5.**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Target</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume commercial navigation</td>
<td>2012</td>
<td>2012</td>
<td>2020</td>
<td>2020</td>
<td></td>
</tr>
<tr>
<td>Arrival pattern</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fast ferry navigation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[min]</td>
<td></td>
<td>[min]</td>
<td>[min]</td>
<td>[min]</td>
<td></td>
</tr>
<tr>
<td>Commercial navigation</td>
<td>45.00</td>
<td>17.32</td>
<td>16.81</td>
<td>20.51</td>
<td>20.98</td>
</tr>
<tr>
<td>Recreational navigation</td>
<td>60.00</td>
<td>13.35</td>
<td>12.99</td>
<td>13.47</td>
<td>13.70</td>
</tr>
<tr>
<td>Fast ferry navigation</td>
<td>8.00</td>
<td>8.08</td>
<td>21.25</td>
<td>7.76</td>
<td>24.66</td>
</tr>
<tr>
<td>All navigation</td>
<td>-</td>
<td>13.46</td>
<td>15.33</td>
<td>14.24</td>
<td>17.26</td>
</tr>
</tbody>
</table>
attributed to the relative long duration of time involved in sailing through the extended lock chamber in relation to lock chamber with minimal dimensions where is no space for vessels to pass inside the lengthened lock chamber.

7.5. Conclusion

The performance analysis of the various alternatives provides insight into the average and the upper 95% confidence band of the passage time of fast ferry navigation and the conventional fleet passing the Schellingwoude lock complex. The results of the performance of the proposed lock system alternatives are compared to the present situation (without fast ferry navigation) and alternative 0 (with fast ferry navigation, without optimization). Explicit target conditions associated with the various navigation types are applied to verify the feasibility of the proposed alternatives. Figure 26 shows an overview of the average passage times based on the performance analysis compared to the applied target conditions. The target conditions are refer to the average value indicated by (——) and the upper 95% confidence interval indicated by (---------).
Figure 26: Summary of the average passage of all alternatives.
The conclusions drawn from the average and the upper 95% confidence band of the passage time of navigation based on the performance analysis is listed in table 32.

Table 32: Conclusions drawn from the performance analysis.

<table>
<thead>
<tr>
<th>Lock system alternative</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing situation</td>
<td>Based on the validation of the model the performance analysis of the existing situation serves as a reference situation on judging the performance of the various lock system alternatives.</td>
</tr>
<tr>
<td>Alternative 0 – Existing lock complex</td>
<td>The average passage time and 95% confidence interval of fast ferry navigation during all scenarios is outside the target conditions associated with water based public transport. Optimization on the passage of fast ferry navigation at the Schellingwoude lock complex is required. Therefore this alternative serves as a reference alternative on optimizing the existing lock operation process.</td>
</tr>
<tr>
<td>Alternative 1a – Priority arrangement</td>
<td>The average passage time and 95% confidence interval of fast ferry navigation during all navigation scenarios is within the target conditions associated with water based public transport. The average passage of recreational navigation increase outside the prescribed target conditions associated with recreational navigation. Therefore this alternative is rejected.</td>
</tr>
<tr>
<td>Alternative 1b – Priority arrangement and separate locking method</td>
<td>The average passage time of fast ferry navigation during all navigation scenarios is within the target conditions associated with water based public transport. Regarding fast ferry navigation these results equal the performance of alternative 1a. The average passage time of recreational navigation shows a significant decrease compared to alternative 1a and even the present situation. This sharp decrease of passage time of recreational navigation displayed by the model in practice cannot be justified, since the additional time in optimizing the lock chamber utilization with slowly maneuvering recreational vessels is accounted for in the model. The average passage time of recreational navigation is not consist with reality. Therefore this alternative is no further elaborated.</td>
</tr>
<tr>
<td>Alternative 2a – Reservation of one lock chamber</td>
<td>The average passage time and the upper 95% confidence band of fast ferry navigation performing a 30 min timetable is within the target conditions associated with water based public transport. During a 15 min timetable the passage time is 5 minutes above the target conditions. The 95% confidence band is approximately 3 minutes above the target conditions. Nevertheless this alternative is further investigated in the social cost benefit analysis.</td>
</tr>
<tr>
<td>Alternative 2b – Reservation of two lock chambers</td>
<td>The average passage time and 95% confidence band of fast ferry navigation performing a 30 min timetable is within the target conditions associated with water based public transport. During a 15 min timetable the passage time is also 5 minutes above the target conditions. The 95% confidence band is approximately 3 minutes above the target conditions. Compared to alternative 2a the added value of reservation of a second lock chamber is limited and also results in a sharp increase of the average passage time of recreational navigation.</td>
</tr>
</tbody>
</table>
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Description</th>
<th>Passage Time</th>
<th>Confidence Band</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Priority arrangement &amp; reservation of one lock chamber</td>
<td>Fast ferry navigation during all scenarios within target conditions for water-based public transport. Increase in average passage time of recreational navigation above target conditions rejects this alternative.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Alternative 4a – Additional minimal lock chamber

The average passage time and 95% confidence band of fast ferry navigation during all scenarios is within the target conditions associated with water-based public transport. Because of the sharp increase of the average passage time of recreational navigation above target conditions, this alternative is rejected.

Alternative 4b – Additional CEMT-class VIb lock chamber

The average passage time and 95% confidence band of fast ferry navigation during all scenarios is within the target conditions associated with water-based public transport. During a 15 min timetable, the average passage time is outside the target conditions in the order of 7 minutes. The 95% confidence band is approximately 5 minutes above the target conditions. Since the limited added optimization during a 15 min timetable and the large construction costs of an CEMT-class VIb lock chamber compared to alternative 4a, this alternative is rejected.

Alternative 5 – Additional innovative structure

The average passage time and 95% confidence band of fast ferry navigation during all scenarios is within the target conditions associated with water-based public transport. During a 15 min timetable, the average passage time is significantly outside the target conditions. Due to the limited optimization during a 15 min timetable and the large construction costs associated with the innovative structure compared to alternative 4a, this alternative is rejected.
8  Social cost-benefit analysis

This chapter is intended to assess the social cost involved in the application of the best performing alternatives as determined in the previous chapter in order to analyse their feasibility.

8.1.  Method

The execution of large infrastructural projects in the Netherlands involves many stakeholders. To ensure a minimal degree of support for a proposed infrastructural project the need and necessity must be demonstrated during the decision making process. This involves a well-defined comparison of best performing project alternatives. The Dutch framework of Long-Term Programme for Infrastructure, Spatial Planning and Transport (MIRT) prescribes the elaboration of two studies to demonstrate the need and necessity of each infrastructural project. These are:

- the environmental impact assessment (MER), and
- the social cost-benefit analysis (MKBA).

With view on the technical feasibility of an optimized passage of a fast ferry at the Schellingwoude lock complex only the social cost-benefit analysis is executed. The environmental impact assessment is not part of the research, since this study mainly focuses on technical feasibility instead of environmental feasibility. This does not imply that environmental issues are to be neglected. A large increase of traffic intensity by fast ferry navigation at lake Markermeer and the construction of an additional lock chamber seriously affect the environment in this area. The execution of a environmental impact assessment is recommended.

For speeding up and improving the application of cost-benefit analysis during infrastructural projects the Dutch institute for Transport Policy Analysis (KiM Netherlands) established decisive information required to quickly and responsibly assess the need and necessity of a project. This information is recorded in the Overview Impacts Infrastructure (OEI-guideline) [39]. In order to assess specific regional infrastructural projects a base format has been established by Rijkswaterstaat DVS [40]. Since many infrastructural projects involve large indirect effects additional information on monetizing these effects is listed. The conditions and qualitative effects are mentioned in the following paragraphs. The quantification of direct effects is listed in paragraph 8.3.

8.2.  Conditions

8.2.1.  Lock system alternatives

This social cost-benefit analysis focuses on the best performing alternatives optimizing the passage of fast ferry navigation at the Schellingwoude lock complex. The performance of each alternative differs, since both alternatives provide additional locking capacity using different methods. The alternatives elaborated during the social cost-benefit analysis are:

- Alternative 2a – Reservation of one lock chamber;
- Alternative 4a – Additional minimal lock chamber.

Both best performing alternatives are compared with the existing situation in which fast ferry navigation is absent.
8.2.2. Navigation scenarios
The navigation scenarios applied during the social cost-benefit analysis equal the navigation scenarios applied during the performance analysis. These scenarios involve the normative traffic intensity of recreational navigation during August. These normative scenarios are summarized in table 33.

Table 33: Normative scenarios applied within the social cost benefit analysis.

<table>
<thead>
<tr>
<th>Scenario [#]</th>
<th>Volume commercial navigation [year]</th>
<th>Arrival pattern fast ferry navigation [... min timetable]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2012</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>2012</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>2020</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>2020</td>
<td>15</td>
</tr>
</tbody>
</table>

8.2.3. Other conditions
Based on the technical feasibility of optimizing the passage of fast ferry navigation at the Schellingwoude lock complex this report quantifies the direct effects involved in the best performing alternatives. Quantification of the direct effect involve the following conditions:

- Life span traffic management software system: 20 years;
- Life span civil works: 100 years;
- Rate of additional waiting time commercial navigation: according to table 34.

Table 34: Rate of additional waiting time commercial navigation.

<table>
<thead>
<tr>
<th>Vessel class</th>
<th>Rate additional waiting time</th>
<th>Vessel class</th>
<th>Rate additional waiting time</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>30 €/h</td>
<td>B04</td>
<td>75 €/h</td>
</tr>
<tr>
<td>M2</td>
<td>44 €/h</td>
<td>B1-I</td>
<td>77 €/h</td>
</tr>
<tr>
<td>M2-container</td>
<td>48 €/h</td>
<td>BII-1</td>
<td>81 €/h</td>
</tr>
<tr>
<td>M3</td>
<td>55 €/h</td>
<td>BII-L-1</td>
<td>84 €/h</td>
</tr>
<tr>
<td>M4</td>
<td>62 €/h</td>
<td>BII-2l</td>
<td>84 €/h</td>
</tr>
<tr>
<td>M5</td>
<td>74 €/h</td>
<td>BII-2b</td>
<td>84 €/h</td>
</tr>
<tr>
<td>M6</td>
<td>77 €/h</td>
<td>BII-4</td>
<td>84 €/h</td>
</tr>
<tr>
<td>M6-container</td>
<td>107 €/h</td>
<td>C1b</td>
<td>105 €/h</td>
</tr>
<tr>
<td>M7</td>
<td>114 €/h</td>
<td>C2l</td>
<td>105 €/h</td>
</tr>
<tr>
<td>M8</td>
<td>119 €/h</td>
<td>C3l</td>
<td>110 €/h</td>
</tr>
<tr>
<td>M8-tanker</td>
<td>119 €/h</td>
<td>C2b</td>
<td>105 €/h</td>
</tr>
<tr>
<td>B01</td>
<td>45 €/h</td>
<td>C3b</td>
<td>110 €/h</td>
</tr>
<tr>
<td>B02</td>
<td>55 €/h</td>
<td>C4</td>
<td>115 €/h</td>
</tr>
<tr>
<td>B03</td>
<td>65 €/h</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The indirect effects and external effects are determined in a qualitative way since quantifying these effects is not part of the objectives of this study. Therefore the cost-benefit ratio is not determined.
8.3. Direct effects

A direct effect is an effect which has an immediate relation to the project alternative. This involves investments costs as a result of reconstruction/adaptation of the physical layout of the existing lock complex or the implementation of a new traffic management system. Additional waiting time of commercial navigation passing the Schellingwoude lock complex is also considered to be a direct effect as a result of the optimization of the passage of fast ferry navigation.

8.3.1. Investment costs

The investment costs involved in the implementation of a new traffic management system applied during alternative 2a serving fast ferry navigation are determined in table 35.

<table>
<thead>
<tr>
<th>Implementation costs</th>
<th>Alternative 2a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptation of traffic management software system</td>
<td>€ 400,000</td>
</tr>
<tr>
<td>Additional training of lock operators</td>
<td>€ 150,000</td>
</tr>
<tr>
<td>Development of guidelines</td>
<td>€ 100,000</td>
</tr>
<tr>
<td>Adaptation of present legislation</td>
<td>€ 350,000</td>
</tr>
<tr>
<td><strong>Subtotal Investment costs</strong></td>
<td><strong>€ 1,000,000</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unforeseen costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project unforeseen costs (10% of subtotal)</td>
</tr>
<tr>
<td><strong>Total unforeseen costs</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total investment costs (ex. VAT)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>€ 1,100,000</strong></td>
</tr>
</tbody>
</table>

The investments costs involved in the construction of an additional lock chamber are derived from a social cost-benefit analysis prepared by ECORYS describing navigation locks with similar dimensions [23]. The cost estimation in this analysis is performed by Rijkswaterstaat. The investments costs involved in the construction of an additional lock chamber with minimal dimensions dedicated to fast ferry navigation as described by alternative 4a are elaborated in table 37.
### Table 36: Investment costs Alternative 4a.

<table>
<thead>
<tr>
<th>Construction costs</th>
<th>Alternative 4a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civil works</td>
<td>€ 10,000,000</td>
</tr>
<tr>
<td>Gates</td>
<td>€ 1,900,000</td>
</tr>
<tr>
<td>Mechanical installation</td>
<td>€ 1,400,000</td>
</tr>
<tr>
<td>Temporary structures</td>
<td>€ 700,000</td>
</tr>
<tr>
<td><strong>Total construction costs</strong></td>
<td><strong>€ 14,000,000</strong></td>
</tr>
<tr>
<td>Engineering costs</td>
<td></td>
</tr>
<tr>
<td>Investigation soil and hydraulic conditions</td>
<td>€ 120,000</td>
</tr>
<tr>
<td>Engineering civil works</td>
<td>€ 300,000</td>
</tr>
<tr>
<td>Engineering gates</td>
<td>€ 133,000</td>
</tr>
<tr>
<td>Engineering mechanical installation</td>
<td>€ 70,000</td>
</tr>
<tr>
<td><strong>Total engineering costs</strong></td>
<td><strong>€ 623,000</strong></td>
</tr>
<tr>
<td>Additional costs</td>
<td></td>
</tr>
<tr>
<td>Soil placement pattern + permit applications</td>
<td>€ 150,000</td>
</tr>
<tr>
<td>Esthetical costs + landscaping</td>
<td>€ 500,000</td>
</tr>
<tr>
<td>Cables and pipelines</td>
<td>€ 60,000</td>
</tr>
<tr>
<td>Temporary traffic management measures</td>
<td>€ 150,000</td>
</tr>
<tr>
<td><strong>Total additional costs</strong></td>
<td><strong>€ 860,000</strong></td>
</tr>
<tr>
<td><strong>Subtotal Investment costs</strong></td>
<td><strong>€ 15,483,000</strong></td>
</tr>
<tr>
<td>Project costs</td>
<td></td>
</tr>
<tr>
<td>Project unforeseen costs (10% of subtotal)</td>
<td>€ 1,548,300</td>
</tr>
<tr>
<td>Internal costs (4% of subtotal)</td>
<td>€ 619,320</td>
</tr>
<tr>
<td><strong>Total project costs</strong></td>
<td><strong>€ 2,167,620</strong></td>
</tr>
<tr>
<td><strong>Total investment costs (ex. VAT)</strong></td>
<td><strong>€ 17,650,620</strong></td>
</tr>
</tbody>
</table>

#### 8.3.2. Avoided investment costs

The present state of the Schellingwoude lock complex carries sufficient capacity serving current and future navigation passing the lock complex. The passage time of commercial and recreational navigation is investigated to stay within acceptable range as recorded in the guidelines. Therefore the investments costs involved in the existing situation without the introduction of fast ferry navigation are determined to be none. Possible avoided investment costs when implementing a new traffic management related measure or the constructing an additional minimal lock.
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

corresponding to the existing situation cannot be accounted for.

8.3.3. Management and maintenance costs
The life span of the lock operation software system is assumed to be 20 years. After this period the adaptation of the complete software system serving traffic management measures is expected to be renewed. The yearly management and maintenance cost of alternative 1, 2a and 3 are therefore calculated to be $1/20^{th}$ part of the costs involved in the adaptation of the existing traffic management software system.

The yearly costs of management and maintenance of the additional minimal lock chamber is expected to be 1.5% of the investment costs of the lock chamber itself. The total management and maintenance costs during the life span of the best performing alternatives is listed in table 37.

| Table 37: Management and maintenance costs best performing alternatives. |
|-------------------------------|-------------------------------|
| **Alternative 2a**            | **Alternative 4a**            |
| Yearly management and maintenance costs | € 20,000 | € 264,759 |
| Life span                     | 100 years                     | 100 years |
| **Total management and maintenance costs** | € 2,000,000 | € 26,475,930 |

8.3.4. Financial consequences additional waiting time
During the performance analysis also the passage time of commercial and recreational navigation is recorded. As a result additional waiting time of commercial and recreational navigation stakeholders are faced with additional costs. These financial consequences are caused by less sailing time and additional fuel consumption. The limited depth of surrounding water prevents the possibility of alternative routes. Especially for commercial navigation less sailing time causes significant financial consequences. The financial consequences of recreational navigation are less significant, but also include financial consequences of water sport related companies. Due to a lack of data the financial consequences of recreational navigation is estimated to be equal to 25% of the financial consequences of commercial navigation. Regarding commercial navigation data on the rate of additional waiting time is used to calculate the total yearly financial consequences. The quantitative value of the financial consequences of commercial navigation is determined by subtracting the average passage time in the present situation from the average passage time based on the performance analysis of the various alternatives. The additional passage time is multiplied with the weighted average costs involved in the waiting of commercial vessel. The weighted average costs are based on the fleet composition of commercial navigation (2012 and 2020). These figures show the financial consequences resulting from additional waiting time during the normative month. Due to the monthly variation in traffic intensity the additional waiting per month is corrected according to the relative traffic intensity recorded throughout the year. The relative traffic intensity is derived from the recordings of the IVS-90 data system as displayed in figure 14 of this report. The total yearly financial damage is based on the volume of commercial navigation passing the Schellingwoude lock complex as simulated within the various navigation
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scenarios. In case of a decrease in passage time the financial damage is calculated to be zero. The monthly financial consequences of the additional waiting time by commercial navigation involved in the best performing alternatives is elaborated in APPENDIX 8. An overview of the yearly financial consequences of commercial and recreational navigation resulting from the additional waiting time at the Schellingwoude lock complex are listed in table 38.

Table 38: Total yearly financial consequence of additional waiting time.

<table>
<thead>
<tr>
<th>Navigation scenario [#]</th>
<th>Navigation type</th>
<th>Alternative 2a</th>
<th>Alternative 4a</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Commercial navigation</td>
<td>€ 1,205,082</td>
<td>€ 0</td>
</tr>
<tr>
<td></td>
<td>Recreational navigation</td>
<td>€ 301,271</td>
<td>€ 0</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td>€ 1,506,353</td>
<td>€ 0</td>
</tr>
<tr>
<td>2</td>
<td>Commercial navigation</td>
<td>€ 1,038,864</td>
<td>€ 0</td>
</tr>
<tr>
<td></td>
<td>Recreational navigation</td>
<td>€ 259,716</td>
<td>€ 0</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td>€ 1,298,580</td>
<td>€ 0</td>
</tr>
<tr>
<td>3</td>
<td>Commercial navigation</td>
<td>€ 1,113,386</td>
<td>€ 1,230,584</td>
</tr>
<tr>
<td></td>
<td>Recreational navigation</td>
<td>€ 278,346</td>
<td>€ 307,646</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td>€ 1,391,732</td>
<td>€ 1,538,230</td>
</tr>
<tr>
<td>4</td>
<td>Commercial navigation</td>
<td>€ 10,123,019</td>
<td>€ 468,794</td>
</tr>
<tr>
<td></td>
<td>Recreational navigation</td>
<td>€ 2,530,755</td>
<td>€ 117,198</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td>€ 12,653,773</td>
<td>€ 585,992</td>
</tr>
</tbody>
</table>

8.4. **Indirect effects**

An indirect effect is determined to be a direct result of the project which is related to the additional impact on the regional economy. The regional economy may lead to an increase of welfare on society, but this assumption cannot be accounted as an indirect effect. Monetizing the indirect effects associated with the best performing alternatives is not elaborated within this study. A qualitative assessment has made to indicate the indirect effect of the alternatives on the regional economy.

8.4.1. **Regional accessibility**

To determine the effect of a water based public transport connection on the route between Amsterdam Central Station and Almere IJland the results on the transportation forecast should be interpreted. The qualitative judgement of the regional accessibility as a result of the alternatives is based on the average passage time at the Schellingwoude lock complex is relation to the timetable applied.

8.4.2. **Employment**

Employment is a strong indicator determining growth or contraction of the local economy. It is expected that the degree of additional employment is proportional to the regional accessibility. A fast water based public transport connection from the centre of Amsterdam towards Almere and vice versa is expected to attract commuters from a larger area. This development leads to expansion of both the cities Amsterdam and Almere.
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8.4.3. Image
Amsterdam is involved in a long tradition on water based transport. The welfare of many habitants is strongly related to the strategic location of Amsterdam at the waterfront of lake IJmeer and lake Markermeer. Nowadays the expansion of Amsterdam is to be limited by the same water on which the current level of welfare is based. A strong network of water based public transport, starting with an optimal passage of fast ferry navigation at the Schellingwoude lock complex, enhances local accessibility and employment, but also contributes to the image of the region. An integral joining of land and water based public transport creating reliable travel time during rush hour is highly respected by inhabitants of the region and abroad.

8.5. External effects
External effects are referred to as uncompensated damage as a result of optimizing the passage of fast ferry navigation at the Schellingwoude lock complex.

8.5.1. Environment
Adding fast ferry navigation to the existing fleet of commercial and recreational navigation leads to an strong increase of vessel passages at the Schellingwoude lock complex. This results in an increase in the number of lockage’s. Since various environmental functions are assigned to the Schellingwoude, additional fast ferry navigation has a direct effect on the environment near the lock complex. It is expected that measures against salinity travelling from lake Binnen-IJ to lake Buiten-IJ need to be improved. Also the siltation of the Amsterdam port-area is expected to increase as a result of an increase in the number of lockage’s. Both environmental effects are expected to be minimal.

8.5.2. Nautical safety
Nautical safety is an important effect when introducing a large amount fast ferry navigation to an existing lock operation system. Focussing on passenger transport the risk on casualties in case of an accident is significant. Separate locking of different vessel types increase the nautical safety during approach and locking at the Schellingwoude lock complex. With view on the arrival pattern of fast ferry navigation, a more frequent arrival pattern is associated with a decrease of the nautical safety near the lock complex.

8.5.3. Maintenance
All hydraulic structures in the Netherlands are to be maintained during the total life span. The reliability of the various functions of an navigation lock is recorded in the design of the structure. As result of additional lockage’s the maintenance activities resulting from the lock process are expected to increase. Additional maintenance and repair might also lead to less operational time of the Schellingwoude lock complex on a yearly basis. The maintenance costs involved in the construction of an additional minimal lock chamber are assumed to be a direct effect.
8.6. Results

This paragraph summarizes the quantitative determination of direct effects and the qualitative determination of direct and external effects. The costs of direct effects associated with all four navigation scenarios are based on a life span of 100 years. A summary of the social cost-benefit analysis added in table 39 (Alternative 2a) and table 40 (Alternative 4a).

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Present situation</th>
<th>Alternative 2a</th>
<th>Alternative 3a</th>
<th>Alternative 4a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct effects:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investments costs</td>
<td>€ 0</td>
<td>€ 1,100,000</td>
<td>€ 1,100,000</td>
<td>€ 1,100,000</td>
</tr>
<tr>
<td>Avoided investments costs</td>
<td>€ 0</td>
<td>€ 0</td>
<td>€ 0</td>
<td>€ 0</td>
</tr>
<tr>
<td>Management and maintenance costs</td>
<td>€ 0</td>
<td>€ 2,000,000</td>
<td>€ 2,000,000</td>
<td>€ 2,000,000</td>
</tr>
<tr>
<td>Financial consequence additional waiting time</td>
<td>€ 0</td>
<td>€ 150,635,259</td>
<td>€ 129,857,982</td>
<td>€ 139,173,195</td>
</tr>
<tr>
<td>Total</td>
<td>€ 0</td>
<td>€ 153,735,259</td>
<td>€ 132,957,982</td>
<td>€ 142,273,195</td>
</tr>
<tr>
<td>Indirect effects:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regional accessibility</td>
<td>+/-</td>
<td>+</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Employment</td>
<td>+/-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Image</td>
<td>+/-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>External effects:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environment</td>
<td>+/-</td>
<td>-</td>
<td>--</td>
<td>-</td>
</tr>
<tr>
<td>Nautical safety</td>
<td>+/-</td>
<td>-</td>
<td>--</td>
<td>-</td>
</tr>
<tr>
<td>Maintenance</td>
<td>+/-</td>
<td>+/-</td>
<td>-</td>
<td>+/-</td>
</tr>
</tbody>
</table>
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

Table 40: Summary of social cost-benefit analysis  Alternative 4a.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Present situation</th>
<th>Alternative 4a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Direct effects:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investments costs</td>
<td>€ 0</td>
<td>€ 17,650,620</td>
</tr>
<tr>
<td>Avoided investments costs</td>
<td>€ 0</td>
<td>€ 0</td>
</tr>
<tr>
<td>Management and maintenance costs</td>
<td>€ 0</td>
<td>€ 26,475,930</td>
</tr>
<tr>
<td>Financial consequence</td>
<td></td>
<td></td>
</tr>
<tr>
<td>additional waiting time</td>
<td>€ 0</td>
<td>€ 0</td>
</tr>
<tr>
<td>Total</td>
<td>€ 0</td>
<td>€ 44,126,550</td>
</tr>
<tr>
<td>Indirect effects:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regional accessibility</td>
<td>+/-</td>
<td>+</td>
</tr>
<tr>
<td>Employment</td>
<td>+/-</td>
<td>+</td>
</tr>
<tr>
<td>Image</td>
<td>+/-</td>
<td>+</td>
</tr>
<tr>
<td>External effects:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environment</td>
<td>+/-</td>
<td>--</td>
</tr>
<tr>
<td>Nautical safety</td>
<td>+/-</td>
<td>-</td>
</tr>
<tr>
<td>Maintenance</td>
<td>+/-</td>
<td>+/-</td>
</tr>
</tbody>
</table>

Based on table 39 and table 40 it is concluded that the direct effects involved in alternative 2a are significantly higher compared to alternative 4a. This is mainly due to the large financial consequences of additional waiting time of commercial and recreational navigation involved in a reservation of an existing lock chamber. The financial consequences of the construction of an additional lock chamber with minimal dimensions serving fast ferry navigation is significantly less. Therefore it is concluded that the construction costs of an additional minimal lock chamber providing an optimized passage of fast ferry navigation during a life span of 100 years result in less social costs compared to the relative small investment cost associated with the reservation of an existing lock chamber.

This overview also involves the qualitative estimation of the indirect and external effects resulting from the introduction of a water based public transport connection on the route between Amsterdam Central Station and Almere IJland. One can say that a 15 min timetable in comparison to a 30 min timetable adds a larger contribution to the regional accessibility driving all other indirect effects following from a water based public transport connection. On the other hand the possible damage following from the external effects of a high frequency timetable is expected to increase. Also the construction of an additional lock chamber affects the environment negatively. In order to quantify all indirect and external effects of the proposed lock system alternatives additional research is recommended.
9 Conclusions and recommendations

Chapter 9 describes the conclusions and recommendations that can be derived from this report.

9.1 Conclusions

Based on the results of the study towards the feasibility on optimizing the passage of fast ferry navigation at the Schellingwoude lock complex it can be concluded that:

1. The introduction of fast ferry navigation at the existing lock operation process (Alternative 0) leads to an average passage time of fast ferry navigation outside the target conditions associated with water based public transport.

   Without any optimization of the lock operation process at the Schellingwoude lock complex the introduction of fast ferry navigation within all navigation scenarios is outside the target conditions associated with public transport. The average passage time of fast ferry navigation is approximately 15 minutes above the target level. This involves navigation scenarios equal to the traffic intensity of recreational navigation during the normative month (August). The sensitivity analysis shows that the less traffic intensity during October and December results in a decrease of the average passage time.

2. The introduction of fast ferry navigation at the existing lock operation process (Alternative 0) has a minor effect on commercial and recreational navigation.

   Without any optimization of the lock operation process at the Schellingwoude lock complex the existing fleet of commercial and recreational navigation is minimal affected by the introduction of fast ferry navigation. The average passage time of commercial and recreational navigation is recorded to be equal to the present situation during fast ferry navigation performing a 30 min timetable. During a 15 minute timetable the average passage of recreational navigation is recorded to increase in the order of 3 minutes. Also future navigation scenarios shows the same result, since future navigation scenarios mainly describe a shift in vessel dimensions and a limited increase in volume of vessels.

3. Optimization of the lock operation process on fast ferry navigation shows a significant decrease in the average passage time of fast ferry navigation.

   The performance analysis on all lock system alternatives shows a significant decrease of the average passage time of fast ferry navigation and the upper 95% confidence band of this value. These are:
   - Alternative 1a – Priority arrangement;
   - Alternative 1b – Priority arrangement and separate locking method;
   - Alternative 2a – Reservation of one lock chamber;
   - Alternative 2b – Reservation of two lock chambers;
   - Alternative 3 – Priority arrangement and reservation of one lock chamber;
   - Alternative 4a – Additional minimal lock chamber;
   - Alternative 4b – Additional CEMT class VIb lock chamber;
   - Alternative 5 – Additional innovative structure.
In order to judge the average passage time of fast ferry navigation to be within the target conditions associated with water based public transport also the upper 95% confidence interval of recorded passage times is recorded. If this value is significantly above the target upper 95% confidence band of the individual passage times of fast ferries the reliability is considered to be outside the punctual performance level associated with water based public transport. This determination is a directly derived of the conclusion that reliability of the average passage time is a highly appreciated value in passenger transport.

4. An additional innovative structure (Alternative 5) lacks capacity to serve fast ferry navigation performing a 15 min timetable within the target conditions associated with water based public transport.

From all lock system alternatives leading to a significant decrease in average passage time of fast ferry navigation an additional innovative structure (Alternative 5) fails to meet the requirements associated with the performance of water based public transport. During fast ferry navigation performing a 15 min timetable (Scenario 2 and 4) an extended lock chamber length creates additional waiting time for individual fast ferry with a sequential arrival time of 15 minutes.

5. Specific lock system alternatives on optimizing the passage of fast ferry navigation show an increase of passage time of recreational navigation outside the target conditions.

From the performance analysis it is concluded that the following lock system alternatives leading to a significant decrease of the average passage time of fast ferry navigation do not meet the required prescribed target conditions applied to recreational navigation:

- Alternative 1a – Priority arrangement;
- Alternative 1b – Priority arrangement and a separate locking method;
- Alternative 2b – Reservation of two lock chambers;
- Alternative 3 – Priority arrangement and reservation of one lock chamber;

Optimization of the passage of fast ferry navigation by means of a priority arrangement or the reservation of two existing lock chamber leads to an increase of the average passage time of recreational navigation outside the target conditions associated with recreational navigation. This phenomena occurs due to the fact that the priority arrangement is applied to the same lock chambers which are allowed to be used by recreational navigation. Commercial navigation is allowed to divert to the PWA-lock chamber which carries sufficient capacity to deal with the additional traffic intensity in the existing and future navigation scenarios. This is why the average passage time of commercial navigation equals the present situation. The reservation of two lock chamber affects the average passage time of commercial and recreational navigation since the available lock capacity for these vessels is halved.

6. Reservation of lock chamber (Alternative 2) and additional lock chambers (Alternative 4) are determined to be the best performing alternatives on optimizing the passage of fast ferry navigation.

From the performance analysis it is concluded that the following lock system alternatives result an average passage time of fast ferry navigation within the target conditions associated with water based public transport, without an increase of passage time of commercial and recreational navigation outside the prescribed target conditions:
Optimizing the passage of fast ferry navigation at the Schellingwoude lock complex

- Alternative 2a – Reservation of one lock chamber;
- Alternative 4a – Additional minimal lock chamber;
- Alternative 4b – Additional CEMT class VIb lock chamber;

Per alternative a distinction is made between two variants. A base variant (a) and an extra variant providing additional capacity for fast ferry navigation (b). The performance analysis on the alternatives providing additional capacity for fast ferry navigation shows minimal or equal performance compared to the base variant. The limited optimization of the average passage time of fast ferry navigation is determined to be less cost effective in relation the base variants. Therefore alternative 2b and 4b are not further elaborated in the social cost-benefit analysis. It is noted that during a significant increase of traffic intensity of commercial navigation above the anticipated economic scenarios alternative 4b on the long provides a valuable solution maintaining the performance is displayed in the present situation.

7. The construction of an additional minimal lock chamber (Alternative 4a) shows the best results regarding the social cost-benefit analysis.

The social cost-benefit analysis shows that the construction of an additional lock chamber with minimal dimensions serving fast ferry navigation (Alternative 4a) leads to less costs compared to the other best performing alternative. The social costs-benefit analysis is mainly focussed in the quantification of direct effects involved in the best performing alternatives. These costs are highly dependent on the financial consequences associated with the additional waiting of commercial and recreational navigation during a period equal to the life span of 100 years. It is noted that in alternative 4a fast ferry navigation is allowed to use the existing lock chamber next to the additional lock chamber constructed. There is no management related measure involved in this alternative.

9.2. Recommendations

With view on the conclusions of the feasibility study stated in this report the following recommendations are done:

1. Further investigation of legal aspects.

Legal aspects related of the introduction of fast ferry navigation in combination with traffic management related measures needs to be further investigated to safeguard the order of lockage and the overall nautical safety in and around the lock complex.

2. Optimization towards changing hourly and daily passenger transport demand.

The arrival pattern of fast ferry navigation is simulated according two scenarios describing a fixed 30 and 15 min timetable throughout the week. In practise the timetable of fast ferry navigation serving mainly commuter-related passenger transport needs to be optimize according the changing hourly and daily transport demand. The hourly transport demand is strongly dependent on the morning and evening rush hour. The sensitivity analysis shows the arrival pattern of commercial and recreational navigation leaves space for additional optimization. Also the passenger transport demand on working days differs from the weekend passenger transport demand. A 30 min timetable is expected to be sufficient to deal with the decreased transport demand during the weekend. Due to the
higher reliability of a 30 min timetable the yearly punctual performance associated with water based public transport is expected to increase. Additional research on the exploitation of a water based public transport connection might lead to more specific functional demands related to the passage of the Schellingwoude lock complex.

3. **Further investigation of non-lock system alternatives.**
   This report gives insight in the optimization of fast ferry navigation by means of divers lock system alternatives in the field of hydraulic engineering. Since it is concluded that a limited number of these alternative leads to an average passage time of fast ferry navigation within the target conditions associated with water based public transport, further investigation of non-lock system alternatives is recommended. Alternatives related to mechanical engineering might lead to an increased feasibility, since these alternatives are less dependent on future water level changes. The principle of a slipway or a moving staircase are examples of mechanical orientated alternatives.

4. **Further investigation of environmental impact of water based public transport connection**
   Regarding environmental feasibility the effect of a water based public transport connection crossing lake Markermeer needs to be investigated. Investigation on these aspects provides insight in the possible damage caused by this connection. It also prevents decreases the chance of unexpected damage to the existing Natura2000-area at lake Markermeer.

5. **Further investigation of indirect and external effects of fast ferry navigation.**
   Additional research on the quantification of indirect and external effects of a water based public transport connection between Amsterdam Central Station and Almere provides complete insight in the cost-benefit ratio of the best performing alternatives. A significant decrease of the average passage of fast ferry navigation at the Schellingwoude lock complex might serve other water based public transport connections from Amsterdam Central Station to lake Markermeer and vice versa. This could lead to an increase of indirect effects resulting in an increase of feasibility of a best performing lock system alternative.
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[26] Interview with mr. G. Schutten (shipping company Aqualiner and Waterbus), d.d. 23-02-2011.

Guidelines
[34] Ontwerp van Schutsluizen Deel 1 & 2, Rijkswaterstaat Bouwdienst, 2000.
Gemeente Amsterdam
Ingenieursbureau

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APPENDICES