Dynamic Transport Model for Nautical Recreational Activities in the IJburgbaai

by

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Preface

This is a thesis written for the MSc Civil Engineering track Transport & Planning. This work describes the development of a dynamic transport model of nautical recreational activities in the IJburgbaai, a water area in the Eastern part of Amsterdam, The Netherlands. This model has been developed as an internship at the municipality of Amsterdam.

The origin of this project lies back in April, when I was looking for an interesting subject for my thesis and I read about the desire of the municipality of Amsterdam for a model to simulate the behavior of nautical recreational activities in the IJburgbaai. Back then I was not familiar with the city of Amsterdam and was therefore not aware of the case of the IJburgbaai and the on-going development of the area around this bay.

Now, around seven months later, I have gained a lot of knowledge about the area and the behavior of the activities in this area. Combining this with the things I have learned about transport modelling during the past few years results in the model that is described in the report you are about to read.

I hereby would like to thank the members of thesis committee for their guidance and help during the past months. Adam and Mark for their advice and feedback provided during the several meetings with the committee and Winnie and Kobus for their insights during our bi-weekly meetings.

Thomas Litjens

's-Gravenzande, December 2022

SUMMARY

In this report the development of a dynamic transport model for recreational activities in the IJburgbaai is described. The IJburgbaai is a bay in Amsterdam-Oost which will be surrounded by the islands of IJburg. The area is still under development. The future development will include a significant increase in facilities for recreational activities on the water. The municipality of Amsterdam has some concerns about the effects of this increase on the nautical traffic flow conditions in the IJburgbaai and is therefore interested in a tool that can predict conflicts and indicate potential bottlenecks in the area.

To be able to develop such model first the current and expected activities in the IJburgbaai have been analysed. Seven types of activities were determined that influence the nautical traffic flows in the IJburgbaai. Large motorboats and sailing boats moored at marinas around IJburg are used for day-trips, which results in one departing trip and one returning trip per vessel through the fairway in the IJburgbaai. Furthermore, there are a lot of smaller motorboats and sloops moored at private jetties around the islands of IJburg. These can be used for day-trips as well, but also to sail closely around the islands.

Besides these activities also a lot of water sports are performed in the IJburgbaai. Small sailing boats, wind surfers and coastal rowers stay in the IJburgbaai during the entire duration of their activity while canoers, kayakers and SUPpers start from the Diemerlagune or Zeeburgerbaai and traverse the IJburgbaai when making a nice tour around the islands of IJburg.

A combination of a tactical model to estimate routes through the IJburgbaai and an operational model to simulate the exact movement behaviour of activities through the bay is determined to provide a solid basis for a dynamic transport model of the IJburgbaai.

To capture the routes of the activities, the routing behaviour of the activities has been captured by determining a set of intermediate points to guide agents through the bay. For this procedure an important distinction is made between activities through the fairway and activities outside the fairway. For both types a shortest path algorithm has been developed that in combination with a specified origin and destination simulates the route choice of traffic through the bay. Furthermore, a method has been introduced to generate intermediate points for the activities that remain in the IJburgbaai.

Then, an operational model is developed to simulate the movement of the agents in the simulation between the intermediate points. The main principle of this operational model is that the agents move through a grid of hexagonal cells with a cell size of 15 m. This grid type was chosen because it has the perfect combination of manoeuvrability (six optional directions) and simplicity (equal distances between each neighbouring cells). The next position of an agent is determined by a cell-choice model in which the following factors have been determined as main factors that influence movement behaviour of activities and are therefore included in the model:

- Direction of next destination.
- Speed differences between different activities.
- Preference for large motorboats and sailboats to stay within the fairway.
- When inside the fairway, a preference to keep the right side of the fairway.
- Presence of other agents.
- Inability of surfers and small sailing boats to sail into the direction of the wind. This creates zigzag behaviour when trying to reach an upwind destination.

Combining the tactical model with the operational model results in a dynamic model that captures all basic behaviours of the activities in the IJburgbaai. Validation of the model shows that the model captures the expected relation between occupancy and amount of conflicts in an area. Furthermore, it is accurately captured that activities with differences in speed in the same area result in an increased amount of conflicts. On the contrary, the expected effects of merging and diverging flows are hardly captured by the model. However, in general the model is good in predicting which areas of the bay will be crowded based on a given demand as input.

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1 INTRODUCTION

In this chapter the main motivation for this thesis is explained in Section 1.1. Then, the research objectives and research scope are presented in Section 1.2 and Section 1.3 and Section 1.4 presents the outline of this thesis.

1.1 MOTIVATION

The city of Amsterdam is expanding with the development of IJburg in Amsterdam-Oost. This project consists of the build and development of a couple of islands in the IJmeer. During the first phase of this development Steigereiland, Haveneiland and the Rieteilanden were developed. The built of those islands started in 1999 and finished in 2013. In 2014 the second phase of the development of IJburg started. During this phase three more islands will be developed, which are Centrumeiland, Strandeiland and Buiteneiland. The total development of IJburg includes the construction of approximately 20,000 houses as well as an increase of facilities for water-related recreational activities. Most of these facilities will be located around the IJburgbaai, which is a water area surrounded by the islands of IJburg as can be seen in Figure 1.1.

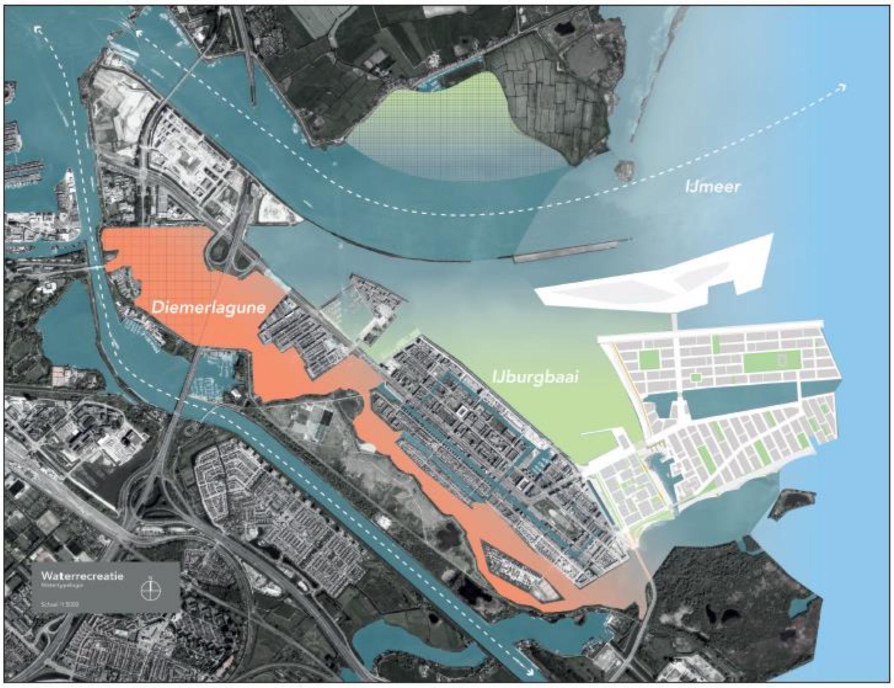

Figure 1.1 Location of the IJburgbaai (Gemeente Amsterdam, 2019)

Due to the increase in facilities for recreational water-use around the IJburgbaai an increase in activities in this area is expected. However, during the planning phase for the expansion of IJburg this potential increase in demand for water-related recreational activities is not considered. To be able to get an insight in the effects of certain decisions related to the planning of new harbours and waterways, the municipality of Amsterdam would like to have a tool that can identify potential conflicts and bottlenecks in the IJburgbaai.

Transport models have proven to be able to identify potential conflicts and bottlenecks for a wide variety of transport modes. However, due to a lack of financial or safety related consequences involved with conflicting recreational activities on the water transport modelling have not been applied for this type of traffic. Recently, (Hoff Wentges EC, 2020) have developed a dynamic transport model for water traffic in the canals in the city centre of Amsterdam. The aim of this model is to be able to show the effects of interventions on busy days.

Yet the interest of the municipality of Amsterdam in modelling recreational water activities has broadened towards the IJburgbaai. The case of IJburg is quite different than the situation in the city centre. First of all, the aim of the model is different. In the city centre the model is a tool to analyse the effect of short-term interventions when the canals appear to become overcrowded. For the IJburgbaai the model should provide information about the effects of the development of recreational water activity facilities on the surrounding land areas and operate more on an urban planning level. Another important difference is the topology of the area. The canals in the city-centre form links in a network along which boats travel. The IJburgbaai is an open-space in which agents can move in any direction.

1.2 Research Objectives

The aim of this project is to develop a dynamic transport model that is able to simulate the behaviour of recreational activities on an open-space water area.

1. The model should be able to determine conflict levels, density, speed and flow of all activities in the IJburgbaai.
2. The model should be able to identify potential conflicts and bottlenecks given a certain demand pattern.
3. The model should be able to differentiate in the behaviour and aims of activities in the IJburgbaai.
4. The model should be able to accurately simulate movement behaviour of different types of activities/users.
5. The model should be able to perform simulations with the order of minutes.
6. The model should be able to generate a graphical output for easy interpretation of the results.

The development of this model can be captured in the research questions below.

Main Research Question:

What model captures the behaviour of recreational activities in the IJburgbaai with enough detail to enable the identification of potential conflicts and bottlenecks?

Sub-Questions:

1. How do recreational water activities behave in the IJburgbaai?
2. What models are able to simulate routing behaviour of recreational water activities?
3. What factors determine which routes are chosen by recreational water users and what is the influence of these factors on route-choice behaviour?
4. What models are able to simulate the movement and interaction behaviour of recreational water activities in an open-space?

1.3 RESEARCH SCOPE

This research focuses on the development of a model to simulate the behaviour of recreational activities on the water, applied to the IJburgbaai. However, the modelling techniques used for the simulation of this behaviour should also provide a basis for the application towards other locations.

Due to the lack of data about activities in the IJburgbaai, the model that is developed will be validated based on the judgement of experts. Data-based validation of the model is an interesting subject for future research. Also calibration of parameters can be included in such research.

1.4 REPORT OUTLINE

This report is structured as follows. First in Section 2 an analysis of the activities in the IJburgbaai is presented. Then in the chapter 3, 4 and 5 the model is presented. This is done by first determining a general approach in chapter 3. Then, in chapter 4 and 5 the two main parts of the model are presented. In each of these three chapter (3, 4 and 5) first relevant theory is presented, which is followed by the application on the development of the model.

2 ANALYSIS OF THE IJBURGBAAI

In this chapter an analysis is presented of the activities in the IJburgbaai. First, in section 2.1 some background information about the development of IJburg and the arise of the IJburgbaai is provided. Then, in section 2.2 the activities in the IJburgbaai are analysed. Finally, in section 2.4 possible causes for potential conflicts and bottlenecks are discussed. Based on this analysis possible modelling techniques can be determined and analysed.

2.1 IJBURG AND THE IJBURGBAAI

IJburg is a neighbourhood in Amsterdam-Oost which consists of multiple islands that have been built in the IJmeer. The development of IJburg is still on-going. During the development two phases have been distinguished. During phase I Steigereiland, Haveneiland and the Rieteilanden were built and developed. This development started in 1999 and finished in 2013. In 2014 the construction of the islands for phase II began. Phase II consist of the development of Centrumeiland, Strandeiland and Buiteneiland. Currently, the first houses have been built on Centrumeiland and the land for Strandeiland has been constructed. In the future houses will be built on Strandeiland and Buiteneiland will be constructed. In Figure 2.1 the location of IJburg w.r.t. the city of Amsterdam and the IJmeer is shown.

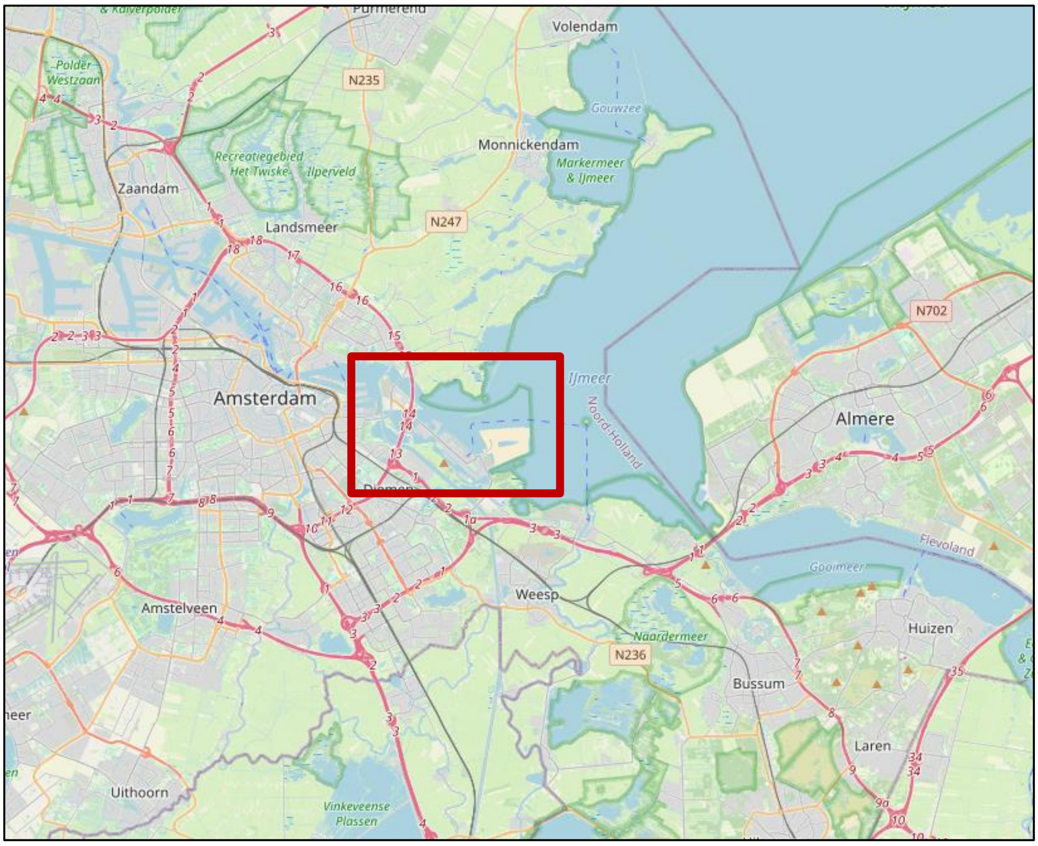

Figure 2.1 Location of IJburg w.r.t Amsterdam and the IJmeer. [1]

[1] https://www.openstreetmap.org/

With the development of IJburg in the IJmeer part of the IJmeer is separated from the large water body and a new bay is created. This bay is called the IJburgbaai. The IJburgbaai is connected to the Buiten-IJ, the IJmeer, the Zeeburgerbaai and the Diemerlagune as can be seen in Figure 2.2. Furthermore, the inner canals of Haveneiland can be reached through the main lock. The IJburgbaai is connected to the Buiten-IJ, which connects the IJ with the IJmeer. The Buiten-IJ is an important waterway for larger ships travelling from Amsterdam towards the IJmeer and vice versa.

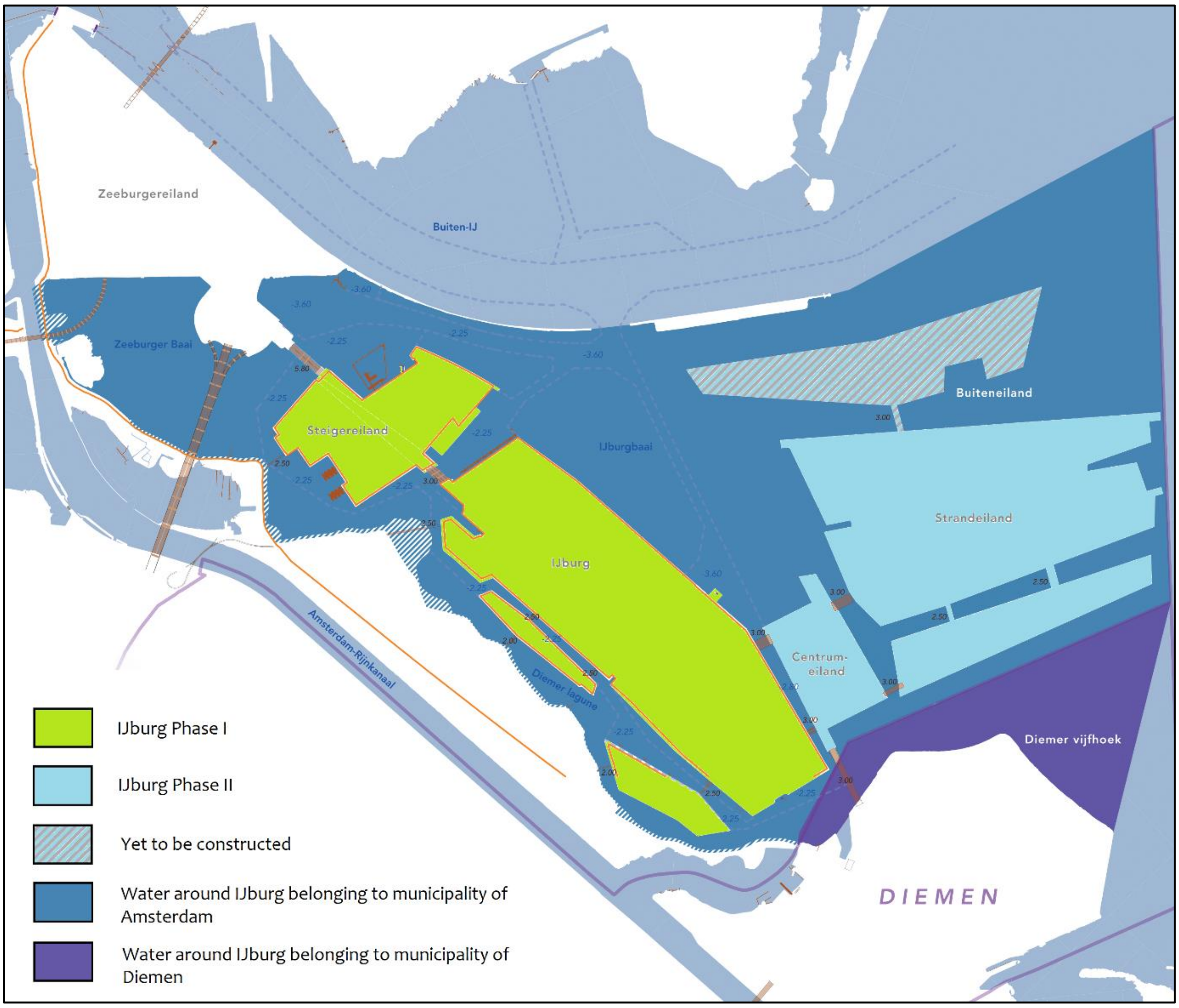

Figure 2.2 The IJburgbaai and surrounding islands and water areas.

2.2 Nautical Traffic Flows through the IJburgbaai

The IJburgbaai facilitate the following types of activities:

1. Recreational motorboats and sailing ships
2. Water sports
3. Ferry connection between IJburg, Pampus and Muiderslot.

To be able to determine the nautical traffic flows through the IJburgbaai it is important to determine from which locations these activities are performed and to map their main movement through the bay. To do this three types of facilities for recreational activities are distinguished: marinas, private jetties and water sports facilities. In the remainder of this section for each of these categories the locations, the type of activities departing from the locations as well as predicted trajectories are analysed.

2.2.1 Marinas

A marina is a location that provide mooring places for motorboats and sailing ships. To use a mooring place in a marina people pay an annual fee. The marinas are therefore mainly used by larger motorboats and sailing ships that cannot be moored at private jetties. In the area around the IJburgbaai there are currently marinas located. In the future two more will be developed.

Not all of these marinas have an influence on the amount of vessels in the IJburgbaai. Larger motorboats and sailing ships are mainly used for daytrips. Popular destinations for these daytrips are the city centre of Amsterdam and (locations around) the IJmeer. The Zeeburgerbaai and Diemerlagune are less attractive. Therefore, most vessels that depart from a marina only travel through the marked fairway in the IJburgbaai from a marina towards the Buiten-IJ and vice versa. Considering this, it is expected that there are two main flows of nautical traffic from the marinas. These are indicated in Figure 2.3.

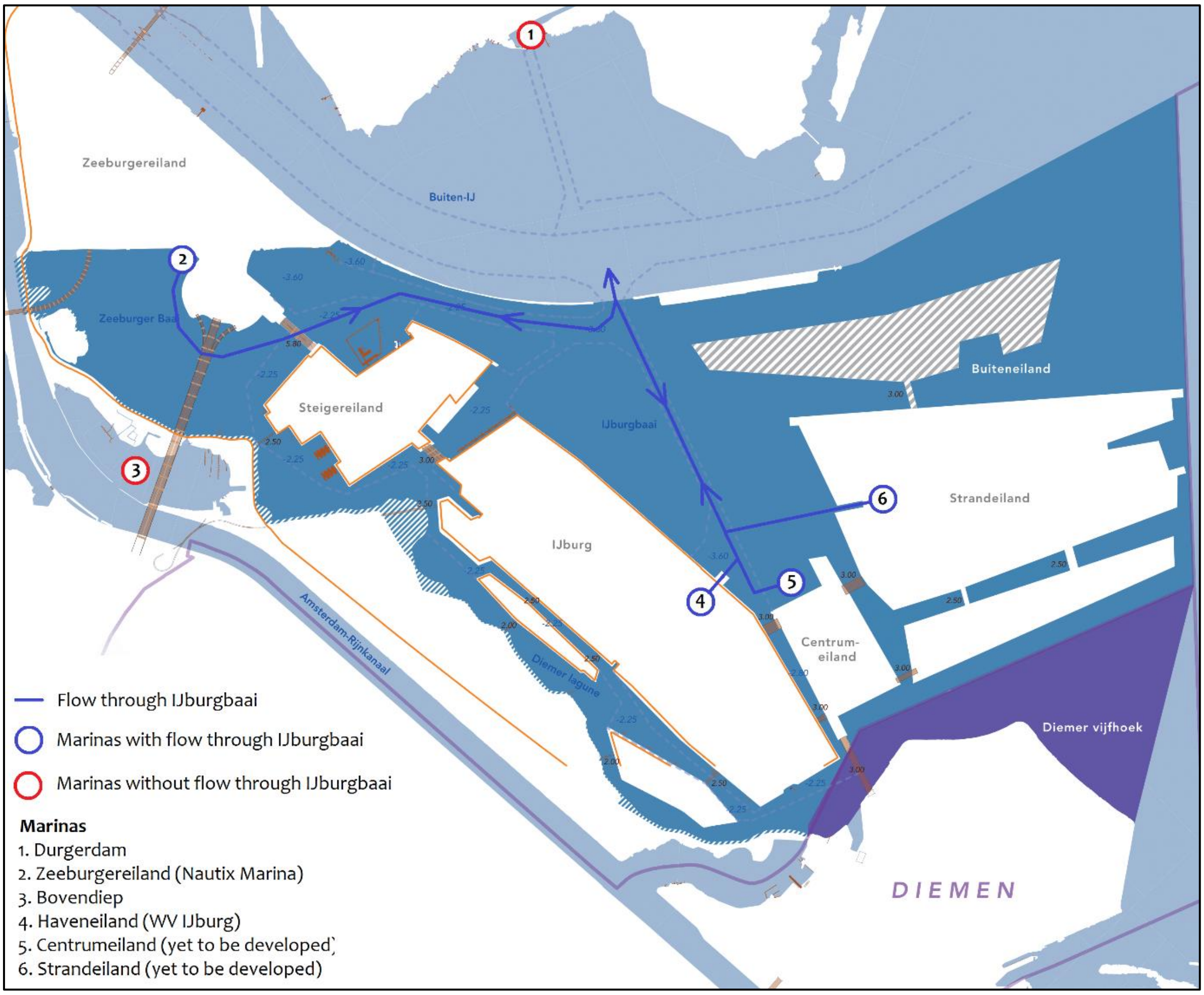

Figure 2.3 Expected nautical traffic flows from vessels moored at marinas.

The first flow is between the Buiten-IJ and the south part of the IJburgbaai between a point south of the bay, where three flows from the marinas at Haveneiland, Centrumeiland and Strandeiland merge. The second flow is between the marina at Zeeburgereiland and the Buiten-IJ, which travels north of Steigereiland.

The ferry towards Pampus and Muiden will be part of the first flow. Currently, the ferry departs from the marina at Haveneiland. However, it is discussed to move the mooring place of the ferry in the future to the yet to be developed marina at Centrumeiland, as the ferry do not have to travel through the lock that separates the marina at Haveneiland and the IJburgbaai.

2.2.2 Private jetties

Private jetties are mooring places for vessels located near houses. These jetties are mainly used for the mooring of smaller recreational vessels, such as inflatable motorboats, sloops and human-powered vessels (canoes, kayaks, rowing boats etc.). In the area around IJburg most of these jetties are located in the Diemerlagune around the Rieteilanden and at the south-west quay of Haveneiland. Furthermore, jetties are located in the inner-canals of Haveneiland. The inner canals of Haveneiland are secluded from the IJburgbaai and the Diemerlagune by three locks and thus vessels sailing from the inner canals of Haveneiland towards the IJburgbaai haver to pass either one of these locks.

Vessels located at private jetties are less dependent on the fairway and might move more freely through the IJburgbaai than vessels moored at marinas. Furthermore their routing is less predictable. They might go for a round-trip towards the previously mentioned popular destinations (Amsterdam & IJmeer) or stay close to IJburg and sail around the islands. However, they are expected to sail from an entrance point of the IJburgbaai towards an exit point and to not keep sailing around in the IJburgbaai. In Figure 2.4 possible entrance and exit locations are indicated by the yellow arrows.

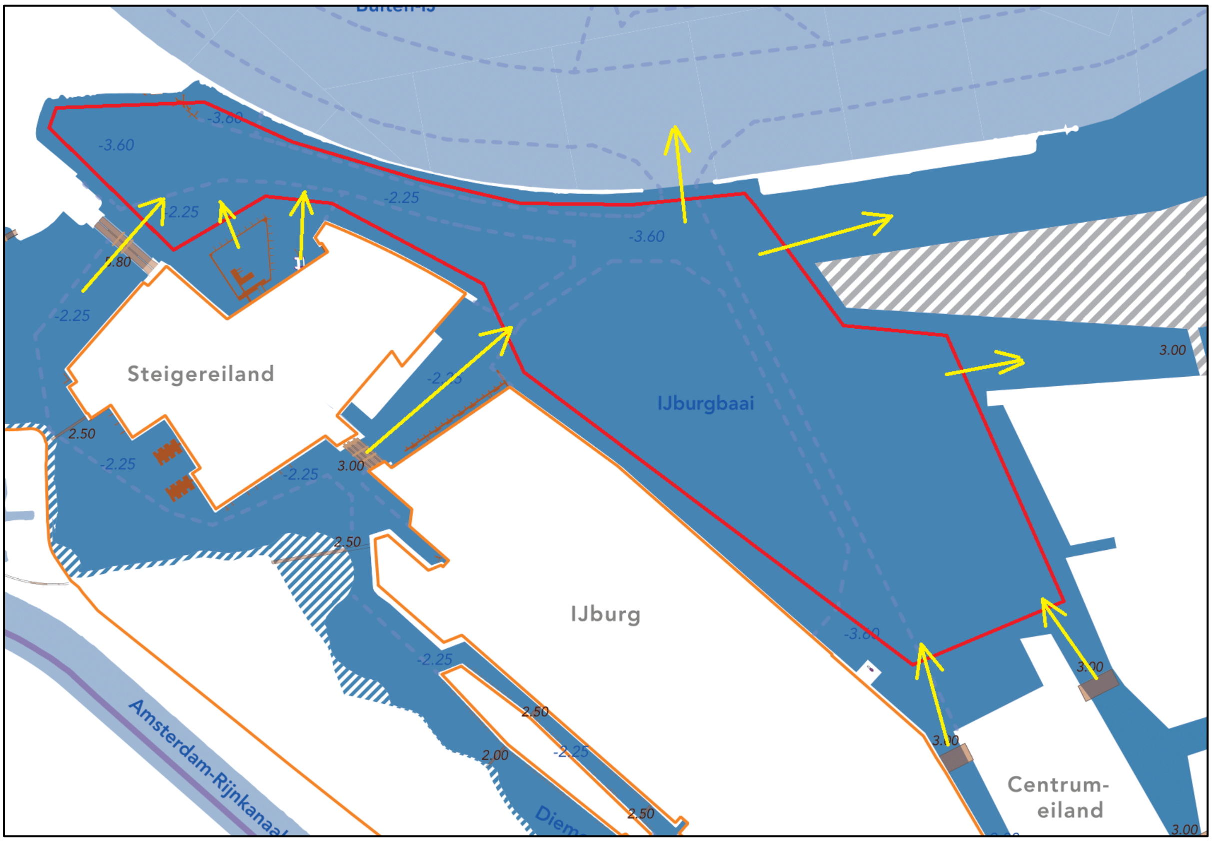

Figure 2.4 Entrance and exit points of small motorboats moored at private jetties around IJburg..

2.2.3 Water sports

Besides a lot of mooring places for motorboats and sailing ships the area around the IJburgbaai also accommodates for some facilities for the performance of water sports. These locations are indicated on the map in Figure 2.5.

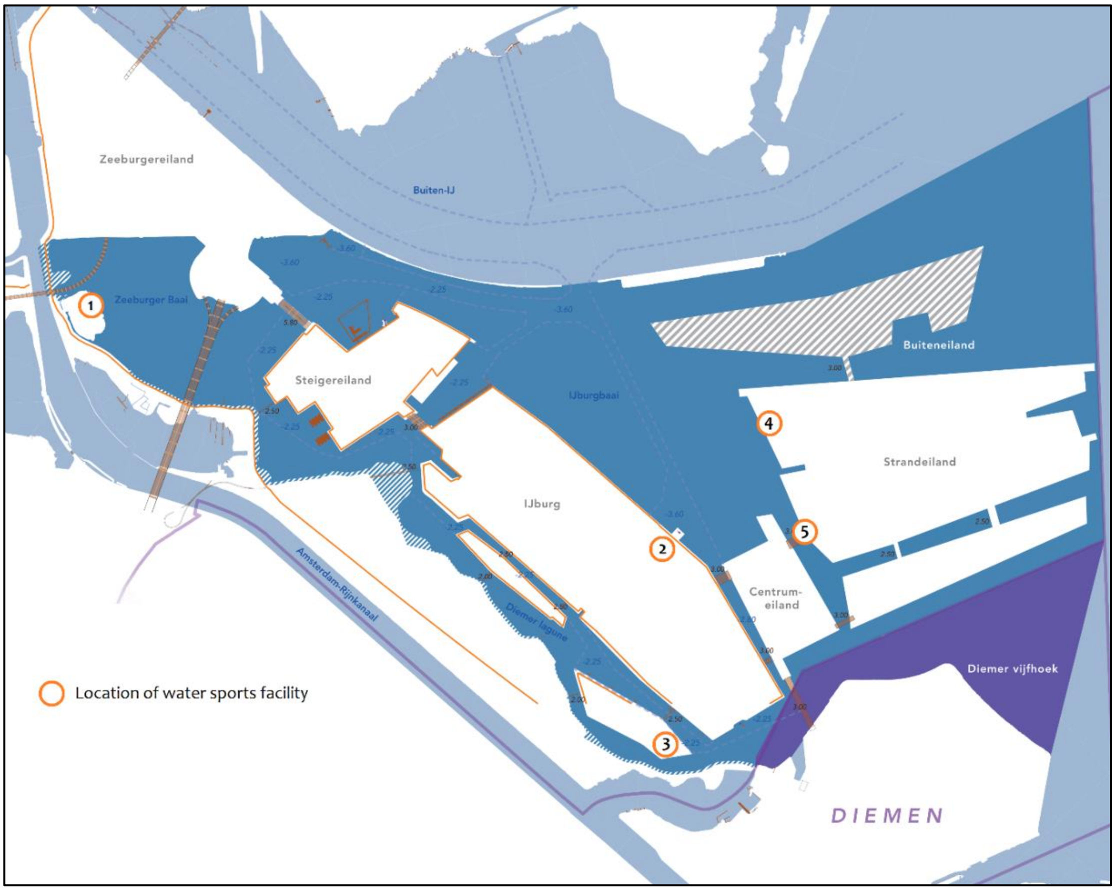

Figure 2.5 Location of water sports facilities around the IJburgbaai.

At these locations the following activities are facilitated:

- Canoeing/Kayaking (1,3)
- Supping (1, 3, 4)
- Wind surfing (4)
- Sports sailing (2)
- Swimming (4)
- Coastal Rowing (4, 5)

Below an analysis of the behaviour of these activities in the IJburgbaai is presented. Based on this analysis possible causes for conflicts can be determined.

Canoeing/kayaking

Canoes and kayak activities around IJburg start at location 1 or location 3 and are preferred to be performed in calm waters. Most canoe/kayak trips have a duration of a few hours. Depending on experience level, canoers have an average speed range of 4 to 8 km/h. For recreational canoers, both camping Zeeburg and Kano op IJburg recommend routes around Steigereiland, Haveneiland and the Rieteilanden. At the right conditions (little wind) or with a higher level of experience canoers might go for longer routes towards Amsterdam or the IJmeer.

Supping

Supping is an activity where people stand on a long board (a SUP) and move by paddling in the water. Around the IJburgbaai SUPs can be rented at camping Zeeburg, M&M SUP and Amsterdam Watersports. Furthermore, Kano op IJburg owns some SUPs that can be used by their members. The preferred conditions, activity duration and speeds are similar to those of canoers. Therefore, similar routes are expected as for canoes.

Sailing

As previously discussed, sailing ships moored in marinas will mainly sail towards the IJmeer through the marked fairway for a daytrip. In the area outside the fairway the water depth is not sufficient for most of these larger sailing ships. However, sailing is also performed in smaller sailing boats as a form of water sport.

Currently, sailing is mainly performed starting at the sailing school located near the main lock of Haveneiland. For sailing windy open water spaces are preferred. Currently the IJburgbaai is very suitable for sailing for smaller sailing boats. However, when buildings are being created on Strandeiland this might change due to changing average wind conditions in the bay.

Wind Surfing

Wind surfing is an often performed water sport in the IJburgbaai. Most wind surfers depart at the beach on Strandeiland, windsurf for some time in the IJburgbaai and then return to the beach. Wind surfers are not expected to leave the IJburgbaai.

Swimming

There is a designated area (demarcated from the rest of the bay by a rope and buoys) for swimmers near the beach of Strandeiland. This will mainly be used by recreational swimmers that are out for a day on the beach and it is expected that most swimmers will stay in the designated area. More experienced swimmers might try to cross the IJburgbaai. However, people whose main aim is to go for a nice swim are expected to go to nearby more suitable areas (Sloterplas, Nieuwe Meer, De Poel, Ouderkerkerplas, Gaasperplas).

Coastal Rowing

Coastal rowing boasts move in straight lines. Currently, coastal rowing boats depart from the beach at Strandeiland and mainly row towards Buiten-IJ and vice versa at the east side of the marked fairway. Possibly this will be moved to a yet to be developed facility near the bridge that connects Centrumeiland and Strandeiland. This would not change the main movement of the rowing boats through the bay.

2.3 Expected Demand

In the previous section the activities in the IJburgbaai and the directions of the resulting nautical traffic flows have been discussed. To be able to determine whether these flows might cause conflicts the amount of traffic should be approximated.

Potential demand

As previously discussed, vessels through the IJburgbaai are either moored in one of the four marinas around the IJburgbaai or at smaller private jetties in the inner waters of the islands. The amount of mooring places is as follows:

- Marina Zeeburgereiland:
    - 65 motorboats
- Marina Haveneiland:
    - ~ 85 sailboats and 35 motorboats
- Marina Centrumeiland:
    - Mixture of sailboats and motorboats, capacity varying from 200-400 vessels.
- Marina Strandeiland:
    - Mixture of sailboats and motorboats, total capacity of around 600 vessels.
- Private jetties:
    - ~800 small motorboats and sloops

The municipality of Amsterdam expects (based on the experiences with the existing marinas) that at most 20% of the moored vessels will sail-out.

Demand factors

Together with the municipality of Amsterdam three factors have been defined that influence the actual amount of activities that will be performed during a day. These are:

- Season
- Day of the week
- Wind conditions

The effect of season and day of the week is similar for each type of activity. In the summer the expected demand is the highest and in the winter the lowest. In the spring and autumn the demand is somewhere in between. Furthermore, the demand is higher during the weekend than on weekdays. The effect of wind varies per type of activity. Sailboats, windsurfers and coastal rowers prefer a relatively high amount of wind while motorboats and canoes/kayaks/SUPs prefer little to no wind.

In Chapter 7 it will be explained how these expected effects and potential demand will be used to construct the OD-matrices to simulate different scenarios.

2.4 POTENTIAL CAUSES FOR CONFLICTS

The aim of the model is to determine potential conflicts and bottlenecks. Therefore, it should be determined which activities are expected to contribute to those conflicts and will be influenced by bottlenecks in the bay.

Conflicts might occur when the intensity of merging or crossing traffic flows is too large. In the IJburgbaai multiple locations are presents where flows merge or cross. These are indicated in Figure 2.6. First of all, there are two areas where traffic flows through the merge. These are located near the Buiten-IJ and near the main lock of Haveneiland.

In the areas outside the fairway there is also risk of conflicts as there is a wide variety of water sports in these areas as well as the presence of small motorboats which all behave differently. Canoes, kayaks, sups and motorboats move in a straight line from origin to destination and sailing boats and surfers zigzag through the area. Furthermore, there are variances in speeds. Canoes, kayaks, sups and sailing boats move relatively slow compared to motorboats and surfers.

Lastly, there are also situations where fairway traffic and water sports may conflict. Traffic from the marina at Strandeiland has to cross the area east of the fairway, which is used a lot by surfers, rowers and sailing boats. Also water sports activities might cross the fairway from the east side of the bay to the west and vice versa when looking for less busy areas in the bay.

Swimmers are not expected to contribute to the occurrence of conflicts as they will mainly stay in the separated area near the beach.

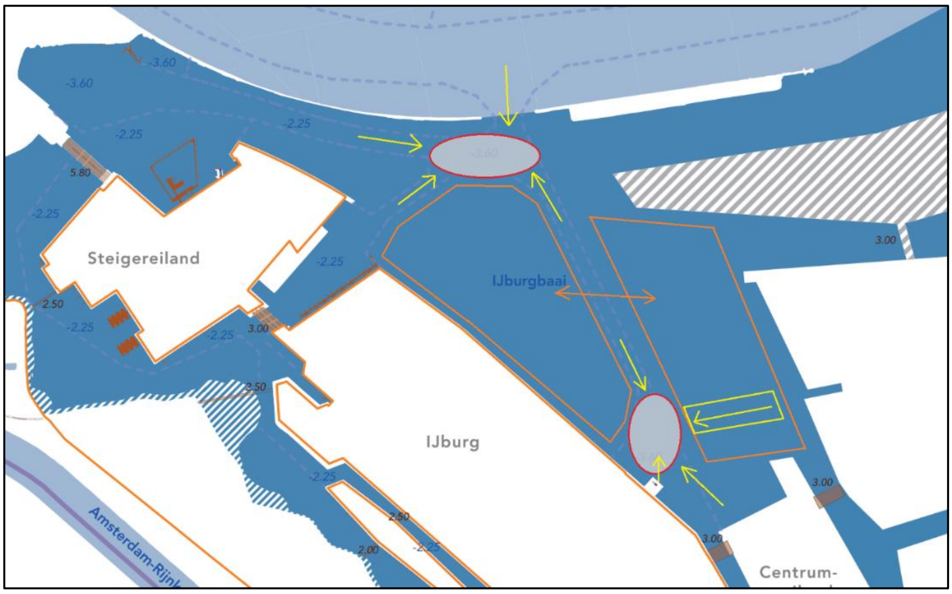

Figure 2.6 Potential conflict areas in the IJburgbaai.

Bottlenecks are locations where traffic might accumulate due to a reduction in capacity. Bottlenecks in the IJburgbaai are locks (at Haveneiland, Steigereiland and Strandeiland) and the bridges.

3 GENERAL APPROACH FOR MODEL DEVELOPMENT

In this chapter the general approach for the development of the IJburgbaai model is discussed. First in Section 3.1 a review on related transport models is prensented. Then, from the findings of this review a general approach for the development of the model is determined which is discussed in Section 3.2.

3.1 REVIEW ON RELATED TRANSPORT MODELS

In this section an overview of relevant knowledge from existing literature is provided. As previously discussed, the aim of this project is to develop a model for recreational activities in open water. Recreational water activities has not been modelled before. Therefore, to determine a suitable modelling paradigm the methods applied in closely related fields of transport modelling are explored. In Section 3.1.1 a review on maritime traffic models is presented. This includes models that are mainly applied to large freight vessels in port areas. In Section 3.1.2 modelling techniques used for the modelling of pedestrians are discussed. An important similarity between pedestrian simulation and the objective of this thesis is that both are dealing with agents in an open space.

3.1.1 Maritime Traffic Models

(Zhou, et al., 2019) analyses 35 different models used for the simulation of maritime traffic of which 13 can be applied for open water. (Zhou, et al., 2019) identifies six different modelling paradigms that have been applied for the simulation of vessel behaviour and categorises them into rule-based and mathematical models. In rule-based models vessel behaviour is simulated by a set of rules and in mathematical models this behaviour is simulated by a set of differential equations.

The most simple form of a rule-based model is a cellular automata. In cellular automata space is discretised into a number of cells of pre-determined size and the agents move from cell to cell based on whether neighbouring cells are occupied or available. For rule-based models in which space is continuous (Zhou, et al., 2019) makes a distinction between generic rule-based models and specific rule-based models. In generic rule-based models the set of rules to describe movement behaviour is the same for all agents under all circumstances. In specific rule-based models, the rules differ between different types of agents. Furthermore, specific rules are defined for interactions for each combination of two types of agents.

Furthermore, (Zhou, et al., 2019) has identified three types of mathematical models that have been used to simulate vessel behaviour in maritime traffic models. These are artificial potential field models, optimal control models and system dynamics models. In artificial potential force models the speed and course of vessels is determined based on artificial attractive and repulsive forces that represent the willingness to travel towards a destination and to avoid static and dynamic boundaries. This principle is adapted from the social-force model in pedestrian modelling developed by (Helbing & Molnár, 1995). In optimal control models vessel behaviour is modelled as a result of the solution of an optimisation problem with an objective function which is related to minimising a specified form of cost to reach a destination and state variables as a function of agent related movement parameters. System dynamics models are maritime models that model the movement of vessels in state-space representation in which actual forces on vessels are considered (generated by internal forces such as a rudder or external forces, such as wind). A benefit of this model is that it models vessel behaviour very accurately. However, this comes at the cost of a very high computational load.

(Zhou, et al., 2019) concludes that each of the paradigms is not limited to the application of either open water or confined water. However, when looking at the analysed models none of the models for open water makes use of the principle of artificial potential field or optimal control.

3.1.2 Microscopic (Pedestrian) Simulation

In microscopic transport modelling often three levels are distinguished as can be seen in Figure 3.1. During the strategic planning phase people decide what they are going to do (activity choice) and where (departure choice) they are going to do this activity. Then, in the tactical phase, people will decide on where to go to and how to get there (route choice). Finally, the operational level describes the exact movement behaviour and interactions with other people.

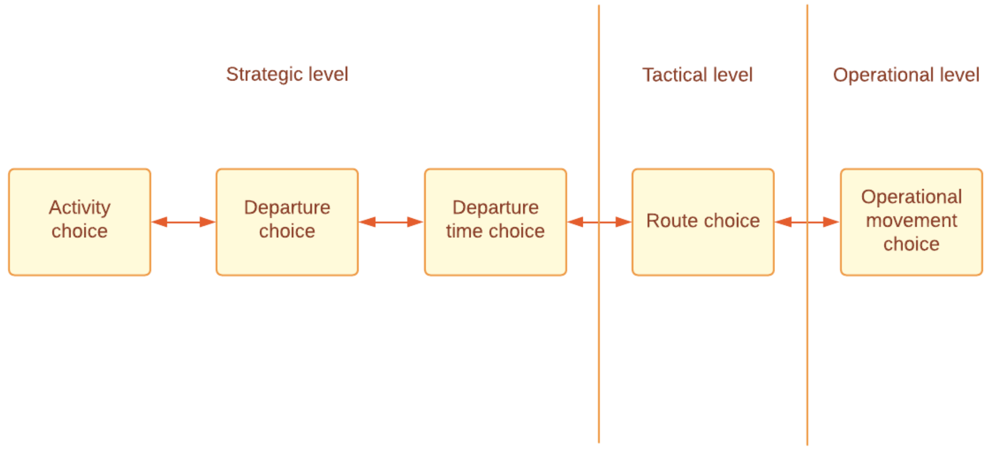

Figure 3.1 General microscopic modelling framework

A field in which microscopic modelling has been widely applied is pedestrian modelling. Some of the modelling paradigms usually applied for pedestrian simulations have also been applied in maritime traffic models and their principles have therefore already been discussed in Section 3.1.1. These are all types of rule-based models and the artificial potential force model, which is in pedestrian simulation referred to as the social force model developed by (Helbing & Molnár, 1995).

3.2 Modelling Approach

This project focuses on modelling the movement and interaction behaviour in the IJburgbaai to enable the identification of potential conflicts and bottlenecks. This type of behaviour requires modelling on operational level. However, due to the strong relation between the movement of agents and route choice, the tactical level will also be of interest for the model.

A good example of how the tactical level and operational level can be combined is provided by (Asano, et al., 2010). (Asano, et al., 2010) combines a microscopic pedestrian simulation model with a tactical model for the simulation of (macroscopic) route choice behaviour. Route choice is dependent on the location of origin and destination of a trip and thus a set of O/D-matrices should be provided. Furthermore, route choice depends on the current situation (e.g. speed and position of other agents). Therefore, the main structure of the model will be as shown in Figure 3.2, with a feedback loop from the operational model towards route choice.

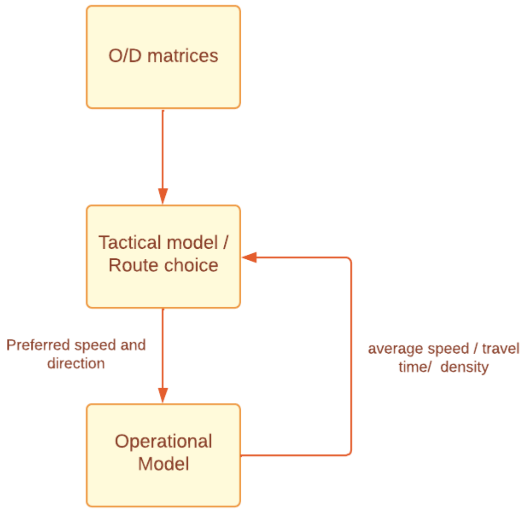

Figure 3.2 Main model structure

3.2.1 Tactical Model

The aim of the tactical model is to model the general routes of agents through the IJburgbaai, by determining intermediate destinations in the IJburgbaai. Based on the analysis of the activities presented in Chapter 2 it is determined that the tactical model should be able to distinguish between three types of activities, which are:

1. Traffic from origin to destination sailing through the fairway.
2. Traffic from origin to destination sailing through the entire bay.
3. Activities starting at a location, performing the activity in the IJburgbaai for some time and then returning towards the origin.

In general route choice models consist of two parts: a choice set generation and a route choice between routes in the generated choice set (Prato, 2009). This however assumes that a network already exists. For this work the area of interest is an open-space. Therefore, first a network has to be generated. In Figure 3.3 the relation between these steps and input (origin, destination and the geometrical area) and output for a single agent are shown.

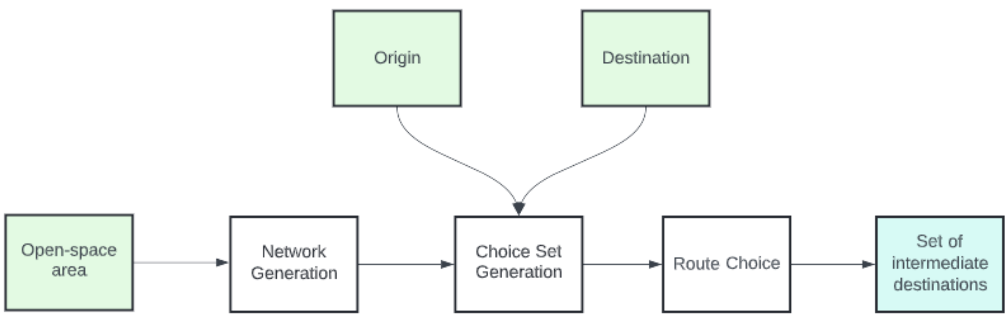

Figure 3.3 General tactical model framework.

However, no relations for recreational water activities and the route choice are known yet. Therefore, the choice set generation and route choice are simplified by just finding the shortest path between origin and destination. Therefore, the input for the tactical model will be the shortest path as a set of intermediate destinations, following the approach by (Anvari, et al., 2014) for shared space and (Xiao, 2014), (Rong, et al., 2014) and (Cheng, et al., 2017) to model routes of container vessels in port water ways. This results in the model framework for the tactical model as shown in Figure 3.4. Origin and destination will already be used in the generation of the network to limit the size of the generated network. Details of this process will be discussed in section 4.3.

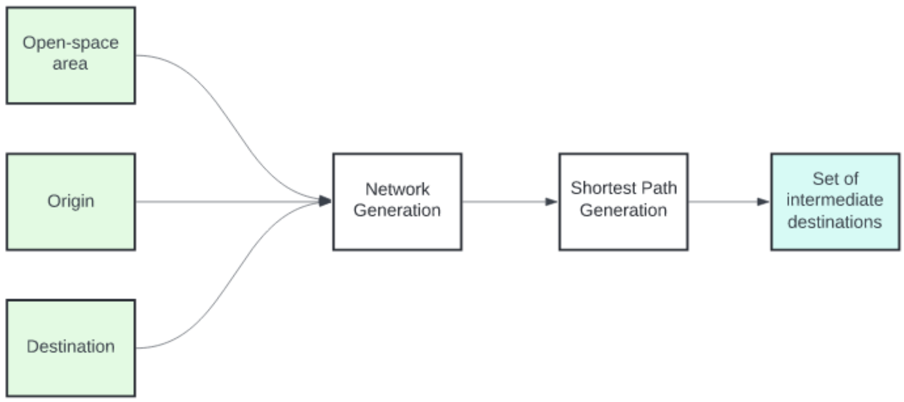

Figure 3.4 Modified tactical model framework

With this general approach the behaviour of activities sailing from origin towards destination can be simulated. Deviations from the exact trajectory compared to the computed shortest path should be simulated in the operational model. For activities for which the origin is the same as the destination a slightly different approach is required as shown in Figure 3.5. A first intermediate destination should be randomly chosen in a pre-determined area. Once this destination has been reached a new destination should be determined. This is either a new random location or the initial origin, based on the time that has been passed since the start of the activity.

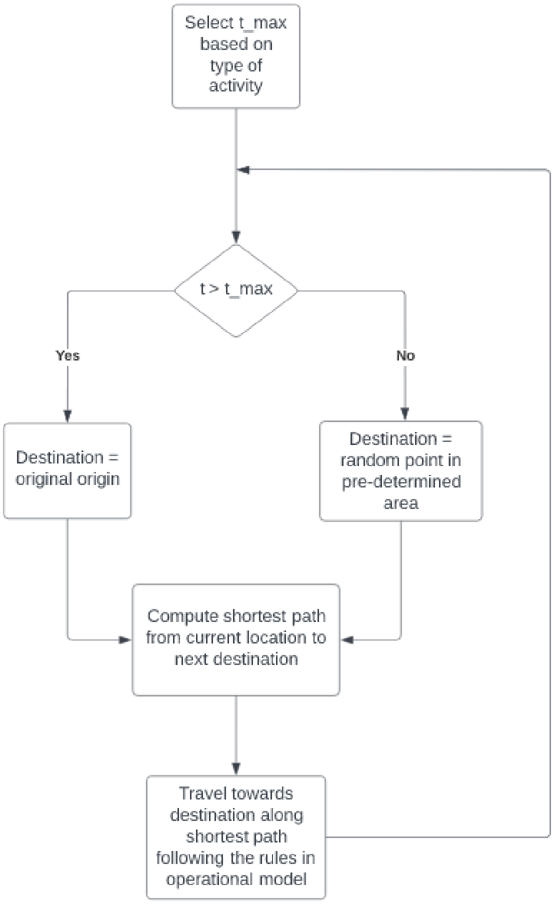

Figure 3.5 Simulation of routing behaviour for activities for which the origin is the same as the destination.

3.2.2 Operational Model

In Section 3.1.1 and Section 3.1.2 some modelling paradigms used for maritime transport and microscopic simulations have been discussed. The most promising are rule-based models and force-based models due to their simple general modelling paradigm which can be adapted such that they are able to simulated the differences in behaviour for each type of activity in the IJburgbaai. The main advantages and disadvantages of these two approaches are listed below.

Rule-based models

+ Relative low computational load.
+ Able to adjust rules such that it most accurately describes the movement behaviour of different types of agents.
- Due to the fact that the specified behavioural rules are often related to the environment it is difficult to apply a developed model for other areas.
- It is difficult to determine an appropriate grid size.

Force-based models

+ Force-based models provide a general mathematical formulation for any type of interaction. Thus only parameters should be estimated/determined.

+ Once parameters have been determined for the relevant nautical activities the model provides a good basis for modelling the same kind of activities in other geographical locations.
- Relative high computational load.

The main difference between the two paradigm is the manner in which space is modelled. In most rule-based models space is discretised which limit the options for the movement of agents in the model. In force-based models space is continuous and the options for the movement of agents is large. Therefore, force-based models are better in realistically modelling exact trajectories of activities. However, the exact behaviour of individual agents in the simulation is not known with a lot of accuracy and for the determination of potential conflicts and bottlenecks realism in the exact interactions is not required. Thus usage of a force-based model has no real advantage over the computationally less extensive approach of using a rule-based model. It is therefore decided to use this approach for the operational model. This means that a grid of cells should be created. Then, the model should model the movement of agents through the IJburgbaai based on the set of intermediate destinations found by the tactical level of the model and some external factors from cell to cell in which the next position is determined following the framework in Figure 3.6.

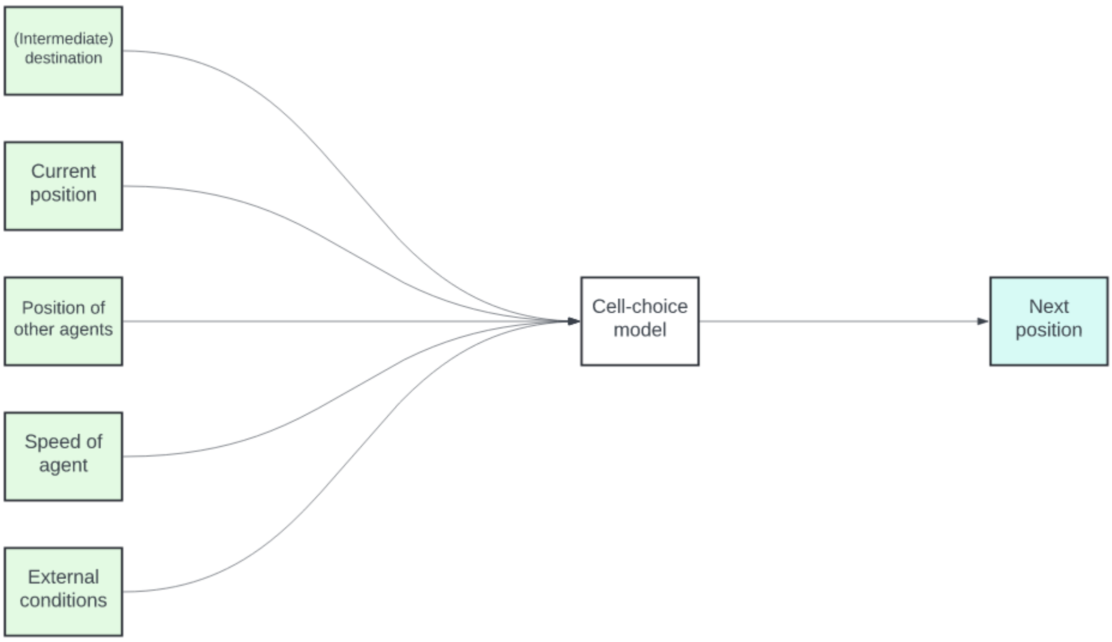

Figure 3.6 Main framework for the operational model.

3.2.3 Categorisation of Activities

Based on the characteristics of the activities described in Section 2.2 the model should be able to capture the following behaviour of activities:

- Type of activity: passing through the IJburgbaai (P) or staying in the IJburgbaai during the entire duration of the activity (S).
- Fairway preference: mainly sailing through the marked fairway (✓) or not (X).
- Wind influence: movement is affected by the wind (✓) or not (X).
- Estimated general speed range.

These criteria lead to the determination of seven categories that are shown in Table 3.1.

Table 3.1 Categorisation of activities

Category	Activity type	Fairway preference	Wind influence
Large Motorboats	P	✓	X
Large Sailing Ships	P	✓	X
Small motorboats/sloops	P	X	X
Canoes/Kayaks/SUPs	P	X	X
Sailing boats	S	X	✓
Wind surfers	S	X	✓
Rowers	S	X	X

3.2.4 Conceptual model

As previously discussed the model that is constructed consists of two components: a tactical level for the modelling of route-choice behaviour and an operational level for the modelling of the movements of agents. In Figure 3.7 the relationship between these two models is shown for both activities that move from an origin towards a destination and activities that remain in the IJburgbaai.

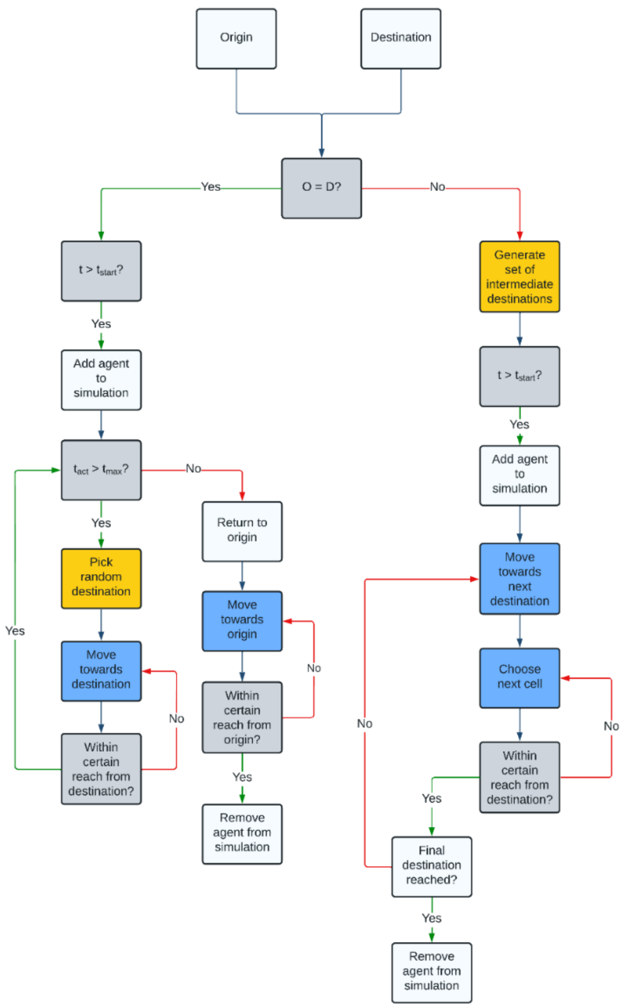

Figure 3.7 Conceptual Model, with in the yellow blocks the actions simulated the tactical model and in the blue blocks the actions simulated by the operational model.

3.2.5 Model Implementation

The model has been built using python[2]. In Appendix C a user manual can be found on how to simulate a certain scenario using the python code of the model. As previously discussed, the model development is split into two major parts: a tactical model to simulate route choice and an operational model to simulate exact movement behaviour. The development of both parts was done gradually, increasing the complexity of the code slightly while continuously verifying the working of new lines of codes and individual modules by checking both visually and quantitatively whether the output matches the expected outcome of certain computations.

[2] https://python.org

4 TACTICAL MODEL

In this chapter the development of the tactical model will be presented. This will be done by first reviewing relevant literature on aspects of the model and then applying the gained information for the development of the model.

As discussed in Section 3.2.1 the framework for the tactical model is as shown in Figure 4.1. Multiple methods for network generation will be reviewed in Section 4.1. Then, in Section 4.2 some shortest path algorithms will be discussed. Finally, in Section 4.3, the model development will be presented.

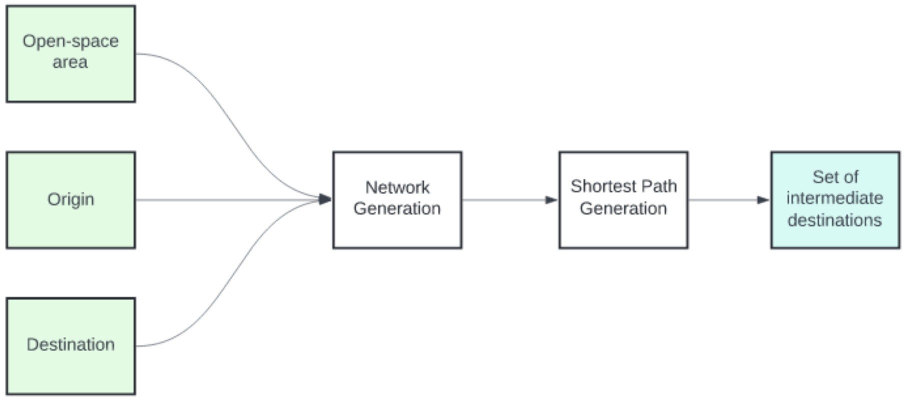

Figure 4.1 Structure of the tactical model

4.1 NETWORK GENERATION

As previously mentioned, for route choice modelling through open spaces first a network has to be generated. Network generation in open-spaces has been subject of many researches for the modelling of pedestrians. The most simple way to deal with an open space is by using the exterior edges of the open space as the network. This method does not require a lot of additional computational effort. However, the resulting route is not very realistic as the route is quite longer than the actual shortest path.

(Graser, 2016) identifies a couple of approaches for the generation of a network-based routing graph for pedestrians through open spaces such as streets, sidewalks and plazas. Some of them might also be applicable for open water bodies.

4.1.1 Grid-based network

In grid-based network generation a regular grid of cells is created. Then, links are created between the centres of these cells. The most simple approach is to only connect the centres with horizontal and vertical links such that each cell-centre is connected to four neighbouring cell-centres. Another approach is to also include diagonal links such that each cell-centre is connected to the centres of eight surrounding cells.

The main challenge when using regular grids for network generation is to find an optimal combination of grid size, the use of diagonal links (or not), computational effort and the quality of the computed shortest path on the generated network.

The smaller the grid size the more accurate the generated path represents the shortest path. However, this comes at the cost of an increased computational effort. The same holds for the application of spider-grids: the generated shortest path is more close to the actual shortest path generated on a regular grid, but this also comes at the cost of an increased computational effort. (Hahmann, et al., 2018) concludes that regular grids are not suitable as they perform significantly less on resemblance with the actual shortest path and are especially bad in generating a (close-to) shortest path between an origin and destination that are positioned diagonally with respect to each-other.

4.1.2 Visibility Graph

In a visibility graph links are created between each pair of nodes that can be connected by a straight line without intersecting any object. The main benefit of using a visibility graph for network generation is that the shortest path computed on a visibility graph equals the actual shortest path (Hahmann, et al., 2018). This comes with the cost of a high computational effort. However, the computational effort is less than when using the spider-grid approach.

Although the visibility graph is better than the spider algorithm regarding graph size and graph creation time, it still results in a lot of unnecessary edges and vertices (Hahmann, et al., 2018). This can result in a high computation time for the shortest path algorithm. When the size of the network is reduced, the time required to go through a shortest path algorithm will also significantly reduce.

A method that reduces the computational effort while remaining the ability of exact shortest path determination is discussed by (Choset, et al., 2005). To reduce the computational effort for creating the visibility graph and for performing a shortest path computation on the visibility graph (Choset, et al., 2005) introduces the reduced visibility graph around polygon obstacles. This reduced visibility graph only includes so-called supporting and separating lines between polygon pairs. A supporting line is a line touching both polygons with both polygons on the same side of the line and a separating line are lines touching both polygons with both polygons on opposite sides of the line, as can be seen in Figure 4.2.

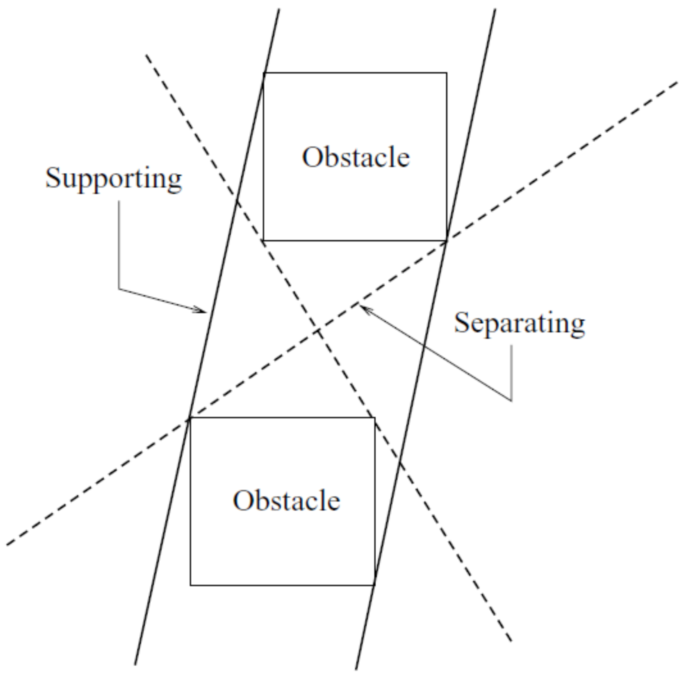

Figure 4.2 Supporting and separating lines for two polygon obstacles (Choset, et al., 2005).

4.1.3 Comparison of Algorithms

(Hahmann, et al., 2018) compares the combined network generation and shortest path computation of algorithms using Dijkstra's algorithm to compute the shortest path on a network generated on the Weisenhausplatz in Pforzheim, Germany, and uses the following four criteria for the comparison:

1. Graph size (size of the generated network)
2. Graph creation time (amount of time it takes to generate the network)
3. Routing performance (amount of time it takes to compute the shortest path on the generated network)
4. Routing quality (comparison of the computed shortest path using the generated network with the actual shortest path through the open-space).

This results in the performance indicators for the previously mentioned network generating algorithms shown in Table 4.1. In this comparison also routing over the exterior edges of an open-space is included, because this method results in the least computational effort. However, this results in a non-realistic shortest path and is therefore not considered as a serious option.

Table 4.1 Comparison of algorithms applied to the Weisenhausplatz in Pforzheim, Germany by (Hahmann, et al., 2018).

	Graph Size	Graph Creation Time	Routing Performance	Routing Quality
Exterior Edges	Optimal	Optimal	Optimal	+48%
Spider 5 m	+25%	+95%	+33%	+5%
Spider 10 m	+9%	+30%	+10%	+7%
Visibility Graph	+7%	+17%	+7%	Optimal

- Optimal
- 0-10% above optimal
- 10-25% above optimal
- 25-50% above optimal
- 50-100% above optimal

It can be seen that for this specific situation the visibility graph performs better both on required computational effort and on routing quality. Computational effort for using a spider grid can be reduced by increasing grid-size. However, this will reduce routing quality even further. When using the visibility graph, computational effort can be reduced without losing routing quality, as was proven by (Choset, et al., 2005). Therefore, for the IJburgbaai model the method of constructing a visibility graph will be used for the generation of a network.

4.2 Shortest Path Algorithms

There exist four algorithms that are generally used for the computation of shortest paths. These are Dijkstra's algorithm, the Bellman-Ford algorithm, the Floyd-Warshall algorithm and the Johnson algorithm. The working of these algorithms have been evaluated by (Abu-Ryash & Tamimi, 2015) and (Wang, 2018) on three criteria, which are space complexity (amount of computational effort related to memory), time complexity (amount of computational time) and the ability to deal with negative edge weights. Similar to the network creation, space complexity is of less importance than time complexity. Furthermore, the ability to have negative edge weights is irrelevant for distance-related shortest path problems as distances are always positive. This leaves time complexity as the determining factor for the choice of shortest path algorithm.

Both (Abu-Ryash & Tamimi, 2015) and (Wang, 2018) conclude that for shortest path computation of networks that do not contain negative edge weights, Dijkstra is computationally the least intensive and will therefore be used as the algorithm to compute the shortest path on the generated network in the IJburgbaai model.

The working of Dijkstra's algorithm is illustrated in Table 4.2**,** Table 4.3 and from Figure 4.3 to Figure 4.8 on a network consisting of 6 vertices connected through 10 edges**.** The algorithm is initialised by creating a list of distances and a list of predecessors, which will be updated after each step.

1. Set the distances from each vertex directly connected with the starting vertex to the weight of the edge between the vertices.
2. Find the vertex with the shortest distance from the origin and set this distance as fixed.
3. For the nodes connected to the fixed node from step 2, update the distance if the distance via the fixed node is shorter than the current saved distance.
4. Again, find the node with shortest distance from the origin and fix its distance and predecessor.
5. Repeat the process described by step 3 and step 4 until the values for all nodes have been fixed, or once the destination node has been reached.

Table 4.2 Distances

	1	2	3	4	5	6
Step 0	0	∞	∞	∞	∞	∞
Step 1	0	7	3	7	∞	∞
Step 2	0	7	3	7	10	13
Step 3	0	7	3	7	10	13
Step 4	0	7	3	7	10	13
Step 5	0	7	3	7	10	13

Table 4.3 Predecessors

	1	2	3	4	5	6
Step 0	1	-	-	-	-	-
Step 1	1	1	1	1	-	-
Step 2	1	1	1	1	3	3
Step 3	1	1	1	1	3	3
Step 4	1	1	1	1	3	3
Step 5	1	1	1	1	3	3

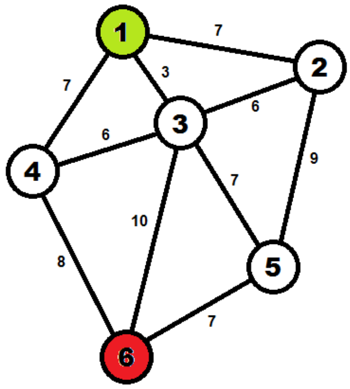

Figure 4.3 Initial network

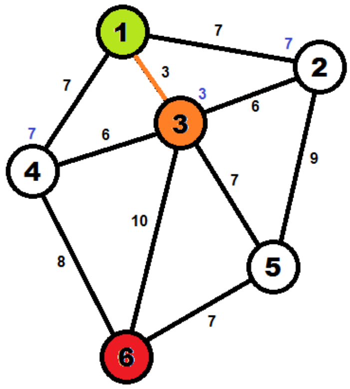

Figure 4.4 Step 1: node 3 is fixed as it has the shortest distance from the origin.

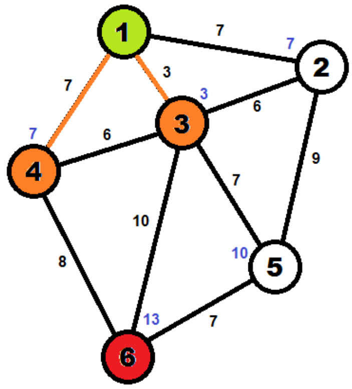

Figure 4.5 Step 2: distance for node 5 and 6 is updated. Node 4 is fixed as its current distance from the origin is the shortest of all not fixed nodes.

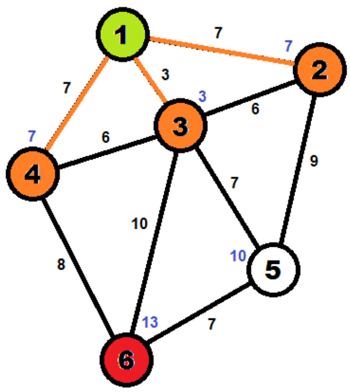

Figure 4.6 Step 3: no distances are updated as routes via node 4 do not result in shorter distances. Node 2 is fixed.

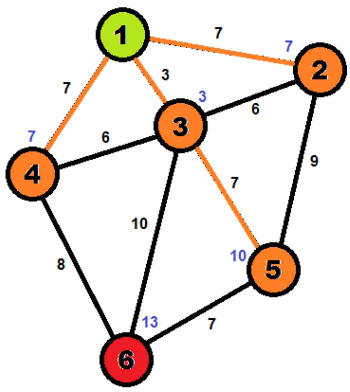

Figure 4.7 No distance updates, node 5 is fixed.

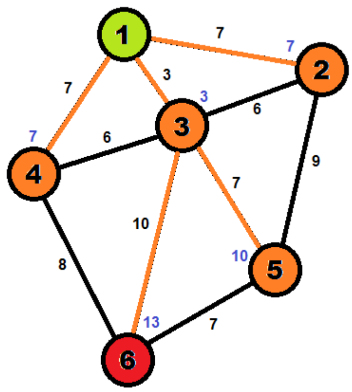

Figure 4.8 Last node is reached, which is also the destination.

4.3 Model Development

For the tactical model a distinction is made between two type of water-users. The first category are the ones that may use all of the available space. The second category are the larger boats that mainly sail through the fairway. Below the algorithms for both types are explained.

4.3.1 Shortest path through open water

To determine the shortest path through open water two steps have to be taken. First a network is generated on which the shortest path will be determined. This is done for each combination and destination individually. To illustrate the working of this algorithm the situation shown in Figure 4.9 is taken as an example, where the aim is to find the shortest route between the green origin and the red destination. Land areas are represented by the cyan polygons. Around these land areas a buffer is created to simulate the effect that nautical traffic keeps a certain distance from the shore. This buffer is represented by the magenta polygon line. For this example a network is created on which a shortest path algorithm will be performed following these steps:

1. Draw a direct line between origin and destination and create a list of nodes, including origin and destination.
2. Append convex vertices of polygons crossed by the line to the list of nodes.
3. Draw a line between each pair of nodes. Append lines that do not cross any polygon to the network.
4. Compute the shortest path using Dijkstra's algorithm with distances as link weights.

Below this process is visualised for the arbitrary origin and destination in Figure 4.9. Step 1 of the abovementioned procedure result in the yellow line between origin and destination shown in Figure 4.10. This line crosses two polygons/land areas. Following step 2, the convex vertices of these polygons shown in Figure 4.11 are appended to a list of nodes. Then links that have a clear line of sight are included in the network according to step 3. This results in the network shown in Figure 4.12. Finally, the shortest path is computed using a Python implementation of Dijkstra's algorithm which results in the path depicted by the yellow line in Figure 4.13. The output of the tactical model is the list of nodes that are part of this path, in the order of which the nodes should be visited.

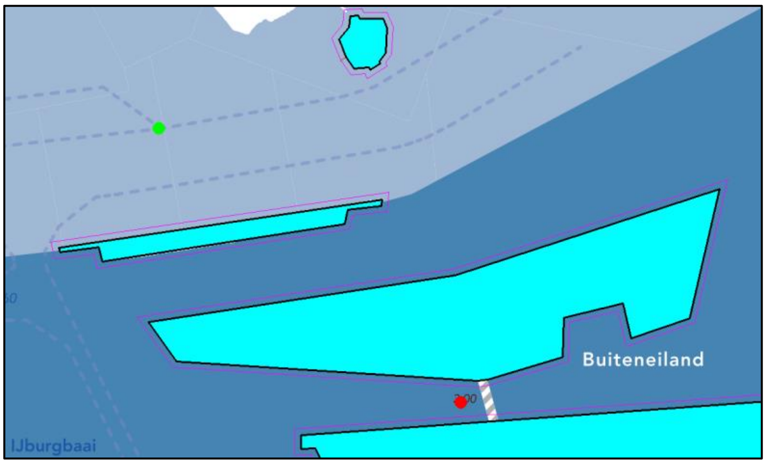

Figure 4.9 Initial situation with the input for the shortest path process: origin (green dot), destination (red dot) and buffer polygons (pink contours).

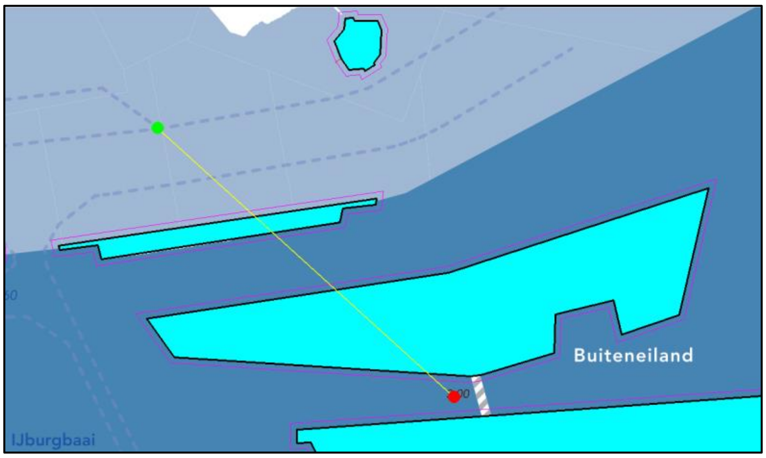

Figure 4.10 A line is drawn from origin to destination.

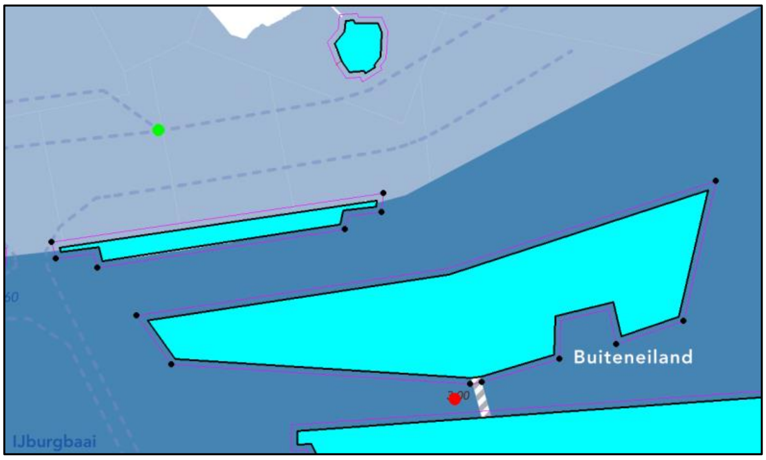

Figure 4.11 Convex vertices of polygons crossed by the line are appended to the network nodes.

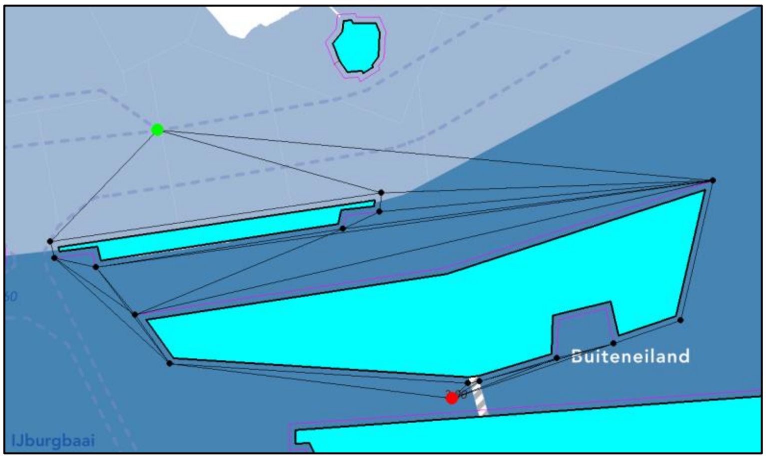

Figure 4.12 Links are appended to the network.

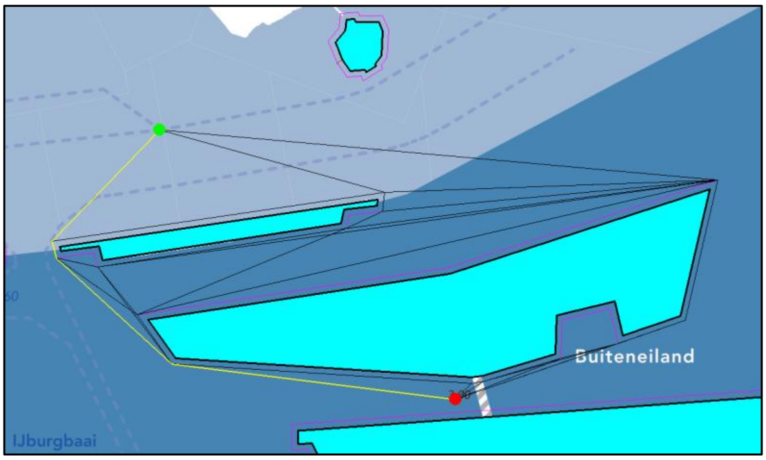

Figure 4.13 Dijkstra's algorithm is used to determine the shortest path in the network between origin and destination.

4.3.2 Shortest path through marked fairway

The algorithm for routing through the fairway is similar to the previous algorithm, but differs on one important aspect. Instead of creating a network around polygons, a network is created inside a polygon, where the polygon represents the area that is covered by the marked fairway. This mainly affects the determination of points to include in the network. As the area is much smaller, it is computationally feasible to create the network as a whole instead for each combination of origin and destination individually. The following steps are taken to find the shortest path between any origin and destination. In Figure 4.14 an example situation is shown to illustrate the below mentioned procedures.

1. Append concave polygon vertices to network. This results in the situation shown in Figure 4.15.
2. Draw a line between each pair of nodes. Append lines that do not exit the polygon to the network. This results in the network shown in Figure 4.16.
3. Compute the shortest path using Dijkstra's algorithm with distances as link weights. This results in the shortest path in Figure 4.17.

Figure 4.14 Initial situation for activities sailing through the fairway, with a buffer inside the polygon that represents the fairway.

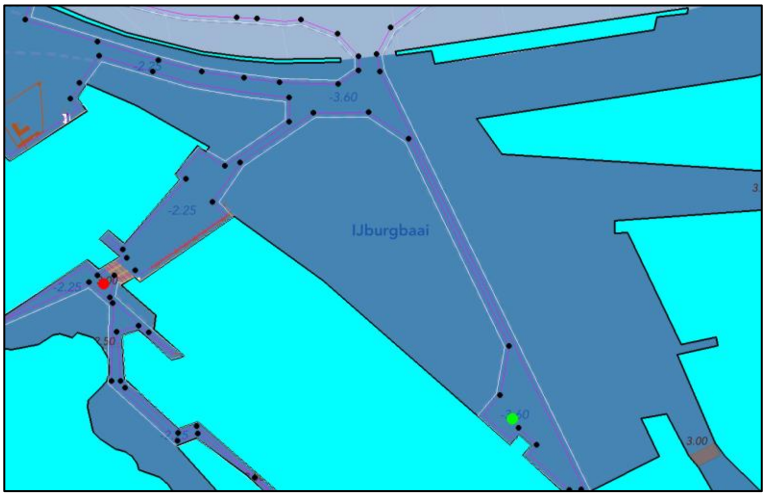

Figure 4.15 Convex polygon vertices are appended to the nodes in the network.

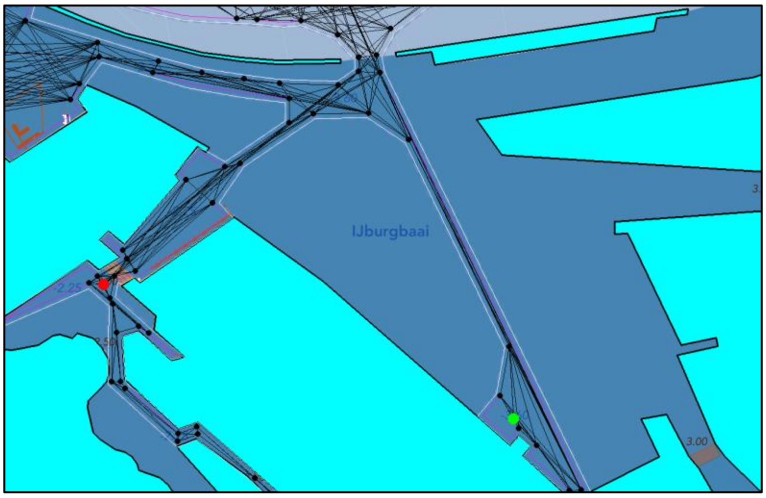

Figure 4.16 Links are created between node pairs with a clear line of sight.

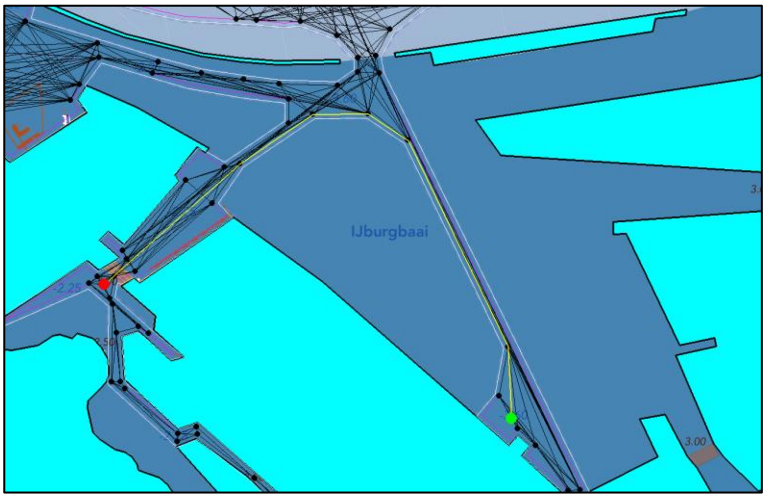

Figure 4.17 Dijkstra's algorithm is used to compute the shortest path between origin and destination on the generated network through the fairway.

4.3.3 Intermediate destinations for sailing, wind surfers and coastal rowers

Small sailing boats and wind surfers remain in the IJburgbaai during the entire duration of the activity. According to the municipality of Amsterdam their behaviour can be more or less summarised as follows:

- Sailboats depart for sailing lessons from the location of the sailing school near the lock at Haveneiland. The duration of a sailing lesson is approximately 1 hour.
- Surfers depart from the beach at Strandeiland and they will mainly surf on the east side of the fairway. When surfing their movement will mainly be parallel to the beach. First zigzagging into the direction of the wind and then trying to obtain higher speed when surfing with the wind.
- Coastal rowers currently depart from the beach at Strandeiland, but in the future most likely from a new facility near the bridge connecting Strandeiland and Centrumeiland. They will row in straight lines parallel to the beach towards the Buiten-IJ and back.

To simulate this behaviour, several areas have been defined for sailing and wind surfing as shown in Figure 4.18. Each time a sail boat or wind surfer reaches an intermediate destination and the maximum activity duration has not been reached a new intermediate destination is randomly chosen in one of the corresponding areas.

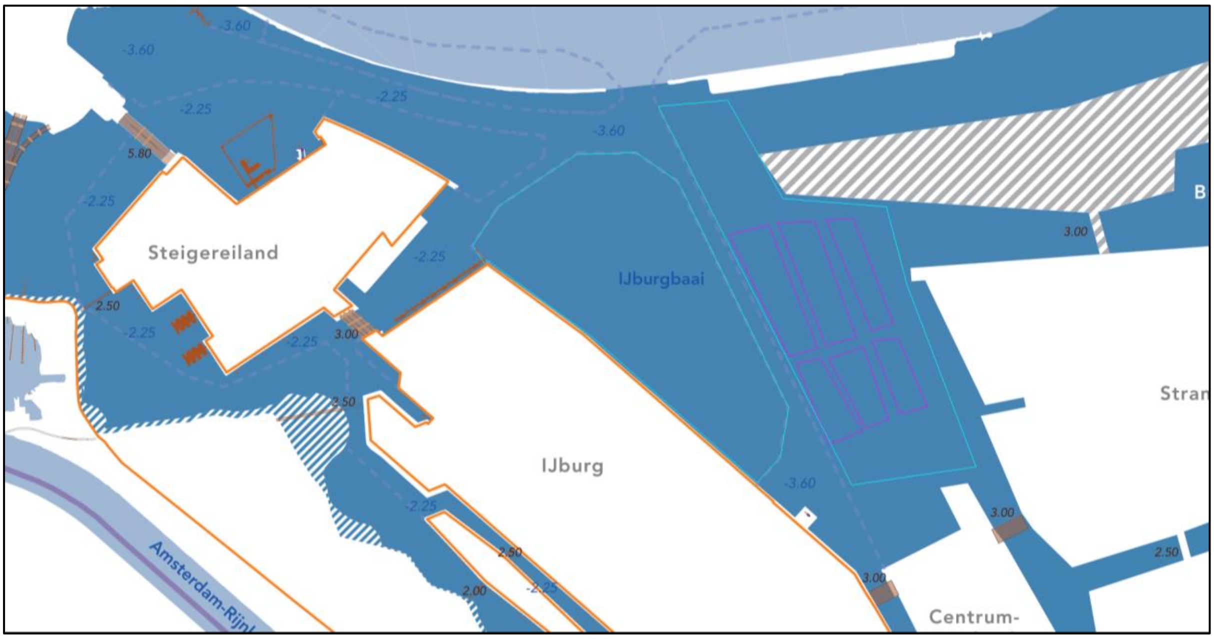

Figure 4.18 Sailing areas (cyan polygons) and wind surf / coastal rowing areas (magenta rectangles) in the IJburgbaai.

To determine the choice between the areas a choice model is used. For the choice between the areas for the small sail boats (either left or right of the fairway) it is chosen to use the logit model discussed by (Hensher & Greene, 2003). This is done to be able to vary the chance of an area chosen depending on the amount of agents in a certain area.

$$P_i = \frac{\exp(U_i)}{\sum \exp(U_j)} \quad (4.1)$$

$$U_i = \sum_{i=0}^{N} \beta_x * x_i \quad (4.2)$$

Where U_i is the utility of area i, occ_i the occupancy of area *i* expressed as the total amount of agents in the area and ca_i a binary variable that is 1 if the agent's current position is within area *i* and 0 if not.

$$U_i = -0.1 * occ_i + 3 * ca_i \quad (4.3)$$

The value of -0.1 for the taste parameter for occupancy and the 3 utils bonus for the area of an agent's current position are chosen by analysing the influence of varying these parameters on c

- If the areas are equally busy, the agent will almost certainly stay in the current area.
- The consideration of changing area of activity should occur when the difference in occupancy is of the order O(10^1).

With the chosen values an agent has a 95% chance to stay in its current area if both areas are equally busy and the probabilities for differences in occupancy as shown in Table 4.4 and a 50% chance of changing area when there are 30 agents less in the other area.

Table 4.4 Probability of switching as a result of its difference in occupancy with the other area based on the difference between utility of the current area and the other area with positive difference representing a higher utility for the other area and negative difference representing a higher utility for the current area

d_occ [# agents]	dU_ca [utils]	P_switch
-90	+6	100%
-80	+5	99%
-70	+4	98%
-60	+3	95%
-50	+2	88%
-40	+1	73%
-30	0	50%
-20	-1	27%
-10	-2	12%
0	-3	5%
10	-4	2%
20	-5	1%
30	-6	0%

For wind surfers and coastal rowers the probabilities of choosing another depending on the current area have been fixed for each possible current position of an agent. Therefore, the choice is independent of the amount of agents in an area. This is done because the main objective is to simulate the movement parallel to the beach and the majority of surfers and coastal rowers will most certainly stay in the area near the beach.

Wind surfers and coastal rowers move in straight lines between one of the three lower areas to one of the three higher areas and vice versa. To simulate that they mainly move parallel with respect to the beach the chance of choosing the area in extension of the agent's current area is fixed to 90%. This means that when an agent is in area 1, as shown in Figure 4.19, it has a 90% chance of picking a random point inside area 4 as its next destination. The same is set for the combination of area 2 with area 5 and area 3 with 6. The chance of 10% for not choosing the preferred area is assigned to the area(s) next to the preferred area. When a wind surfer or coastal rowing boat enters the simulation the chance is 1/6 for all areas. In Table 4.5 an overview of all probabilities is provided.

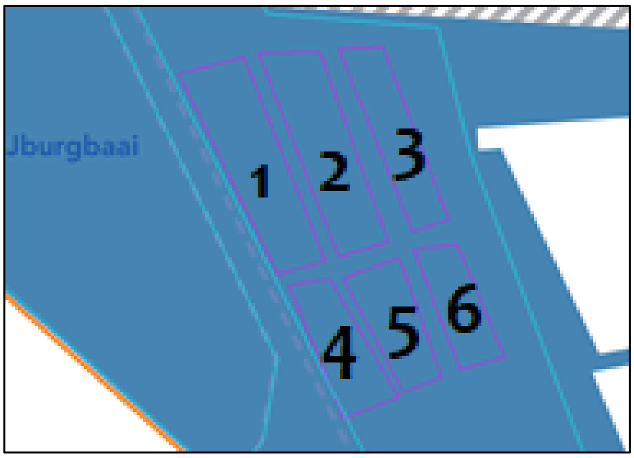

Figure 4.19 Wind surf and coastal rowing areas.

Table 4.5 Area choice probabilities for wind surfers and coastal rowers

Current area	1	2	3	4	5	6
1	0%	0%	0%	90%	10%	0%
2	0%	0%	0%	5%	90%	5%
3	0%	0%	0%	0%	10%	90%
4	90%	10%	0%	0%	0%	0%
5	5%	90%	5%	0%	0%	0%
6	0%	10%	90%	0%	0%	0%
None of the above	17%	17%	17%	17%	17%	17%

5 OPERATIONAL MODEL

In this chapter the operational model is presented. First, a more thorough analysis of the movement behaviour of the different activities is made that should be captured by the operational level of the model in Section 5.1. Then, in Section 5.2 the structure of the grid for the model is determined and in Section 5.3 the development of the operational model is discussed.

5.1 MOVEMENT BEHAVIOUR OF ACTIVITIES

In this section the behaviour of the activities that should be captured by the operational model is described. In the tactical level intermediate destinations of agents in the IJburgbaai are determined. The aim of the operational level is to simulate the movement behaviour of the agents from their current position towards the next (intermediate) destination. This behaviour consists of the following components:

- Interactions with other agents
- Influence of the wind
- Speed

5.1.1 Interactions with other agents

Activities want to keep a certain distance towards others. The amount of distance is dependent on the size and speed of both the own vessel as well as the vessel that is to be avoided. Canoes, kayaks and sups are small and have a low speed and stay relatively close to each other while they keep more distance from larger motorboats.

Another aspect that should be included in the model is that oncoming traffic prefer to pass each other on the right side. This is especially an important factor to include for traffic through the fairway, because the flow there is mainly bidirectional.

5.1.2 Influence of wind

Wind is a huge influencing factor on the behaviour of sailing boats and wind surfers. The influence of the wind can be subdivided into two components: wind speed and wind direction. For sailing a minimum wind speed of 5 knots (~10 km/h) is required. Sailing at wind speeds above 20 (~40 km/h) is considered to be dangerous. Furthermore, wind speed determines the maximum speeds that can be reached. In general, the more wind the faster someone can sail.

The direction of the wind determines in what direction surfers and sail boats can sail. Sailing directly in the direction of the wind is not possible. Sailing with the direction of the wind is in theory possible, but in practice avoided as well due to safety issues involved with an increased instability of a sailboat at downwind sailing (Plumet, et al., 2015). Therefore, sailing boats sail with an angle with the wind direction between 45° and 150° as can be seen in Figure 5.1. When a sailing boat wants to reach a destination that is in the direction of one of the two no-go zones, the sailboat will zigzag by continuously switching sailing direction into one of the two operational areas.

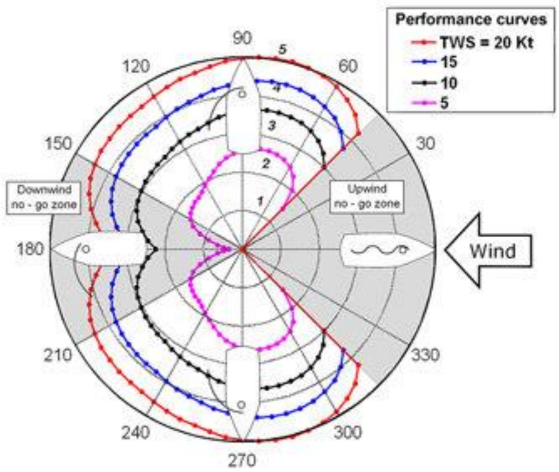

Figure 5.1 Polar diagram for a sail boat with an indication of achievable speeds based on wind speed and direction. (Plumet, et al., 2015)

Sailing boats achieve the highest speeds when sailing slightly in the direction of the wind. However, the differences with the other directions in the operational area are not that large. For wind surfers the operational wind speed area ranges from 3 to 30 knots (6 – 60 km/h). Wind surfers achieve their highest speed when surfing into the direction 120-150° from wind direction.

The movement of large sailing ships is also influenced by the wind. However, this is only the case when they sail on the IJmeer. In the IJburgbaai they only sail through the fairway towards the Buiten-IJ. If the wind conditions are unfavourable they will still sail in a straight line through the fairway using an on-board motor.

5.1.3 Speed

The activities in the IJburgbaai all have their own speed range in which they operate. Wind surfers can reach very high speeds compared to canoes and rowing boats. In an agent-based model, speed differences between agents can be modelled by either varying the range (amount of cells) an agent can travel per time step or by varying the interval between two subsequent movements of agents.

The main disadvantage of the first approach is that when determining the cell choice of an agent the state of more cells should be considered which increases the complexity of the model.

In the IJburgbaai the speed of motorboats and sailing ships is restricted by the speed limit of 20 km/h. In a research on classification of recreational boat types (Pelot & Wu, 2007) found a mean speed of 14.3 km/h for recreational motorboats, 7.4 km/h for sailboats, 3.2 km/h for canoes and 3.9 km/h for kayaks. For recreational boating in sloops often a speed of 7 km/h is assumed for trip planning purposes.[3]

As previously discussed, the speed of sailboats is dependent on the wind conditions. Under ideal conditions cruising speeds are approximately between 7 and 11 km/h for small sailboats and between 11 to 14.5 km/h for larger sailboats[4].

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[3] https://www.sloepennetwerk.nl/

[4] https://improvesailing.com

For recreational rowers, the speed that can comfortably be maintained for longer periods of time is around 5 km/h[5]. Wind surfers can obtain speeds between 20 and 30 knots[6] when sailing into the optimal direction, which corresponds to a range from 37 to 55 km/h.

5.2 Space Discretization

As discussed in Section 3.2.2 the IJburgbaai should be discretised into a number of cells for the operational level of the model. For this space discretization cell type and cell size should be determined. (Nitzsche, 2013) identifies three type of regular grid structures that have been used for rule-based pedestrian modelling. These are a triangular grid, a rectangular grid and a hexagonal grid as shown in Figure 5.2.

The most important factor to consider in the selection of a grid is that the available cells for position choice of an agent are sufficient to model the general movement behaviour of the activities. As discussed in the previous section, sailboats and wind surfers cannot sail directly into the wind and also downwind is not preferred. Therefore, it is important that an agent has a diagonal option compared to the wind direction to be able to reach an upwind destination by zigzagging through the water. The three and four choice options that are provided by a triangular and rectangular grid are therefore not sufficient. E.g. if the wind comes from the north, wind surfers should in a model with a rectangular grid only be able to move towards west, east or south, while northwest and northeast are also options that are required to be able to simulate upwind surfing.

This problem can be solved by also including cells that only share a corner in the process of determining the next position of an agent. This results in the case that the distances towards the options are different and it is therefore more difficult to model speed of the agents. Furthermore, the hexagonal grid is able to provide sufficient options with a smaller choice set and results therefore in a less complex model. Therefore, it is concluded that a hexagonal grid structure is the best option for the IJburgbaai model as it provides enough options to simulate that surfers and sailboats cannot sail directly into the direction of the wind while remaining equal distances towards each neighbouring cell and not increasing the amount of cells unnecessarily.

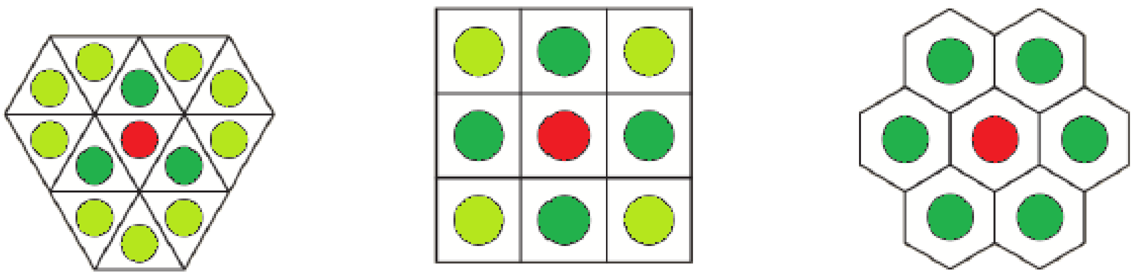


Figure 5.2 Three different grid structures. The red agent's possible next positions are indicated for the case only cells that share a side are considered as neighbouring cells (dark green) and for the case cells that share a corner are also included (light green) (Nitzsche, 2013).

[5] https://en.wikipedia.org/wiki/Rowing
[6] https://www.quora.com/How-fast-can-a-windsurfer-go

A distance between the cell centres of 15 metres is chosen. This is around the average ship domain of a recreational motorboat or sailboat (Rijkswaterstaat, 2011). Furthermore, the grid is slightly rotated, such that 4 lanes in the main part of the fairway are formed. This increased the realism of modelling the behaviour of vessels from the south of the IJburgbaai towards the Buiten-IJ through the fairway, which is an expected busy connection and possible cause for multiple conflicts as discussed in Section 2.4. This results in a grid from which the location of the cell centres are shown in Figure 5.3, where a distinction in colours is made for cells that are not part of the IJburgbaai (red), cell centres in the fairway (light blue) and cells outside the fairway (dark blue).

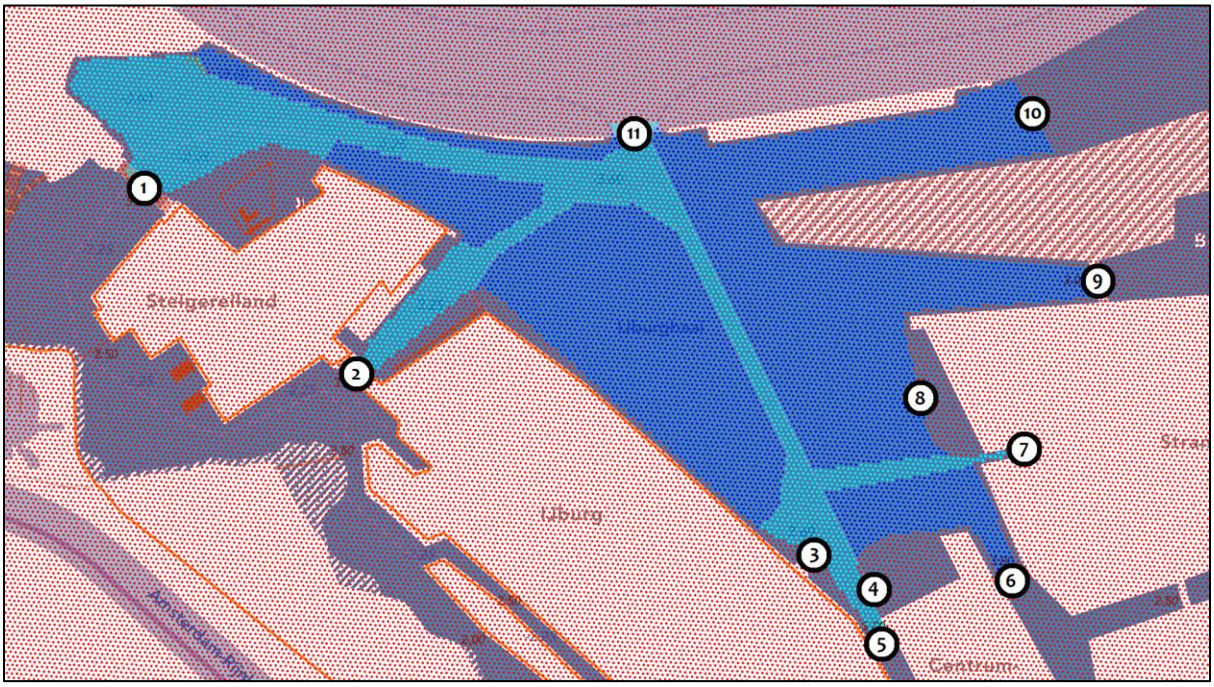


Figure 5.3 Location of cell centres in the IJburgbaai for a slightly rotated hexagonal grid and 15 m cell size.

5.3 Model Development

In this section it the development of the operational model will be discussed.

5.3.1 Agent Generation

The operational model starts by generating agents from a given set of OD matrices. For each activity an OD matrix should be provided for a certain amount of periods. For now, distinguishing four periods of 3 hours is sufficient to be able to determine different scenarios for the IJburgbaai. These periods are:

Morning	09:00 – 12:00
Early Afternoon	12:00 – 15:00
Late Afternoon	15:00 – 18:00
Evening	18:00 – 21:00

For each agent some characteristics should be generated. Firstly, a random moment is selected for the exact moment the agent enters the simulation. This moment is within the time period corresponding to the OD matrix and is a multiple of the size of the time step in the simulation. Furthermore, the origin, destination and the path the agents should follow is stored. For agents for which the origin is the destination the first intermediate location is determined and added to the path according to the procedure described in Chapter 4.

5.3.2 Update Interval and Time Step

Once an agent enters the simulation the agent is appended to a list of active agents. For each active agent its position should be updated after a certain amount of time. The interval between two successive position updates is determined based on the speed of the agent, which is in turn dependent on the agent's activity.

The size of the time step in the simulation determines the amount of detail in which differences in speed can be modelled. With a small time step smaller speed differences can be modelled. However, this also means that the total simulation time will increase. Another aspect that determines the speeds that can be modelled is the cell size, which is 15 m. This means that the required update interval t_{int} (in seconds) to model a certain speed V (in km/h) can be computed according to Equation 5.1.

$$t_{int} = \frac{s}{V} = \frac{15}{V} \left[\frac{m}{s}\right] = \frac{54}{V}\left[\frac{km}{h}\right] \qquad (5.1)$$

In Section 5.1.3 the speeds of the activities in the IJburgbaai were approximated. These are listed in the first column of Table 5.1. The speeds of most activities can be nicely approximated by an update interval of a multiple of 4 seconds. This can only not capture the speeds wind surfers can obtain when sailing downwind. To model those speeds an update interval of around 1-2 seconds is required. An interval of 2 seconds is chosen, because the mentioned speed of 35-55 km/h is the range for the maximum speed that can be reached. As the wind surfers also have to accelerate and decelerate the average will be lower.

Table 5.1 Approximate speed, update interval and simulated speed for activities in the IJburgbaai.

Activity	Speed [km/h]	Chosen update interval [s]	Corresponding speed [km/h]
Large Motorboats	~ 14	4.0	13.5
Small Motorboats	~ 7	8.0	6.8
Large sailing boats	~ 7	8.0	6.8
Small sailing boats	~ 5	12.0	4.5
Wind surfers	downwind: 35 - 55 upwind: 5	downwind: 2.0 upwind: 16.0	27.0 3.4
Coastal Rowing	4-6	12.0	4.5
Canoes/Kayaks/SUPs	3-4	16.0	3.4

5.3.3 Choice Set Generation

Initially, all six surrounding cells in the hexagonal grid are appended to the choice set. Then, some cells might be removed from this choice set. This is done if a cell meets one of the following three criteria:

1. The cell is marked as inaccessible as it resembles land or water outside the modelled area.
2. The occupancy of the cell would exceed the maximum allowable occupancy of a cell if the cell is chosen by the agent.
3. The choice for the cell would mean that the agent is sailing upwind and the activity of the agent is either windsurfing or sailing in a small sailing boat.

The first criteria is quite straightforward. For the second criteria, it should be defined how many agents of a certain activity should be allowed inside one cell. This amount is translated into an occupancy factor. As the cell size is determined based on the area required by large motor- and sailing boats the occupancy factor of agents in category of SB1 and MB1 is 1. For small motorboats an occupancy factor of 0.5 is taken.

For canoes the distance between themselves is less important. However, they prefer to stay away from motorised nautical traffic. The other water sports move slightly faster and do therefore prefer some more distance. To roughly simulate the described behaviour the occupancy factors presented in Table 5.2 are used in the model.

Table 5.2 Occupancy factor per activity in the IJburgbaai.

Activity	Occupancy Factor
Large motorboats	1.0
Small motorboats	1.0
Large sailing boats	1.0
Small sailing boats	0.4
Wind surfing	0.5
Coastal rowing	0.5
Canoe/Kayak/SUP	0.2

The influence of the wind is modelled by excluding certain cells from the choice set. As can be seen in Figure 5.4 the area with an angle of ± 45° with the wind direction is part of the no go zone for upwind sailing.

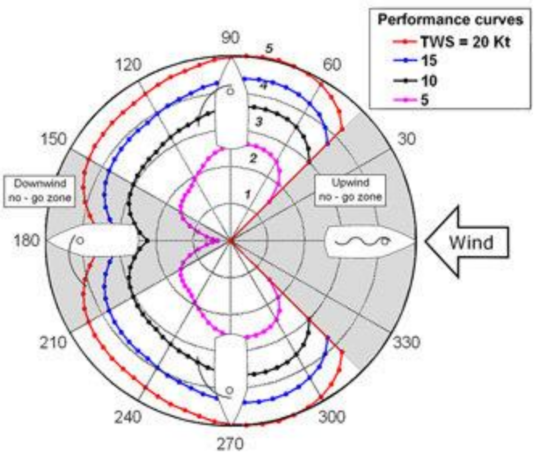


Figure 5.4 Performance curve of a sailboat.

It is chosen to only exclude cells that are entirely in a no-go zone. For upwind sailing this means that cells are excluded if the difference between direction towards a cell and the wind direction is less than 30°. This excludes an area of 60°.

If for an agent all surrounding cells are excluded from the choice set due to either one of these three criteria, the choice set will be empty and the agent will remain in the current cell.

5.3.4 Update order

The update order is determined by the order of priority. In general wind propelled vessels (sailing boats, surfers) have priority over muscle propelled vessels (rowing boats/canoes) which have priority over motor powered vessels.[7] Furthermore, large vessels have priority over smaller vessels. In the model this is implemented by first updating the positions of the vessels that travel through the fairway. Combined with the wind-muscle-motor order the following order in which the positions of agents in updated has been determined:

1. SB1 – (Large) sailboats through the fairway
2. MB1 – (Large) motorboats through the fairway
3. SB2 – Small sailboats
4. SF – Wind surfers
5. RW – Rowing boats
6. CN – Canoes/Kayaks/SUPs
7. MB2 – Small Motorboats and sloops

The order of agents in the same category is randomly determined at each time step.

5.3.5 Cell Choice

To determine the next position of an agent in the simulation, a choice model is required. The most common way to model discrete choices in transport models is by using the logit model. In a logit model the choice between options in a discrete choice set is expressed as a probability determined based on the utility of the options. This utility of an option is computed using choice specific attributes as shown by Equation 5.1 from which the choice probability is computed using Equation 5.2 (Hensher & Greene, 2003).

$$U_i = \sum_{i=0}^{N} \beta_x * x_i \tag{5.2}$$

$$P_i = \frac{\exp(U_i)}{\sum \exp(U_j)} \tag{5.3}$$

In these expressions U_i is the utility of cell *i*, β_x the taste parameter (weight factor) of attribute *x* and x_i the value of attribute *x* for choice *i*. The probability of choosing option *i*, P_i, is computed by taking the ratio of the exponent of the utility of *i* and the sum of the exponents of the utility for all options in the choice set.

The most important parameter that influences cell choice is the direction of the next intermediate destination. To simulate this, the difference between the preferred direction and the direction towards a cell in the choice set is included as an attribute in the utility function. To determine an appropriate weight factor for this attribute the two most extreme cases are analysed, which are shown in Figure 5.5. These cases correspond to the situation in which the preferred direction lies exactly between two cells and the situation in which the preferred direction is exactly into the direction of a cell centre.

[7] https://varendoejesamen.nl/kenniscentrum/artikel/de-5-belangrijkste-vaarregels

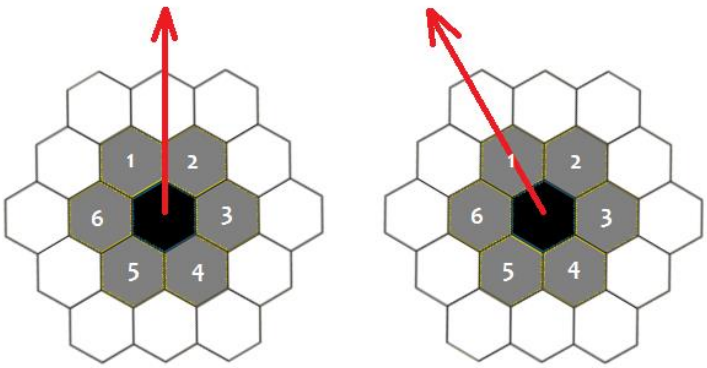


Figure 5.5 Two most extreme scenarios of the preferred direction w.r.t. the cell choice options.

Starting point of the estimation is that when neglecting all other influences, the probability of choosing either cell 1 or cell 2 in the left situation and choosing cell 1 in the right situation is at least 90%. This makes sure that vessels can deviate from their initial path, but that they still roughly follow a straight line without too much deviations when no other traffic is present. Using this approach a factor of -0.1 times the difference in the angle (in degrees) has been determined as the basis for the utility of a cell.

Furthermore, the behaviour of agents sailing through the fairway should be captured by the model. The two most important components that the model should simulate are:

- Keeping to the right side of the fairway
- Preference for cells inside the fairway

To simulate these components utility bonuses are awarded to cells in the choice set of agent with a preference for travelling through the fairway

The value with which the utility of the cell directly at the right from the cell is determined by visually inspecting the behaviour of agents inside the fairway in the simulation.

- The bonus for fairway cells should be sufficiently large such that under normal conditions (no overcrowding) agents with a preference for the fairway do never leave the fairway.
- The bonus for the cell directly right from the cell in ideal direction should be sufficiently large to direct agents coming from the lock at Haveneiland to the right side of the fairway as shown in Figure 5.6.
- The bonus for the cell directly right from the cell in ideal direction should not be so large that agents take unnecessary detours at for example the north entrance of the bay or when traversing the fairway towards the marina at Centrumeiland, as shown in Figure 5.7 and Figure 5.8 respectively.

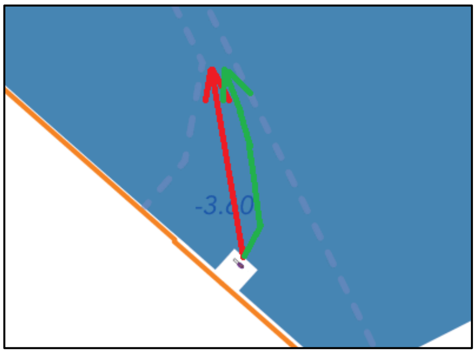


Figure 5.6 Preferred and undesired trajectories of agents departing at marina Haveneiland.

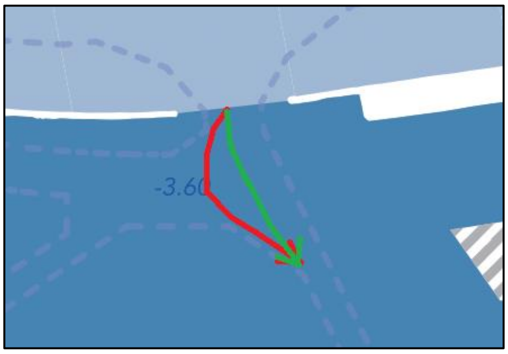


Figure 5.7 Preferred and undesired trajectories of agents entering the IJburgbaai from the Buiten-IJ.

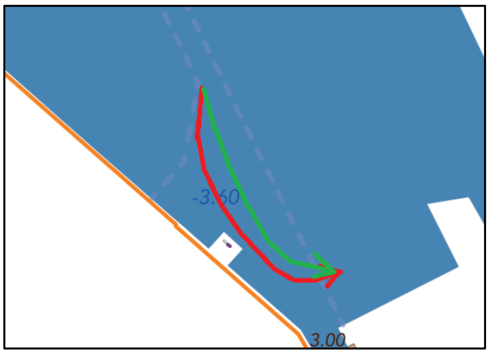


Figure 5.8 Preferred and undesired trajectories of agents traversing the fairway towards marina Centrumeiland.

By trial-and-error it is determined that a value of 4 utils for the bonus of the cell right from the cell into the direction of the next destination is ideal to avoid all the undesired trajectories from Figure 5.6, Figure 5.7 and Figure 5.8. Furthermore, a value of 10 utils for the bonus for fairway cells shows to be sufficiently large to avoid agents leaving the fairway under normal conditions.

Agents that do not necessarily travel through the fairway do not have a penalty for fairway cells. The main reason for this is that this results in unrealistic movement of agents at the points where the fairway has to be crossed. Furthermore, the paths that were obtained from the tactical model do not travel unnecessarily long through the fairway.

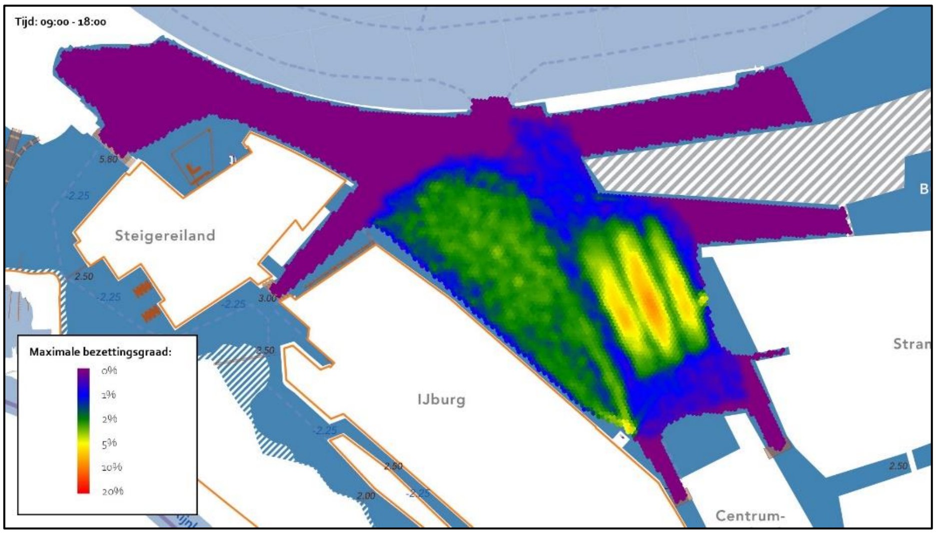
5.3.6 Model Output

The preferred output of the model are the density in the different areas and some measure for the amount of conflicts. The density is represented by the occupancy of the cells. The occupancy of a cell is determined by summing the occupancy factors of all agents at a certain time step. (e.g. if a cell is occupied by a motorboat, its occupancy is 100%. If a cell is occupied by a canoe and a small sailing boats, its occupancy is 0.2+0.4 = 60%). The average occupancy of cells is stored with a temporal resolution of 15 minutes. Therefore, for each given time frame during the day the average of each cell can be obtained as well as the average during the most busy 15 minutes.

For both occupancy and conflicts the final value assigned to a cell is the average of the cell and its six neighbouring cells. This data is stored as a matrix in a csv file from which values in certain areas in the bay can be analysed. Furthermore, some plots are saved for easy visual interpretation of the results. The occupancy at which conflicts might occur is highly dependent on the speed of vessels. At slow speeds it is relatively safe for vessels to remain close to each other. When cruising over 11 km/h often a safety distance of approximately 30 m is recommended.[8] Taking this as a basis for the definition of the colour scale in the occupancy plots the colours in the example in Figure 5.9 is based on the distance between agents and the corresponding occupancy shown in Table 5.3 Average cell occupancy of an area based on the distance between two agents (with an occupancy factor of 1).

Table 5.3 Average cell occupancy of an area based on the distance between two agents (with an occupancy factor of 1).

Distance towards nearest agent	Corresponding occupancy
< 15 m	> 14%
15-30 m	5-14%
> 30 m	< 5%



[8] https://transportsafety.vic.gov.au/maritime-safety/recreational-boating/safe-operation/operating-rules/speed-and-distance

Figure 5.9 Examples of a generated plot showing maximum occupancy of cells in a scenario with only small sailing boats and wind surfers.

A conflict is defined as the situation in which the total occupancy of a cluster of 7 cells is above 1. This means that a distance of 15 m is not preserved and some dangerous situations might occur. Similar to the occupancy the amount of conflicts is summed over 15 minutes and averaged over a cell and its neighbours. Lastly the value is adjusted to display the amount of conflicts per hour. An example of a map with conflicts is shown in Figure 5.10.

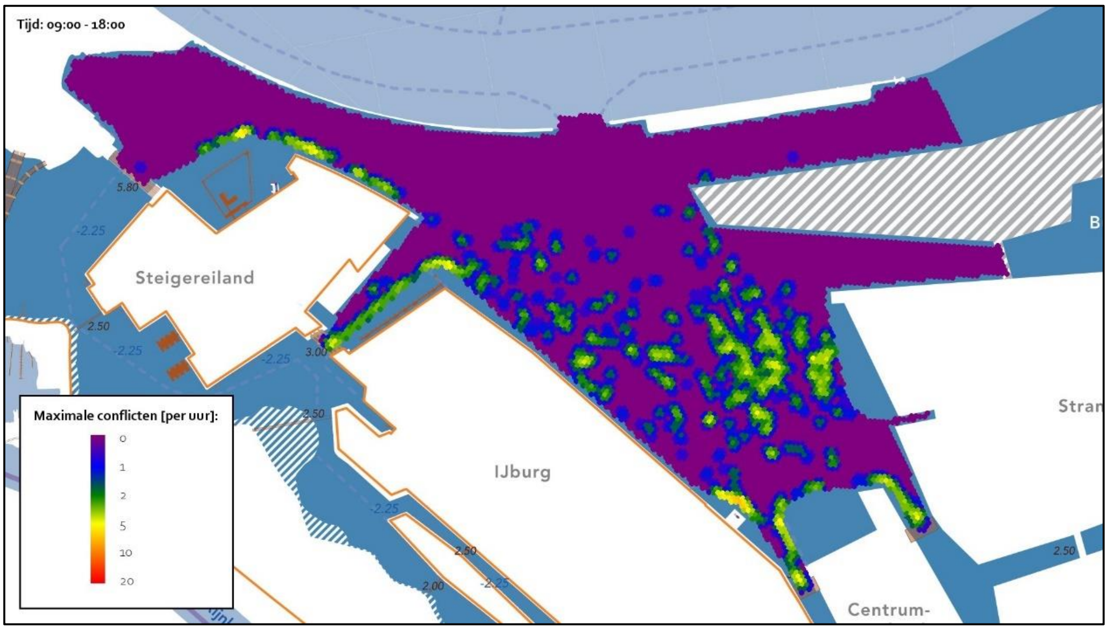


Figure 5.10 Map with conflicts for a scenario with small motorboats and canoes/kayaks/SUPs (used during validation of the model).

6 MODEL VALIDATION

To validate the working of the model, the output of the model should be compared to real life situations. However, due to a lack of data for the research area and the fact that the model is mainly constructed to simulate future scenarios (in the current situation no conflicts occur in the IJburgbaai), the best way to validate the model is by designing certain scenarios for which experts expect conflicts at certain locations of the area and then check whether this expectation is represented by the model.

6.1.1 Validation A: Traffic flow through the fairway

The first validation is done on the behaviour of sailboats and motorboats through the fairway by varying the amount of vessels departing from the four marinas. The goal is to check if the model accurately resembles expected effects on occupancy and amount of conflicts. Together with an expert on nautical traffic from the municipality of Amsterdam three main influencing factors on the amount of conflicts have been determined. These factors and their expected impact are as follows:

1. *A mixture of different types of activities* – causes more conflicts due to speed differences and thus overtaking manoeuvres.
2. *More activities* – result in a higher density of activities and therefore more conflicts.
3. *Merging and diverging of flows* – results in more conflicts.

A base scenario with 100 motorboats and 100 sailboats departing and arriving from each marina is created. Furthermore, 5 scenarios are designed to test the above mentioned effects. For each scenario a sail-out percentage of 50% is used and the amount of sailboats and motorboats in the marinas is varied as shown in Table 6.1. For each scenario a medium windy weekend day in the summer is simulated such that the demand multiplication factor is 1 for both motorboats and sailboats.

Table 6.1 Scenarios for Validation 1 with sailboats / motorboats per marina and sail-out fraction of 50%.

	Scenario 1	**Scenario 2**	**Scenario 3**
Marina Haveneiland	100 / 100	200 / 0	0 / 200
Marina Centrumeiland	100 / 100	200 / 0	0 / 200
Marina Strandeiland	100 / 100	200 / 0	0 / 200
Marina Zeeburgereiland	100 / 100	200 / 0	0 / 200
	Scenario 4	**Scenario 5**	**Scenario 6**
Marina Haveneiland	133 / 133	0 / 0	100 / 100
Marina Centrumeiland	133 / 133	300 / 300	100 / 100
Marina Strandeiland	133 / 133	0 / 0	100 / 100
Marina Zeeburgereiland	0 / 0	100 / 100	0 / 0

For each scenario the occupancy of the cells and the amount of conflicts is analysed for two areas as shown in Figure 6.1. These areas correspond to the locations where the flows through the fairway merge and diverge, one in the northern part of the bay and one in the southern part.

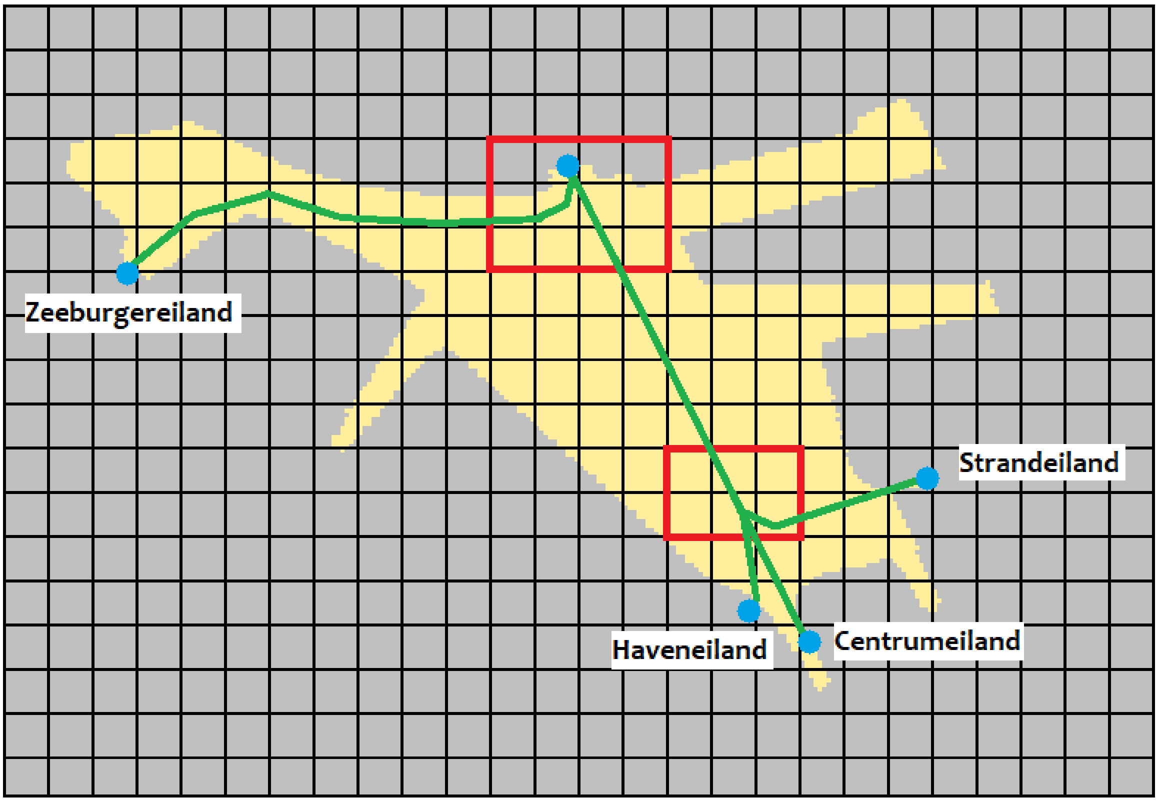


Figure 6.1 The paths through the fairway from the marinas and the analyzed areas for validation A.

The aim of scenario 2 and scenario 3 is to validate the effect of the mixture of different activities which introduces a speed difference between activities and overtaking manoeuvres. It is expected that a mixture of vessel types results in an increase of conflicts. However, in scenario 2, only sailboats are part of the simulation. The speed of sailboats is lower than motorboats, thus with the same amount of vessels the distances between the vessels will in general be smaller which should have a positive effect on the amount of conflicts.

Scenario 4, 5 and 6 are designed to validate the effects of merging and diverging flows. In scenario 1 flows merge in both areas of interest. In scenario 4 and 6 one of the flows (from and towards the marina at Zeeburgereiland) affecting the northern area is removed. In scenario 4 the trips from and towards the marina at Zeeburgereiland is redistributed over the other marinas such that the total amount of trips remains the same. For scenario 6 this has not been done and thus the flow towards the southern area is not effected.

Scenario 5 removes merging and diverging flows in the southern area by letting all vessels from the marinas at Haveneiland, Centrumeiland and Strandeiland in scenario 1 depart from Centrumeiland.

Due to the variation in flows between the scenarios, the following output is expected compared to the output of scenario 1:

- Scenario 2: Increase in occupancy due to lower average speed, relative to occupancy less conflicts due to lack of speed differences between vessels.
- Scenario 3: Decrease in occupancy due to higher average speed, decrease in conflicts due to lack of speed differences between vessels.
- Scenario 4: More conflicts and higher occupancy in southern area due to increased amount of traffic from and towards this area. Possibly less conflicts in the northern area as there

is no merging/diverging with the flows from Zeeburgereiland. However, the fact that more vessels want to go through the (relative narrow) fairway may also have a contrary effect.

- Scenario 5: Equal occupancies in both areas and equal conflicts in the northern area. For the southern area less conflicts might occur However, the fact that the amount of trips from and towards the marina at Centrumeiland has tripled might induce new conflicts.
- Scenario 6: Less conflicts and density in the northern area. Equal conflicts in the southern area.

As the simulation includes some randomness, the output varies between different runs. To be able to determine whether the changes have a significant effect the number of runs should meet the condition set by Equation 7.1 (Hoad, et al., 2007).

$$n \geq \left(\frac{Z_{\frac{\alpha}{2}}}{d} * \sigma \right)^2 \qquad (7.1)$$

Where n is the number of runs, $Z_{\alpha/2}$ the Z-score (1.96 for $\alpha = 0.05$), d the desired accuracy and σ the standard deviation between the different runs. Often d is taken to be 10% of the average outcome of all runs and is therefore also done for this validation. For each scenario the average and maximum for both occupation and amount of conflicts is determined for each cell. Then the 95th percentile of both areas of interest is taken as the indicator to determine differences between the scenarios. This parameter is also used to determine whether the amount of runs had been sufficient.

For each scenario initially two runs where simulated. Then, additional runs where done if required until for each output parameter the requirement set in Equation 7.1 was. In Appendix A the results of all runs can be found and in Table 6.2 and Table 6.3 the average of all runs per scenario are presented for the northern and southern area. In Table 6.4 the output of scenarios 2-6 are compared to the output of scenario 1, which is useful to determine whether a change in conflicts is purely a result of a change in occupancy or if other scenario specific factors are also influential.

Table 6.2 Average output for Validation A scenarios in the northern area of interest.

	# runs	Average occupation [%]	Maximum occupation [%]	Average conflicts [# per hour]	Maximum conflicts [# per hour]
Scenario A-1	5	1.42	4.60	1.00	8.34
Scenario A-2	4	1.81	6.13	1.16	9.08
Scenario A-3	14	0.91	3.01	0.63	6.49
Scenario A-4	5	1.79	5.54	1.65	11.72
Scenario A-5	2	1.40	4.61	1.15	9.71
Scenario A-6	4	1.39	4.57	1.03	8.57

Table 6.3 Average output for Validation A scenarios in the southern area of interest.

	# runs	Average occupation [%]	Maximum occupation [%]	Average conflicts [# per hour]	Maximum conflicts [# per hour]
Scenario A-1	5	1.43	4.70	1.02	9.03
Scenario A-2	4	1.84	5.96	1.15	9.29
Scenario A-3	14	0.90	3.06	0.55	6.29
Scenario A-4	5	1.83	5.87	1.78	12.35

Scenario A-5	2	1.43	4.26	1.14	9.14
Scenario A-6	4	1.42	4.79	1.06	9.86

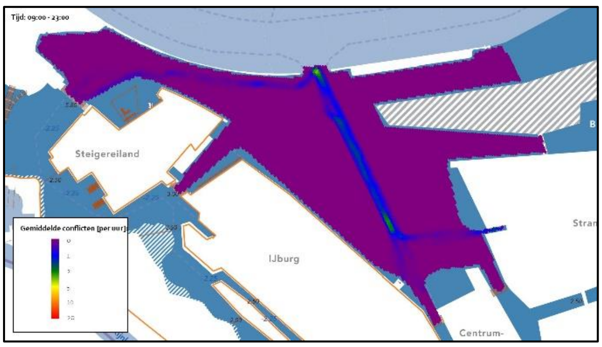
Table 6.4 Comparison of output for scenario 2-6 with scenario 1.

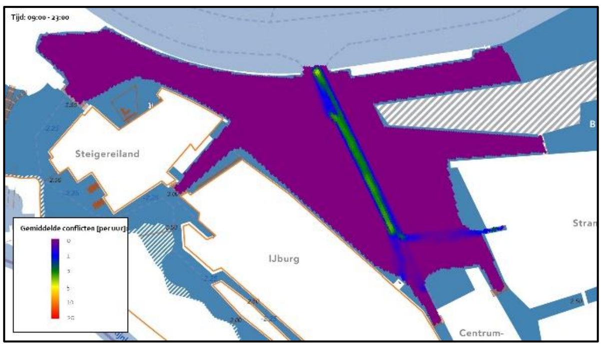
	Average occupancy [%]	**Maximum occupancy [%]**	**Average conflicts [# per hour]**	**Maximum conflicts [# per hour]**
Scenario 2 North	+27%	+33%	+16%	+9%
Scenario 2 South	+29%	+27%	+13%	+3%
Scenario 3 North	-36%	-35%	-37%	-22%
Scenario 3 South	-37%	-35%	-46%	-30%
Scenario 4 North	+26%	+20%	+65%	+41%
Scenario 4 South	+28%	+25%	+75%	+37%
Scenario 5 North	-1%	+0%	+15%	+16%
Scenario 5 South	+0%	-9%	+12%	+1%
Scenario 6 North	-2%	-1%	+3%	+3%
Scenario 6 South	-1%	+2%	+4%	+9%

The expectation was that scenario 2 and scenario 3 had (relatively) less conflicts than scenario 1. In scenario 3 this effect can clearly be seen. Both occupancy (due to higher average speeds) and conflicts (due to a lack of overtaking manoeuvres) decrease. It cannot be determined though to what extent the reduction of conflicts is caused by the reduction in occupancy and what proportion is caused by the uniformity in type of agents.

Due to the decrease in average speed the occupancy increases for scenario 2 with approximately 30%. The increase in conflicts is however only around 15% on average and 5% for the worst period of the day. When comparing this with scenario 4, which has a slightly less increase in occupancy, it can be seen that for scenario 4 the amount of conflicts increases a lot more.

In scenario 4 the flow does not merge/diverge in the northern part, but more traffic is going through the north-south fairway. According to the model output in both the northern as the southern area the density and amount of conflicts increase. For the southern area this is as expected. For the northern part it is a slightly more surprising outcome. To better understand what is happening the visual output of the model results is inspected. In Figure 6.2 and Figure 6.3 it seems that for scenario 4 more conflicts are caused because agents coming from the southern part of the bay all want to exit the bay at the right part of the passage, whereas for the scenario with the flow from the Zeeburgerbaai, this flow more or less exits the bay through the middle of the passage. Thus the flows do not really interfere in the model.





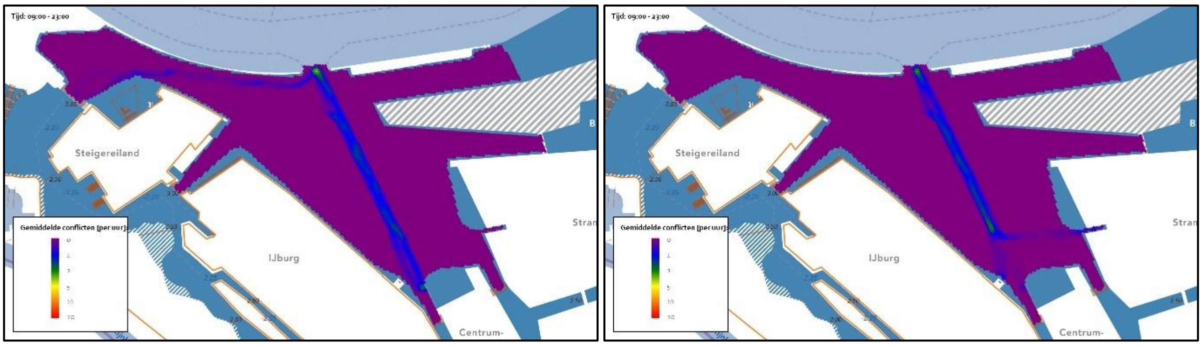


Figure 6.2 Average amount of conflicts for scenario 1, 4, 6, 5 (rotating clockwise starting top left).

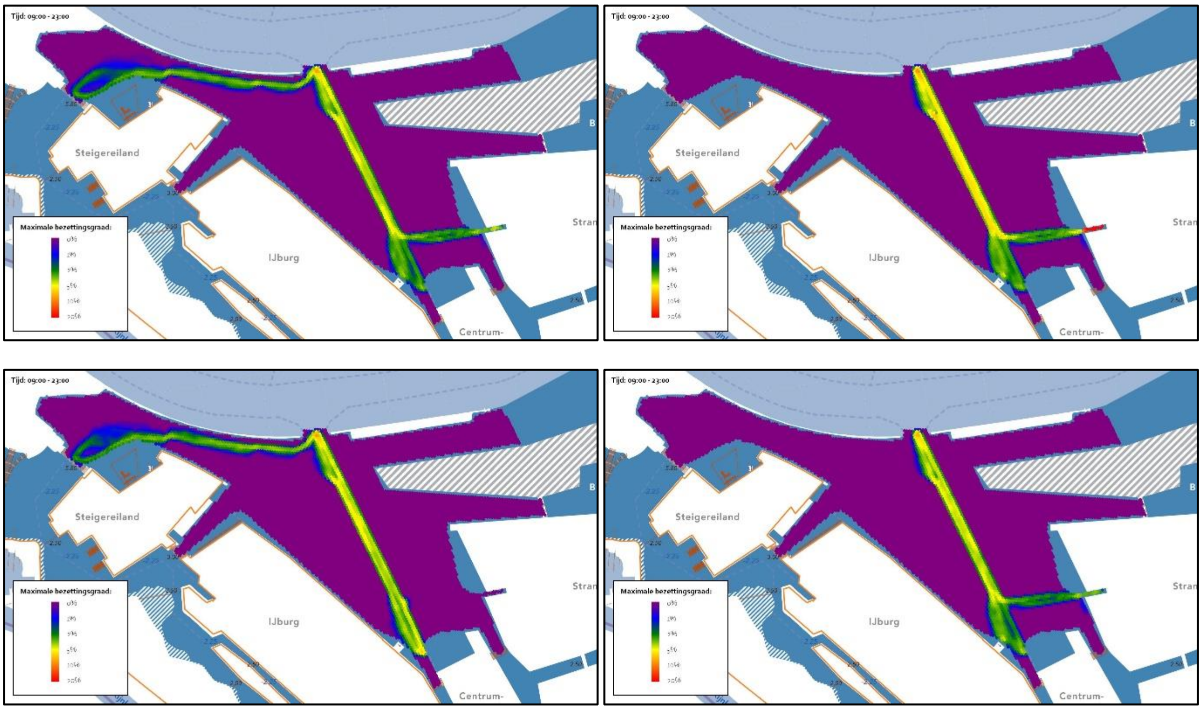


Figure 6.3 Maximum amount of conflicts for scenario 1, 4, 6, 5 (rotating clockwise starting top left).

In general it can be concluded that the model captures the effect of two of the three analysed influencing factors as expected. The behaviour of the amount of conflicts to a mixture of vessel types and speed differences between agents is as expected. Furthermore, an increased occupancy leads in most cases to an expected increase in conflicts. However, the model seems to have some difficulties by capturing the relationship between merging and diverging flows and the amount of conflicts. This might have multiple causes, such as:

- Inaccurate representation of agent behaviour: vessels might keep more distance when overtaking.
- The agents in the simulation only react on other agents within a distance of one cell size. In reality people react earlier on others. Therefore, the model might overestimate the amount of conflicts in some situations.
- The definition of a conflict is too broad and not distinctive enough from density/occupancy.

6.1.2 Validation B: Activities outside the fairway

A second validation is performed on the modelling of activities outside the fairway. The focus is on the two main areas in which water sports are performed, west and east from the fairway as shown in Figure 6.4. This is represented by analysing the output in the areas marked in Figure 6.5.

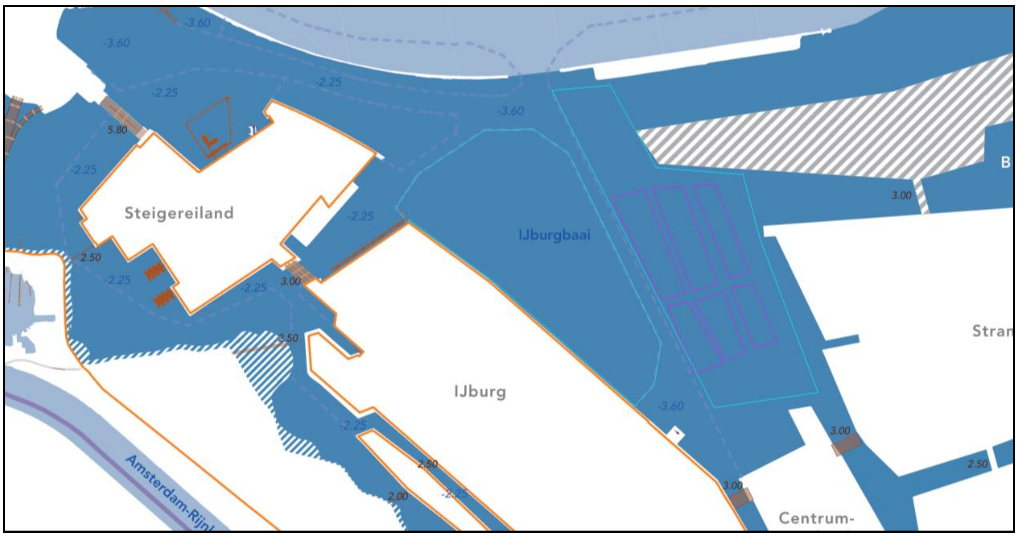


Figure 6.4 Main water sport areas in the IJburgbaai.

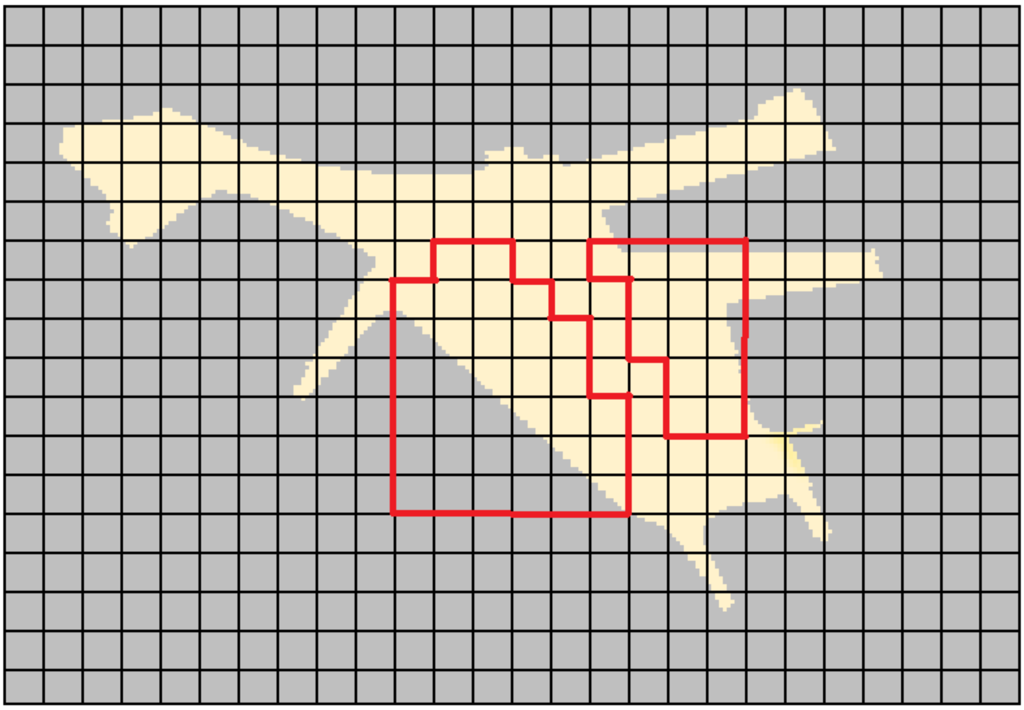


Figure 6.5 Analyzed areas in the IJburgbaai for validation B.

The main focus of this validation is to analyze what happens when the water sport areas are traversed by canoes/kayaks/SUPs and small motorboats/sloops. Therefore, an initial scenario is developed in which only small sailboats and wind surfers are present in the IJburgbaai. In a second scenario only motorboats/sloops (moored at private jetties) and canoes/kayaks/SUPs enter the IJburgbaai. To see the effect when these activities are combined scenario and scenario 2 are combined in scenario 3, with half of the amount of agents per activity to keep an equal amount of total activities. The amount of activities is chosen such that for each period 100 users per activity will enter the IJburgbaai in scenario 1 & 2 and 50 users per activity in scenario 3. When setting the scenario to a medium windy, summer weekend day this requires the input shown in Table 6.5.

Table 6.5 Model input for amount of activities under ideal conditions for validation B.

	Scenario 1	Scenario 2	Scenario 3
Sailboats	300	0	150
Wind surfers	500	0	250
Small motorboats	0	430 (f_{max} = 50%)	215 (f_{max} = 50%)
Canoes/kayaks/SUPs	0	500	250

It Table 6.6 and Table 6.7 the values of the 95th percentile in the western and eastern area of the IJburgbaai are presented. Keeping the amount of activities per category equal does not necessarily result in similar density of activities for each scenario. This is caused by the fact that wind surfers and sail boats stay for a longer period in the IJburgbaai, compared to motorboats and canoes/kayaks/SUPs. Therefore, the comparison in percentage increase/decrease for scenario 1 and 2 compared to scenario 3 in Table 6.8 provides more valuable information.

Table 6.6 Average output for Validation B scenarios in the western area of interest

	# runs	Average occupation [%]	Maximum occupation [%]	Average conflicts [# per hour]	Maximum conflicts [# per hour]
Scenario B-1	2	0.89	2.85	0.02	0.57
Scenario B-2	2	0.35	1.91	0.10	2.86
Scenario B-3	2	0.47	2.14	0.08	2.29

Table 6.7 Average output for Validation B scenarios in the southern area of interest

	# runs	Average occupation [%]	Maximum occupation [%]	Average conflicts [# per hour]	Maximum conflicts [# per hour]
Scenario B-1	2	3.62	7.03	0.84	7.65
Scenario B-2	2	0.33	1.82	0.10	2.86
Scenario B-3	2	1.75	4.12	0.15	3.72

Table 6.8 Change in occupation and conflicts for scenario B-1 and B-2 compared to scenario B-3.

	Average occupation	Maximum occupation	Average conflicts	Maximum conflicts
Scenario B-1 west	+89%	+33%	-75%	-75%
Scenario B-1 east	+107%	+71%	+460%	+106%
Scenario B-2 west	-26%	-11%	+25%	+25%
Scenario B-2 east	-81%	-56%	-33%	-23%

It can be seen that in scenario 1, where only wind surfers and small sailing boats are in the simulation, the occupation in both areas is quite a bit higher, caused by the fact that these agents remain in these areas for a longer amount of time. However, the amount of conflicts in the western area is much lower and in the eastern part much higher. This is due to the speed differences between sailing boats and wind surfers.

For the scenario with only small motorboats and canoes/kayaks/SUPs the reversed pattern can be observed: the overall occupancy is lower than in scenario 3, with more conflicts in the western part of the bay and less conflicts in the eastern part of the bay. The model seems to have in general a logical response on mixture of different activity types in the areas outside the fairway.

7 Scenario Development

In this chapter several scenarios are discussed and a method to implement these scenarios in the construction of the OD-matrices that are required for the model is explained.

7.1 Estimating Total Demand

The municipality of Amsterdam is interested in the nautical traffic conditions on different kind of days, which vary on the following aspects:

- Season
- Weekday or weekend day
- Weather (amount of wind)

No exact information is available about the influence of these variables on the demand for activities in the IJburgbaai (not for the current situation and certainly not for the future when all marinas are developed). However, based on current experiences in the IJburgbaai by the municipality of Amsterdam a rough estimation has been made of the influence of the variables.

To express the effect of the variables on the demand a multiplication factor is estimated based on season, type of day (weekday/weekend) and amount of wind. This multiplication factor is a factor between 0 and 1 and expresses the estimated demand as a fraction of the demand during ideal conditions. A multiplication factor is estimated for each variable. Multiplication of all factors results in the total fraction of the maximum demand for a day with given conditions, as is expressed by Equation 6.1.

$$MF_{total} = MF_{season} * MF_{day} * MF_{wind} \qquad (6.1)$$

7.1.1 Seasonal variation

The pattern in variation of demand is expected to be similar for each activity. The demand is high in the summer, low in the winter (0-20% of summer demand) and medium high (60-80% of summer demand) in the autumn and spring. It is expected that the drop in demand during autumn and spring is higher for motorboats and sailboats than for most of the water sports (surfing, coastal rowing, canoeing, kayaking, SUPping). Based on this expectation demand multiplication factors as estimated per combination of activity and season as can be seen in Table 7.1.

Table 7.1 Seasonal variation in demand multiplication factor

Category	Winter	Autumn	Summer	Spring
Large motorboats	0.20	0.60	1.00	0.60
Small motorboats	0.00	0.60	1.00	0.60
Large sailboats	0.10	0.70	1.00	0.70
Small sailboats	0.00	0.60	1.00	0.60
Wind surfing	0.20	0.80	1.00	0.80
Coastal rowing	0.20	0.80	1.00	0.80
Canoes/kayaks/SUPs	0.00	0.70	1.00	0.70

7.1.2 Weekend scenario

The demand for activities in the IJburgbaai is the highest in the weekend. On weekdays the demand is approximately 60-80% of the weekend demand. The demand for daytrips with large motor and sailing boats is relatively low during weekdays (around 60% of weekend demand) and the demand for small motorboats, sloops and windsurfing remains relatively high during weekdays (around 80% of weekend demand). This estimation results in the demand multiplication factors for weekdays and the weekend presented in Table 7.2.

Table 7.2 Demand multiplication factors per category for weekdays and weekend.

Category	Weekday	Weekend
Large motorboats	0.60	1.00
Small motorboats	0.80	1.00
Large sailboats	0.60	1.00
Small sailboats	0.75	1.00
Wind surfing	0.80	1.00
Coastal rowing	0.75	1.00
Canoes/kayaks/SUPs	0.75	1.00

7.1.3 Variation in wind

Each activity has their own preferred wind and wave conditions. Motorboats, sloops, canoes, kayaks and SUPs prefer calm water conditions (thus little wind), while sailboats and surfers cannot operate without wind. Coastal rowers prefer rough water conditions and therefore a lot of wind.

For the model the amount of wind has been categorised into three levels, with corresponding resulting wave conditions:

1. Little wind → wind force < 3 on the Beaufort scale
2. Medium wind → windforce between 3 and 5 on the Beaufort scale
3. Lot of wind → wind force > 5 on the Beaufort scale

For each activity the influence of demand in the IJburgbaai for each of the three mentioned wind conditions has been estimated. This estimation results in the demand multiplication factors shown in Table 7.3.

Table 7.3 Demand multiplication factors per wind condition and type of activity.

Category	Little wind	Medium wind	Lot of wind
Large motorboats	1.00	1.00	0.50
Small motorboats	1.00	0.70	0.00
Large sailboats	0.00	1.00	0.80
Small sailboats	0.00	1.00	1.00
Wind surfing	0.00	0.80	1.00
Coastal rowing	0.60	0.80	1.00
Canoes/kayaks/SUPs	1.00	0.60	0.00

7.1.4 Mooring places and maximum sail-out percentage

Apart from the previously discussed factors, the total demand for motorboats and sailing boats is dependent on the amount of mooring places around the IJburgbaai. As discussed in Section 2.2 there are four marinas around the IJburg that have an effect on the nautical traffic through the IJburgbaai. For each of these four marinas the demand is computed based on the number of mooring places ($N_{mooring}$), the percentage of vessels sailing out on a day with ideal conditions (f_{max}) and the previously determined multiplication factor (MF_{total}), as shown by Equation 6.2.

$$Total\ demand\ = f_{max} * MF_{total} * N_{mooring} \qquad (6.2)$$

The municipality of Amsterdam expects that on a day with ideal conditions around 20% of the vessels moored in the marinas will sail out for a day-trip. The current amount of mooring places at Zeeburgereiland and Haveneiland, and expected amount at Centrumeiland, Strandeiland and private jetties are:

- Marina Zeeburgereiland:
  - 65 motorboats
- Marina Haveneiland:
  - ~ 85 sailboats and 35 motorboats
- Marina Centrumeiland
  - Mixture of sailboats and motorboats, capacity varying from 200-400 vessels.
- Marina Strandeiland
  - Mixture of sailboats and motorboats, total capacity of around 600 vessels.
- Private jetties:
  - ~800 small motorboats and sloops

7.1.5 Water sport activities

For water sport activities the total demand is estimated from the multiplication factor and an estimation for the total amount of activities on a day with ideal conditions (N_{max}), and can thus be computed using Equation 6.3.

$$Total\ demand\ = N_{max} * MF_{total} \qquad (6.3)$$

7.1.6 Total demand to number of trips per period

As discussed in Section 5.3 four time periods are distinguished for the simulation in which agents are added to the simulation. These periods are morning (9:00-12:00), early afternoon (12:00-15:00), late afternoon (15:00-18:00) and evening (18:00-21:00). Sailing lessons are around one hour each and do not take place in the evening. Furthermore, also canoeing/kayaking and supping are not regularly performed during the evening hours. For boats that are moored at either a marina or a private jetty that are used for day-trips it is important to distinguish between departing (from mooring places around IJburg towards the Buiten-IJ and IJmeer) and returning trips (from the Buiten-IJ and IJmeer towards mooring places around IJburg). An average day-trip lasts around 4-6 hours[9]. Therefore, in the morning period only departing trips take place and in the evening only returning trips. In the afternoon a mixture of both type of trips is present in the IJburgbaai. Table 7.4 provides an overview of when each activity takes place.

[9] https://waterrecreatienederland.nl/resultaten-watersportonderzoek-2021/

Table 7.4 Travel pattern per type of activity.

Category	Morning	Early Afternoon	Late Afternoon	Evening
Large Motorboats	✓ (D)	✓ (D+R)	✓ (D+R)	✓ (R)
Small Motorboats	✓ (D)	✓ (D+R)	✓ (D+R)	✓ (R)
Large sailing boats	✓ (D)	✓ (D+R)	✓ (D+R)	✓ (R)
Small sailing boats	✓	✓	✓	X
Wind surfing	✓	✓	✓	✓
Coastal Rowing	✓	✓	✓	✓
Canoeing/Kayaking/SUPs	✓	✓	✓	X

✓ = activity is performed during this period, X = activity is not performed during this period, (D) = departing trips only, (R) = returning trips only, (D+R) = both departing and returning trips.

For water sports activities the total demand is simply divided by the amount of periods in which the activity is performed to estimate the demand per period. For motorboats and sailing boats each vessel sailing out results in two trips: one departing trip and one returning trip. The departing trips are equally divided over the three periods from 9:00 to 18:00 and the returning trips over the three periods from 12:00 to 21:00 as shown in Table 7.5.

Table 7.5 Computing departing and returning trips per period from total demand.

	9:00-12:00	12:00-15:00	15:00-18:00	18:00-21:00
Departing trips	1/3*total demand	1/3*total demand	1/3*total demand	0
Returning trips	0	1/3*total demand	1/3*total demand	1/3*total demand

7.2 OD-Matrices

To create OD-matrices the computed demand for each activity should be translated into trips between locations around the IJburgbaai. The locations included in the model are shown in Figure 7.2.

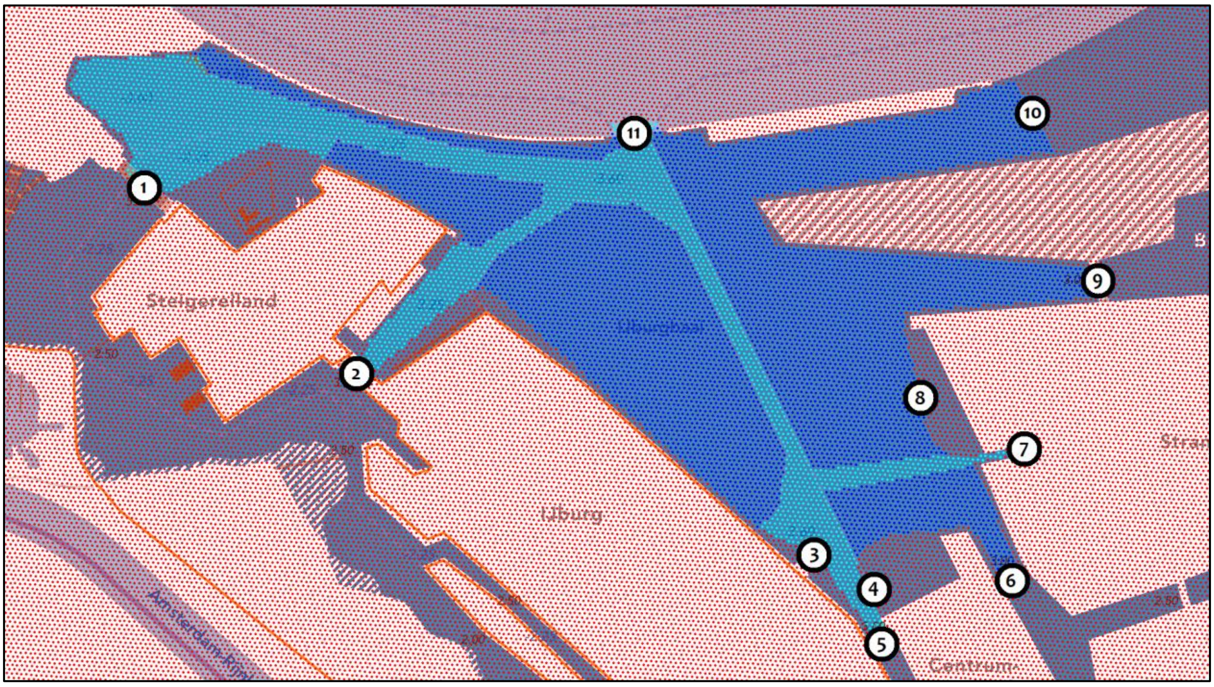


Figure 7.1 Locations of origins/destinations in the model.

In Section 2.2 an analysis was presented of the activities in and traffic flows through the IJburgbaai. This analysis resulted in the traffic flows and locations of water sports facilities shown in Figure 7.2.

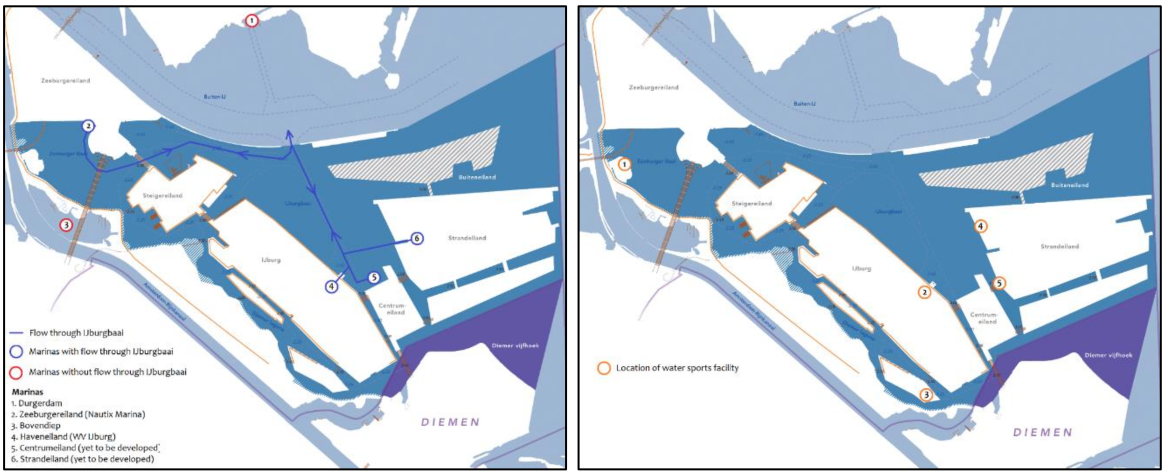


Figure 7.2 Nautical traffic flows through from marinas (left) and locations of water sports facilities (right).

To accurately represent the nautical flows from vessels moored at marinas and at private jetties, the origins and destinations shown in Table 7.6 have been chosen where the numbers correspond with the locations in Figure 7.1. For the marinas a single origin and destination has been defined per type of trip. Therefore, the amount of trips is equal to the previously computed amount of trips based on the demand per marina. For trips from private jetties, the amount of trips per OD-combination is determined by equally dividing the trips over each possible combination of origin and destination.

Table 7.6 Origins and destinations for motorboats and large sailing boats.

	Departing trip		Returning trip	
Mooring place	**Origin(s)**	**Destination(s)**	**Origin(s)**	**Destination(s)**
Marina Zeeburgereiland	1	11	11	1
Marina Haveneiland	3	11	11	3
Marina Centrumeiland	4	11	11	4
Marina Strandeiland	7	11	11	7
Private jetties	1, 2, 5, 6	1, 2, 5, 6, 9, 10, 11	1, 2, 5, 6, 9, 10, 11	1, 2, 5, 6

The total demand for canoeing/kayaking/supping is equally divided over the morning and afternoon periods. These make trips around the islands of IJburg and do not go towards the Buiten-IJ or IJmeer. Therefore, locations 1, 2, 5 and 6 are origins and destination for canoeing/kayaking/SUP trips. From these four locations 12 different O → D combinations can be made. The amount of trips is equally divided over these 12 combinations. Therefore, during each period the amount of trips for each combination is 1/3*1/12*total canoe/kayak/SUP demand.

Wind surfers, small sailing boats and coastal rowers depart at location 8, 3 and 6 respectively from which they will choose their first destination following the method described in Section 4.3.3. They keep choosing new destinations until the average activity duration has been reached.

8 CONCLUSION AND DISCUSSION

The aim of this project was to develop a dynamic traffic model that can simulate recreational activities in the IJburgbaai such that bottlenecks and potential conflicts can be identified. During this project the following research questions were established to provide a good basis for the development of the model:

Main Research Question:

What model captures the behaviour of recreational activities in the IJburgbaai with enough detail to enable the identification of potential conflicts and bottlenecks?

Sub-Questions:

1. How do recreational water activities behave in the IJburgbaai?
2. What models are able to simulate routing behaviour of recreational water activities?
3. What factors determine which routes are chosen by recreational water users and what is the influence of these factors on route-choice behaviour?
4. What models are able to simulate the movement and interaction behaviour of recreational water activities in an open-space?

8.1 CONCLUSION

Seven types of activities were determined that influence the nautical traffic flows in the IJburgbaai. Large motorboats and sailing boats moored at marinas around IJburg are used for day-trips, which results in one departing trip and one returning trip per vessel through the fairway in the IJburgbaai. Furthermore, there are a lot of smaller motorboats and sloops moored at private jetties around the islands of IJburg. These can be used for day-trips as well, but also to sail around the islands.

Furthermore, small sailing boats, wind surfers and coastal rowers stay in the IJburgbaai during the entire duration of their activity. Lastly, canoers, kayakers and SUPpers start from the Diemerlagune or Zeeburgerbaai and traverse the IJburgbaai when making a nice tour around the islands.

It was determined that a combination of a tactical model to estimate routes through the IJburgbaai and an operational model to simulate the exact movement behaviour of activities through the bay should provide a solid basis for a dynamic transport model of the IJburgbaai.

To capture the routes of the activities, the routing behaviour of the activities has been captured by determining a set of intermediate points to guide agents through the bay. For this procedure an important distinction is made between activities through the fairway and activities outside the fairway. For both types a shortest path algorithm has been developed that in combination with a specified origin and destination simulates the main directions of traffic through the bay. Furthermore, a method has been introduced to generate intermediate points for the activities that remain in the IJburgbaai.

Then, an operational model was developed to simulate the movement of the agents in the simulation between the intermediate points. The main principle of this operational model is that the agents move through a grid of hexagonal cells with a cell size of 15 m. This grid type was chosen because it has the perfect combination of manoeuvrability (six optional directions) and simplicity (equal distances between each neighbouring cells). The next position of an agent is determined by a cell-choice model in which the following factors have been determined as main factors that influence movement behaviour of activities and are therefore included in the model:

- Direction of next destination.
- Speed differences between different activities.
- Preference for certain activities to stay within the fairway.
- When inside the fairway, a preference to keep the right side of the fairway.
- Presence of other agents.
- Inability of surfers and small sailing boats to sail into the direction of the wind. This creates zigzag behaviour when trying to reach an upwind destination.

Combining the tactical model with the operational model results in a dynamic model that captures all basic behaviours of the activities in the IJburgbaai. Validation of the model showed that the model captures the expected relation between occupancy and amount of conflicts in an area. Furthermore, it is accurately captured that activities with differences in speed in the same area result in an increased amount of conflicts. On the contrary, the expected effects of merging and diverging flows are hardly captured by the model. However, in general the model is good in predicting which areas of the bay will be crowded based on a given demand as input.

8.2 DISCUSSION

During the development some decisions have been that might not always have a certain degree of validity. Sometimes these decisions are a consequence of a lack of information, in other cases a consequence of the desire to keep some simplicity in the basis of the model. Firstly, some parameters have been estimated during the model development whose accuracy can be disputed. These parameters are:

- Occupancy factor: amount of agents of one type that can safely sail in the same cell. The estimate is accurate for motorboats and sailing boats, but due to lack of knowledge less accurate for water sport (especially windsurfing and canoeing).
- Probabilities for the areas in which a next destination is chosen for water sports that remain in the IJburgbaai.

Besides the sometimes rough estimation for some factors in the model there are also some factors that are part of the model to preserve some sort of simplicity of the model, but might result in behaviour of agents that is quite off from reality and would have a significant effect on the model outcome when implemented.

- Agents only react on agents in neighbouring cells. Other agents or busy areas are only avoided when directly next to a cell with another agent. This might result in predicted conflicts that are in reality avoided by vessels by reacting on the situation well in advance.
- Each agent of a certain type has the same speed. Furthermore, the speed remains the same during the entire duration of the activity (no slowing down when approaching busy areas/other agents).
- Agents do not update their route based on the situation in the bay. In reality people might choose a different option to exit the bay when it is really crowded around a certain location

Therefore, some future steps in the further development of this model could be:

- Gathering data to enable better validation of the model and calibration of model parameters.
- Investigate the possible effect of implementing the abovementioned “short-comings” of the model with respect to reality.

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APPENDIX A: RESULTS VALIDATION A

Table A1 Average occupancy (%) validation A

	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6	
	North	South	North	South	North	South	North	South	North	South	North	South
Run 1	1.43	1.49	1.82	1.81	0.90	0.90	1.82	1.82	1.40	1.44	1.40	1.39
Run 2	1.44	1.44	1.81	1.84	0.92	0.87	1.69	1.72	1.40	1.42	1.40	1.45
Run 3	1.45	1.42	1.79	1.87	0.92	0.92	1.81	1.83			1.40	1.41
Run 4	1.37	1.34	1.80	1.85	0.91	0.90	1.81	1.88			1.36	1.43
Run 5	1.41	1.46			0.92	0.90	1.81	1.91				
Run 6					0.91	0.89						
Run 7					0.90	0.90						
Run 8					0.92	0.91						
Run 9					0.92	0.92						
Run 10					0.92	0.90						
Run 11					0.91	0.89						
Run 12					0.90	0.92						
Run 13					0.93	0.91						
Run 14					0.90	0.90						
Run 15												
Average	1.42	1.43	1.81	1.84	0.91	0.90	1.79	1.83	1.40	1.43	1.39	1.42
St.Dev	0.03	0.05	0.01	0.02	0.01	0.01	0.05	0.06	0.00	0.01	0.02	0.02
n	0.15	0.48	0.01	0.05	0.04	0.08	0.29	0.48	0.00	0.02	0.06	0.10

Table A2 Maximum occupancy (%) validation A

	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6	
	North	South	North	South	North	South	North	South	North	South	North	South
Run 1	4.51	4.64	5.71	5.71	2.79	2.92	5.60	5.88	4.64	4.19	4.54	4.54
Run 2	4.73	4.83	5.71	6.06	3.05	3.14	5.40	5.66	4.57	4.32	4.75	4.83
Run 3	4.65	4.83	6.60	5.97	2.89	3.02	5.62	5.94			4.37	4.64
Run 4	4.83	4.70	6.48	6.10	3.08	3.24	5.94	5.97			4.61	5.15
Run 5	4.30	4.51			2.98	2.98	5.16	5.91				
Run 6					2.98	3.05						
Run 7					2.96	3.05						
Run 8					2.78	3.21						
Run 9					3.18	3.24						
Run 10					3.30	3.43						
Run 11					3.11	2.86						
Run 12					3.00	2.92						
Run 13					3.05	2.86						
Run 14					2.95	2.98						
Run 15												
Average	4.60	4.70	6.13	5.96	3.01	3.06	5.54	5.87	4.61	4.26	4.57	4.79
St.Dev	0.18	0.12	0.42	0.15	0.13	0.16	0.26	0.11	0.03	0.06	0.14	0.23
n	0.62	0.26	1.78	0.25	0.77	1.06	0.83	0.14	0.02	0.09	0.34	0.90

Table A3 Average conflicts [per hour] validation A

	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6	
	North	South	North	South	North	South	North	South	North	South	North	South
Run 1	1.02	1.13	1.02	1.19	0.86	0.54	1.78	1.93	1.12	1.20	0.93	1.10
Run 2	0.99	1.03	1.22	1.13	0.73	0.52	1.30	1.67	1.18	1.08	1.14	1.03
Run 3	1.04	1.00	1.30	1.17	0.61	0.65	1.69	1.75			0.96	1.09
Run 4	0.91	0.88	1.10	1.12	0.69	0.55	1.77	1.79			1.08	1.03
Run 5	1.06	1.06			0.61	0.61	1.70	1.74				
Run 6					0.65	0.57						
Run 7					0.43	0.45						
Run 8					0.63	0.54						
Run 9					0.77	0.69						
Run 10					0.63	0.59						
Run 11					0.39	0.52						
Run 12					0.62	0.50						
Run 13					0.67	0.53						
Run 14					0.55	0.47						
Run 15												
Average	1.00	1.02	1.16	1.15	0.63	0.55	1.65	1.78	1.15	1.14	1.03	1.06
St.Dev	0.05	0.08	0.11	0.03	0.12	0.06	0.18	0.09	0.03	0.06	0.09	0.03
n	1.05	2.50	3.31	0.24	13.28	5.08	4.47	0.90	0.26	1.06	2.68	0.36

Table A4 Maximum conflicts [per hour] validation A

	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6	
	North	South	North	South	North	South	North	South	North	South	North	South
Run 1	8.57	10.29	8.31	8.57	7.43	6.29	11.43	12.60	9.71	9.71	8.00	9.14
Run 2	7.43	8.00	8.57	9.71	6.29	5.71	10.60	12.60	9.71	8.57	9.14	10.86
Run 3	8.57	9.14	10.29	8.60	7.43	6.86	13.14	12.00			8.00	9.14
Run 4	8.57	8.03	9.14	10.29	7.43	6.29	11.43	12.57			9.14	10.29
Run 5	8.57	9.71			6.29	6.29	12.00	12.00				
Run 6					6.86	6.86						
Run 7					6.29	5.71						
Run 8					5.14	6.29						
Run 9					6.86	7.43						
Run 10					7.43	7.43						
Run 11					5.14	5.72						
Run 12					7.43	6.29						
Run 13					5.14	5.71						
Run 14					5.71	5.14						
Run 15												
Average	8.34	9.03	9.08	9.29	6.49	6.29	11.72	12.35	9.71	9.14	8.57	9.86
St.Dev	0.46	0.91	0.76	0.74	0.88	0.65	0.84	0.29	0.00	0.57	0.57	0.75
n	1.15	3.88	2.70	2.41	7.09	4.10	1.97	0.21	0.00	1.49	1.70	2.20

APPENDIX B: RESULTS VALIDATION B

Table B1 Average occupancy [%] validation B

	Scenario 1		Scenario 2		Scenario 3	
	West	East	West	East	West	East
Run 1	0.87	3.68	0.35	0.32	0.47	1.75
Run 2	0.91	3.55	0.34	0.33	0.46	1.74
Run 3						
Average	0.89	3.62	0.35	0.33	0.47	1.75
St.Dev	0.02	0.07	0.00	0.01	0.00	0.01
n	0.19	0.12	0.08	0.09	0.04	0.00

Table B2 Maximum occupancy [%] validation B

	Scenario 1		Scenario 2		Scenario 3	
	West	East	West	East	West	East
Run 1	2.82	7.02	1.98	1.73	2.15	4.15
Run 2	2.87	7.03	1.83	1.90	2.13	4.09
Run 3						
Average	2.85	7.03	1.91	1.82	2.14	4.12
St.Dev	0.03	0.01	0.08	0.09	0.01	0.03
n	0.03	0.00	0.60	0.84	0.01	0.02

Table B3 Average conflicts [per hour] validation B

	Scenario 1		Scenario 2		Scenario 3	
	West	East	West	East	West	East
Run 1	0.02	0.82	0.10	0.09	0.08	0.14
Run 2	0.02	0.86	0.09	0.10	0.07	0.16
Run 3						
Average	0.02	0.84	0.10	0.10	0.08	0.15
St.Dev	0.00	0.02	0.01	0.01	0.01	0.01
n	0.00	0.22	1.06	1.06	1.71	1.71

Table B4 Maximum conflicts [per hour] validation B

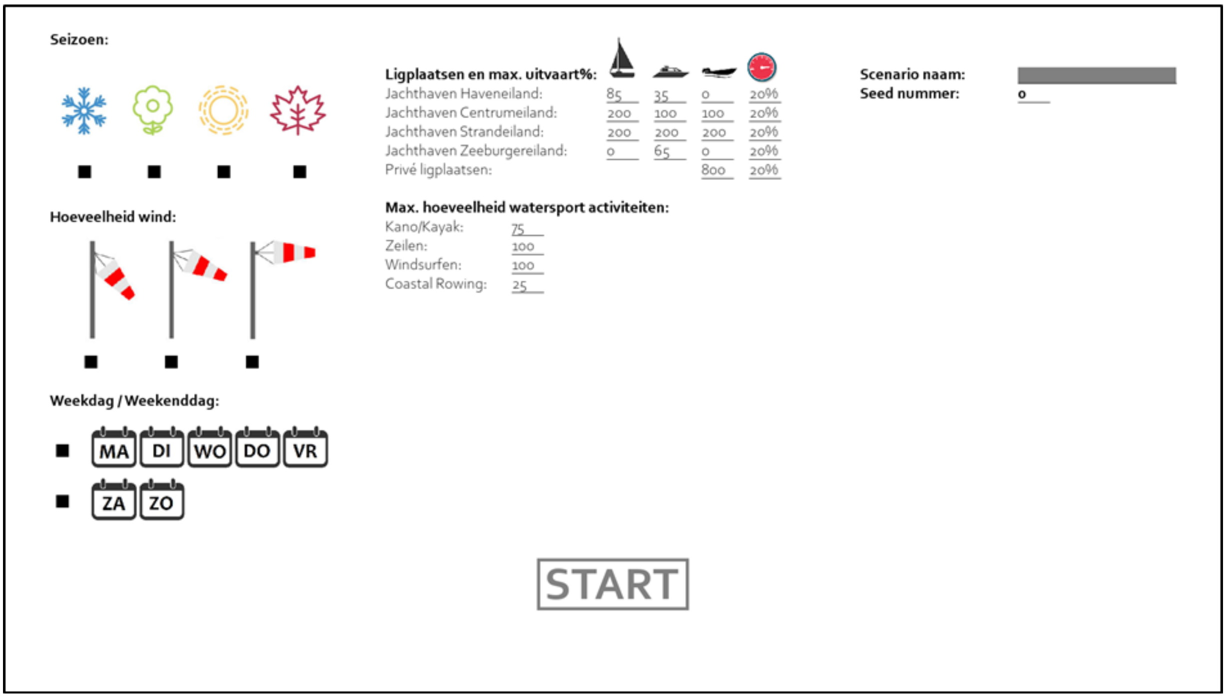
	Scenario 1		Scenario 2		Scenario 3	
	West	East	West	East	West	East
Run 1	0.57	7.86	2.86	2.86	2.29	3.43
Run 2	0.57	7.43	2.86	2.86	2.29	4.00
Run 3						
Average	0.57	7.65	2.86	2.86	2.29	3.72
St.Dev	0.00	0.22	0.00	0.00	0.00	0.29
n	0.00	0.30	0.00	0.00	0.00	2.26

Appendix C: User Manual Model

Required python packages
To run the model the following python packages are required, with a link towards information about how to install these packages:

- pandas (https://pandas.pydata.org/docs/getting_started/install.html)
- pygame (https://www.pygame.org/wiki/GettingStarted)
- shapely (https://shapely.readthedocs.io/en/stable/project.html#installing-shapely)
- numpy (https://numpy.org/install/)
- igraph (https://igraph.readthedocs.io/en/0.10.2/index.html)

How to enter a scenario and run simulation
The model can be started by running the *FINAL_MODEL.py* file. First, a screen will open on which input for a scenario can be selected and a name for the scenario can be entered, as shown in the image below:



On the left side of the screen season, type of wind and type of day should be selected and the name for the scenario can be entered on the top right.

In the middle information about the potential demand for the activities can be entered. For these parameters some base values have already been entered. These can be changed by clicking on the value and using [BACKSPACE] to remove the last digit and the number keys to enter new digits. To easily jump between input lines the arrow keys and [TAB] can be used. Lastly the seed number can be adapted to enable the simulation of different runs.

In the middle upper block, the values under the pictograms correspond to the following information (from left to right):

- mooring places large sailing boats
- mooring places large motorboats

- mooring places small motorboats
- maximum percentage of vessels sailing out

If everything has been selected and entered correctly the START button will become green. When clicking on the green start button a progress bar will appear to show the progress on preparatory computations. Once 100% has been reached a map of the IJburgbaai will appear and the simulation is ready to be started. To start and/or pause the simulation the spacebar have to be pushed. Besided the spacebar some other keys have a special action involved. These are the following:

- [SPACE] → start/pauses simulation
- [ESC] → end simulation
- [N] → when the simulation is paused the simulation will progress with one time step (2 sec.) when this key is pushed.
- [S] → shows/hides the middle points of the hexagonal cells. When cell centers are shown the simulation will slow down significantly, so it is better to run the simulation without showing them. The colors indicate the following:
    - Red → non-accessible cell
    - Blue → cell outside the fairway
    - Light-blue → cell inside the fairway
- [W] → shows/hides the water sport areas
- [L] → shows/hide the locations of origins/destinations in the area.
- Arrow keys → can be used to navigate through the map
- [R] → returns the view towards the initial position on the map.

How to end a simulation a process results
The simulation ends when its either closed manually by pressing the escape key or when time has reached 23:00. In the latter case escape should still be pressed to close the screen on which the simulation is displayed. The results will be stored both as csv-files and as image and can be found in the folder *Results.*

The results will be stored in the following format:

*name*_Run*X*_*AA*_*aaa*_*h1h2*.*file*

where:

- name = scenario name
- X = seed number
- AA = *BG* for occupancy and *CF* for conflicts
- aaa = *avg* for the average over a period and *max* for the maximum value experience during any 15 minute interval
- h1 = start of the ouput period (hour)
- h2 = end of the output period (hour)
- file = csv or jpeg

For example, a scenario named Scenario1, with seed number 0 the average occupancy in the period from 09:00 till 23:00 will be saved as *Scenario1_Run0_BG_avg_923.csv* and *Scenario1_Run0_BG_avg_923.jpeg.*

The period for which results are stored can be changed by adapting two lines in the code of *FINAL_MODEL.py.* These are line 1524 and 1525 as shown below.

```
# Define intervals for results
h1_lst = [9] # start of intervals [h]
h2_lst = [23] # end of intervals [h]
```

In h1_lst the start moments of periods are stored and in h2_lst the end moments. As a base value h1_lst = [9] en h2_lst = [23], which provide results for the period 09:00-23:00. If, for example, it is preferred to obtain the results for 3h intervals, these lines can be adapted as such:

```
# Define intervals for results
h1_lst = [9,12,15,18] # start of intervals [h]
h2_lst = [12,15,18,21] # end of intervals [h]
```

This will provide csv-files and images for the periods 9:00-12:00, 12:00-15:00, 15:00-18:00 and 18:00-21:00.