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Geographical Information Management and Applications

Using agent-based modelling to explore the influence of canal cruise docks on the crowdedness in the city centre of Amsterdam

Final thesis for GIMA

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Abstract

In the last years, the crowdedness within the city centre of Amsterdam caused by tourists has come to a point where it is causing nuisance and discontent to the residents of Amsterdam. The Municipality of Amsterdam has tried to find solutions to this problem, such as a halt on new hotels within the city centre and by promoting the outer region of Amsterdam it hopes that tourists will spread out. A new measure of the Municipality is to ban the boarding and disembarking docks of the canal cruises from the city centre and to relocate them outside the city centre. This thesis examines the effect of this imminent policy. An agent-based model was developed to research the influence of the locations of the canal cruises on the crowdedness caused by tourists in the city. The developed model simulates the movement patterns of tourists that take a canal cruise based on two scenarios: one with the current dock locations and one with new dock locations outside the city centre. The agents in the model are based on an operationalization of the actual tourists in Amsterdam. The results from the model show that the relocation of the docks could lead to the spread of tourists towards the neighbouring areas of the city centre. However, the city centre remains the most crowded area in the results from the agent-based model, because a lot of the other activities that tourist engage in on their trip in Amsterdam are still clustered in or nearby the city centre.

Preface and acknowledgements

You are about to read my thesis, in which I invested a lot of time in during last year. In the process, my view on the city centre of Amsterdam has been changed: today I cannot bike through the city centre without noticing where tourist walk and identifying crowded areas. When biking along the canals, I explicitly look for the many canal cruise boats, linking the specific company to the current locations of the docks in my mind. This all relates to the relevance of my thesis subject, as the crowdedness caused by tourists in Amsterdam has become a source of discontent and the cause of nuisance in the last years. With the expectation of even more tourists coming to Amsterdam, it is necessary to look at ways to reduce the crowdedness in the centre and to spread the tourists out across the city.

This thesis has confirmed my interests in the combination of GIS and urban geography: finding solutions to urban problems with the use of spatial data and GIS and to map out and analysing urban processes. I am even more assured now that this is the field I want to start my professional career in.

While the process of writing my thesis was not always easy, it has thought me a lot. For example, it has thought me not to be scared of learning new things, in this case a whole new programming language. As well, I learned that it is best to sometimes let a problem rest for the night if you are unable to find a solution. When looking at the same problem the next day again, a fresh mind helps finding the solution to the problem.

I want to thank Arend Ligtenberg for his supervision. We had useful discussions about my thesis topic from which valuable ideas arose. Thank you for reviewing my model when I got stuck and thank you for providing me with feedback.

As well, I want to thank my parents and sister for unconditionally supporting me in finishing my thesis in what have not been the easiest of times for our family. Thank you, Ruben, for always saying it will be fine in the end, turns out, for my thesis this is indeed true. As well, I want to thank my fellow GIMA students for all the pleasant and well-deserved coffee breaks during the process of writing our theses. Our conversations were not always about our thesis topics, but often they were, and it provided me with useful new insights.

I hope you enjoy reading my thesis and that it crosses your mind the next time you walk or bike through the crowded, but still beautiful, city of Amsterdam.

Nina Jensen
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1 Introduction

1.1 General

When moving through the inner-city centre of Amsterdam, if this is by foot, bike or car, you immediately notice how crowded it feels: there are a lot of people in the small streets along the canals that are so typical for Amsterdam. These typical streets have always been a little cramped, but it is very noticeable that nowadays it is not only Amsterdam inhabitants that are wandering the streets. Tourists are taking over the image of inner Amsterdam, much to the disapproval of residents of the affected neighbourhoods. A striking example of such a crowded place where tourists, residents and the small public space clash is near the Anne Frank House. This location is not only crowded with tourists standing in line for the Anne Frank House, there is also a dock for the boarding and disembarking of canal cruises. This causes a lot of hustle in one place. An article that was published in In Het Parool, Kruyswijk (2018) discussed concerns the local residents have about a plan of the Municipality of Amsterdam to place extra docks for the canal cruises: they are afraid for even more clustering of tourists in this area. This is not the only location in the city centre where the boarding and disembarking docks of the canal cruises are causing the clustering of tourists. This problem is the focus point of this thesis.

In this section the problem addressed in this thesis will be described from both a societal and scientific point of view. This is followed by the determination of the research objectives and research questions. Lastly, this section provides a reading guide for the thesis.

1.2 Societal problem statement and relevance

The last decade Amsterdam has become a very popular destination for tourists in Europe. In 2016 Amsterdam was in the top 5 of European cities with the highest number of hotel guests per 100 inhabitants (OIS Gemeente Amsterdam, 2017b). It is expected that the amount of hotel stays will only increase further: from 17,3 million in 2015 to 23,5 million in 2025 (Gemeente Amsterdam, 2016). The iconic canals of Amsterdam are UNESCO World Heritage and determine the image of the inner city. Kavaratzis & Ashworth (2007) state that tourists associate Amsterdam with 'City of Canals' and that they see this as a significant asset of Amsterdam. Taking a cruise on the iconic canals is on a lot of tourists 'must do-list' and this makes the canal cruises one of the most visited attractions in the Netherlands. In 2016, 5,2 million people did a canal cruise, which is a growth of almost 300.000 people compared to the year before, in which a lot of tourists came to the city for the nautical SAIL event (OIS Gemeente Amsterdam, 2016, 2017a). The growth of tourism is expected to continue for a longer period of time. For Amsterdam, there are three main developments that will influence this growth (OIS Gemeente Amsterdam, 2017b). The first is the economic growth in the countries of origin where a lot of tourists come from, such as Germany and the USA. The second important development is the Brexit: a 'hard' Brexit will slow down the incoming flow of tourists as the UK is one of the biggest countries of origin of tourists, but on the other hand, Amsterdam is seen as a good alternative for London regarding business visitors. The third development is the sense of security that people have in Amsterdam after terrorist attacks in other cities such as Paris and Brussels.

The increasing number of tourists coming to the city of Amsterdam has a lot of positive aspects for the city. Both foreign and Dutch tourists spend their money during their stay in Amsterdam, creating a sales increase for hotels, shops, restaurants and cultural institutions. The growth of the incoming tourist flow also has as a positive effect that it creates more jobs in the touristic sector: in 2017 there was a growth-rate of 8% of people working in the touristic sector (OIS Gemeente Amsterdam, 2017b).

As well, the popularity of the Amsterdam canals offer a lot of opportunities for entrepreneurs along the waterways in form of boat rentals, transport of tourists, marina's and hospitality ventures (Gemeente Amsterdam, 2016).

However, over the last couple of years the negative side effects of the increasing number of tourists are getting clear. The inhabitants of Amsterdam are complaining about nuisance and crowdedness in the city centre and there is being talked about "Pretpark (theme park) Amsterdam" (Gemeente Amsterdam, 2017a). The Municipality of Amsterdam is trying to get the 'balance' back in the city, which started with the "Stad in Balans" initiative in 2015, in which four goals are set to better regulate the growing incoming flow of tourists (Gemeente Amsterdam, 2017b). The first goal is to create more quality and diversity in shopping and facility resources; the second is to reduce nuisance and to set boundaries with stricter rules; the third goal is to make better use of the city and to focus on the profiling of the region; the last goal is to create more space on the streets in crowded areas (Gemeente Amsterdam, 2017b).

In May 2018 the new elected board of the Municipality of Amsterdam presented a partial agreement with the main purpose of reducing the pressure of the increasing tourist flow on the city (Gualtherie van Weezel, 2018). One of the proposed measures is to move the boarding and disembarking locations of the popular canal cruises outside the city centre as the current locations in the city centre are causing a lot of crowdedness and traffic congestions in the already crowded inner city centre. As can be seen in figure 1, all the currently offered canal cruises have their boarding and disembarking docks located in the inner-city centre. Already in 2016 the Municipality of Amsterdam suggested that there should be new locations for the docks of the canal cruises along other waterways, outside of the city centre, in the "Watervisie 2040" report (Gemeente Amsterdam, 2016). Figure 2 shows the possible waterways where new docks can be located along. As well, it shows a new location that has already been designated as a new dock outside the inner city centre (Gemeente Amsterdam, n.d.). The first reactions about this specific proposed measure in the media are positive but also somewhat sceptic. In an article from NOS the tourism expert Stephen Hodes questions if the displacement of the canal cruise docks will actually have a big impact; tourists probably still want to go to the authentic inner-city centre of Amsterdam. As well, it is put to the question how realistic it is to get the 5 million visitors of the canal cruises a year out of the city centre, how they will get there and if that will not result in even more traffic congestions (Gualtherie van Weezel, 2018; Houthuijs, 2018).

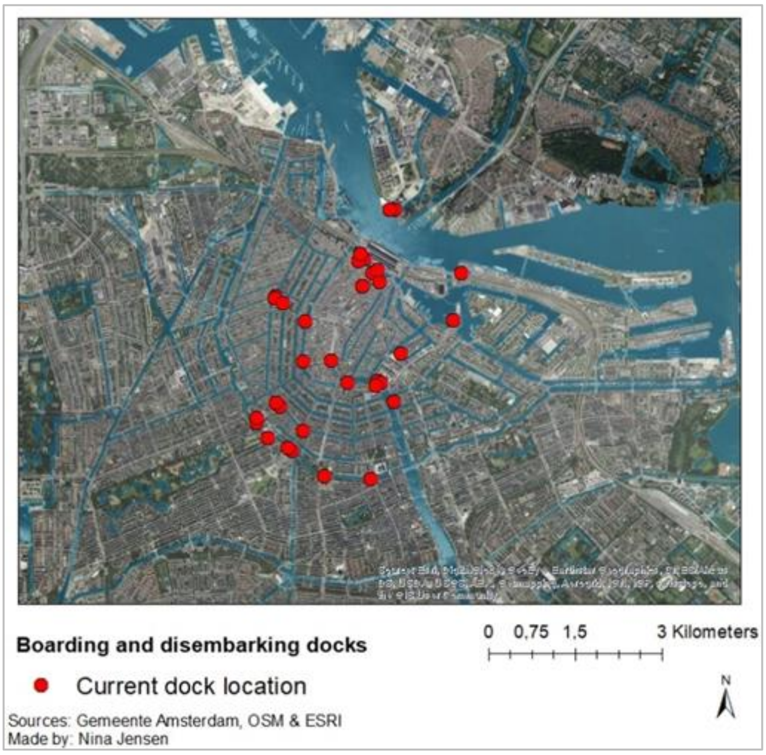

Figure 1 – Location of the current canal cruise docks in 2019

This thesis will focus on this relocation of the boarding and disembarking docks of the canal cruises from the inner-city centre to outside of the inner-city centre and how it will influence the flow of tourists causing overcrowding in Amsterdam. This will be done with the use of Agent Based Modelling, which will be discussed in the next paragraph.

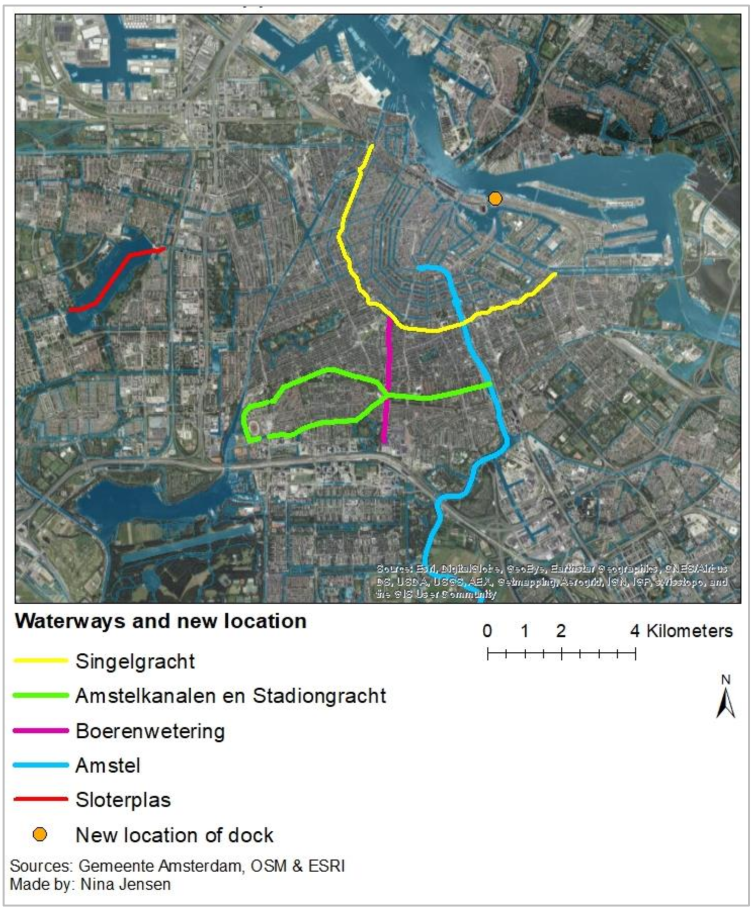

Figure 2 – Possible waterways to create new canal cruise docks along as proposed in 'Watervisie 2014', together with an already appointed new dock location

1.3 Scientific problem statement and relevance

The aim of this study is to analyse how the flow of tourists in the city centre of Amsterdam is influenced by the locations of the boarding and disembarking docks of the canal cruises. This will be done by building an Agent Based Model (ABM). ABMs consist of a number of 'agents' that are able to interact with both each other and their environment. The agents are assigned a certain behaviour on which they make decisions and change their actions upon, as well as a result of the interactions they have (Matthews et al., 2007). Ligtenberg, van Lammeren, Bregt & Beulens (2010:424) give the following definition of an ABM:

> *"the main concept of ABM is that it captures the observed behaviour of organized complex systems by using fine-grained entities (the agents) that represent the main drivers of changes in the state of the system. All agents are structurally coupled to an environment and to each other by a set of rules. In principle, each agent ''behaves" autonomously. The reactive or pro-active behaviour of individual agents is determined by rules and based on reasoning about observations of an agents of its environment. The cumulative effect of the individual behaviour of agents is a global change in the state of the environment."*

With an ABM, a simplified representation of the social reality is created that portrays as clearly as possible the way that this social reality operates (Gilbert, 2008). Crooks, Castle,& Batty (2008) discuss the ABM approach as a good way to understand urban problems such as segregation, sprawl and congestion on which researchers have recently focused as a bottom-up approach to urban systems. Specifically, modelling the influence of spatial decision-making on the environment, is an important aspect of ABMs (Matthews et al., 2007). ABM thus is a suiting method to use in this research for the modelling of the tourist flows in Amsterdam, influenced by the locations of the canal cruise docks.

A lot of research has been done with the use of agent-based models. Both Berger (2001) and Matthews et al. (2007) and An (2012) as well, give a review of applications that use ABM. However, all three articles are about land-use models and policy analysis and testing in the agricultural sector. This is aligned with the whole scientific literature body about ABM, in which not a lot of articles can be found about policy testing specific in urban areas. The research conducted for this thesis fills the 'urban policy testing' gap that is present in the scientific literature body about ABM. The urban policy testing done in this thesis is the proposed new measure of the Municipality of Amsterdam to relocate the boarding and disembarking docks of the canal cruises outside of the city centre. The characteristics of ABMs make them suitable for policy related research, in both urban and agricultural areas. Crooks et al. (2008:417) provide us with seven key challenges for ABMs that should be considered to *"make them scientifically relevant and policy applicable"*. As well, Filatova, Verburg, Parker, & Stannard (2013) name the importance of sensitivity analysis, verification and validation when ABMs are applied in a policy context. The testing of policies can be done by variating with particular model variables to match the changing policy conditions. In this way the ABM approach can best be described as conducting experiments in an artificial world, based on social reality, in order to obtain insights for policy development and evaluation (Berger, 2001). This research will therefore use ABM as a tool for policy testing.

Scientific research on the movement behaviour of tourists is mostly focused on inter-destination patterns and not how tourists move intra-destination. Most of this research on inter-destination tourist movements is conducted by following the actual movements of tourists. Edwards & Griffin (2013), Grinberger, Shoval, & McKercher (2014) and van der Knaap (1999) discuss the use of GPS to track tourists' movements and the use of GIS-tools to uncover the patterns. This thesis goes beyond these previous researches, as it looks at movement behaviour intra-destination. However, it will not track the real movements of the tourists in Amsterdam, but it will aim to model the movements, based on an extensive literature review and proper operationalization of the tourists in Amsterdam. ABM is a flexible tool to test policies before implementing them. It makes it possible to test the outcomes of various scenarios and to evaluate the impact of imminent policies. This reduces the risk of policy failure or unwanted effects after the implementation.

1.4 Research objectives and questions

1.4.1 Objectives

Based on the problems introduced in the previous paragraphs the objectives of this thesis are formulated. The main objective of this thesis is to provide an insight into the influence of the canal cruises that sail along the canals of Amsterdam on the crowdedness in the inner city. Primarily there will be looked at the influence of the locations of the docks that the canal cruises use for boarding and debarking their passengers. What do these locations of the docks mean for crowdedness in the surrounding streets, in regards of pedestrian flows caused by tourists? The municipality has proposed new locations for the canal cruise docks that are located more outside of the city centre in the 'Watervisie 2040' report. As well, during the negotiations of the new city government in March 2018 the plan was made to ban docks for the boarding and disembarking of canal cruises from the city centre as a whole. The main research objective of this thesis is to simulate and analyse how the current dock locations and alternative locations outside of the city centre influence the flows of tourist and crowdedness in the city centre. Will the ban on canal cruise docks in the city centre make a big difference in the crowdedness in the city centre? These results can be very interesting for the municipality of Amsterdam and the canal cruise branch.

Furthermore, it is an objective to create an ABM that generates plausible pattern outcomes, relatable to the real-world movement patterns of tourists in Amsterdam. Therefore it is important to operationalize the tourist behaviour in such a way that it represent the actual behaviour of the tourists. To test the plausibility of the modelled patterns, a sensitivity analysis will be executed. Unfortunately, a full validity of the ABM not feasible, as there is a lack of empirical and statistical data about tourist movements in Amsterdam. It is not possible to collect this data within the given time span of this thesis.

1.4.2 Main research question and sub questions

To meet the research objectives of this thesis a main research question is formulated:

To what extent can an ABM simulate the influence of the locations of the canal cruise docks on the crowdedness in the city centre of Amsterdam caused by tourists?

To be able to formulate a comprehensive answer to the main research question, the research is divided into sub research questions that all focus on different aspects of this research. They are as follows:

1. How can the movement behaviour of tourists in Amsterdam be operationalized and modelled in an ABM?
2. What are the tourist movement patterns in the city based on the following two scenarios and what are the differences between the two scenarios?
   Scenario 1: The current canal cruise dock locations in the inner-city centre
   Scenario 2: The new canal cruise dock locations outside of the city centre along the waterways as proposed in the 'Watervisie 2040'
3. To what extend can the developed ABM be validated based on verification, validity and sensitivity of the model and how plausible are the found patterns?

1.4.3 Scope of the research

It is important to make the scope of this research clear. Firstly, the canal cruises that this research considers are only the ones with manned docks and are based on the list of canal cruises as listed on the website on Amsterdam Marketing. This excludes unmanned boat rentals and pedalo's from the research and small canal cruise companies that are not represented by Amsterdam Marketing are excluded as well. Secondly, this research does not consider the perception of the residents of Amsterdam. There will not be looked at how residents that live close to the canal cruise docks experience the crowdedness caused by them. It can be imagined that residents that live nearby the new locations for the canal cruise docks are not happy with more crowdedness caused by tourists in their neighbourhood. This NIMBY aspect of the relocation of the docks will not be researched. As well, this thesis is not a research about finding the best location to place the new docks. Only a small multi-criteria analysis is done to find possible options along the waterways proposed in the 'Watervisie 2040' report, but these locations are not designated to become canal cruise docks.

1.5 Reading guide

After this introduction to the problem that will be addressed in this thesis, the conducted research is described in the next chapters. The theoretical framework in chapter 2 provides an extensive literature review on relevant subjects such as the general theories of ABMs and its validation, modelling pedestrian and tourists' movements and tourist types in Amsterdam. Chapter 3 discusses the methodology of the research and the design of the canal cruise ABM. This is followed by chapter 4 in which the results of the research are presented and analysed. In chapter 5 the findings are summarized by answering the sub research questions, after which an answer to the main research question of this thesis is formulated. Lastly, the research process and choices are reflected on and recommendations for further research on this subject are made in chapter 6.

2 Theoretical framework

2.1 Agent-based models

2.1.1 ABM theory

In the problem statement the definition of an agent-based model was given, as defined by Ligtenberg et al. (2010). To resume, Gilbert (2008:5) defines agents as follows: *"Agents are either separate computer programs or, more commonly, distinct parts of a program that are used to represent social actors—individual people, organizations such as firms, or bodies such as nation-states"*. The author states that it is a crucial feature of ABMs that the agents can interact, as this is the main way in which agent- based modelling differs from other types of computational models. One of the most essential aspect of agents is that they also have behaviours, often described by simple rules. Their interaction with other agents in turn influence their behaviours (Macal & North, 2010). Macal & North (2010:151) also argue for the individual aspect of the agents: "By modelling agents individually, the full effects of the diversity that exists among different agents in their attributes and behaviours can be observed as it gives rise to the behaviour of the system as a whole". But, the understanding of an agent-based model is not gained from understanding just the behaviour of a single agent, it is understanding their behaviour as a collective (Hall & Virrantaus, 2016).

Another important aspect of an ABM is the virtual environment in which the agents will operate. For spatial simulations, environments are composed of points, areas and networks (Crooks et al., 2008). The environment can be an entirely neutral medium with little to no effects on the agents, or as in this model, the environment may be as carefully crafted as the agents themselves. Models in which the environment represents a geographical space are called 'spatially explicit' (Gilbert, 2008). Bierlaire, Antonini, & Weber (2003) identified two approaches in simulations: event-based simulations and time-based simulations. The latter is of interest for this thesis; the simulation proceeds in fixed time steps and all entities in the simulation are updated at each of these steps.

Bonabeau (2002) argues that the benefits of ABMs over other modelling techniques can be summed up in three statements. The first is that ABM captures emergent phenomena, the second is that ABM provides a natural description of a system and the third is that ABM is flexible. The author also identifies four areas of application for ABMs, with some examples:

1. **Flows**: evacuation, traffic, and customer flow management.
2. **Markets**: stock market, shopbots and software agents, and strategic simulation.
3. **Organizations**: operational risk and organizational design.
4. **Diffusion**: diffusion of innovation and adoption dynamics.

This thesis research falls within the 'flows' application of ABMs, as the tourist flows in the Amsterdam city centre will be studied. Butakov, Nasonov, Knyazkov, Karbovskii & Chuprova (2015:523) have used the ABM approach in their framework for detectors layout optimization and state that *"Pedestrian flows formed by people's movements have a great influence on different characteristics of the crowded place."* This emphasizes the influence that the tourist in the city of Amsterdam have on their environment.

In the scientific problem statement the suitability of using agent-based models for policy making and analysis was already emphasized on. Joffre et al. (2015) add to that that ABMs as a tool can be used to promote communication between stakeholders, researchers and decision makers that are involved in policy processes. Using ABMs in this way facilitates discourse and discussion among the people with interest.

2.1.2 Validation of ABMs

Within the field of agent-based modelling a good sensitivity analysis, verification and proper validation of developed ABMs are seen as a key aspect (Filatova et al., 2013; Gräbner, 2018; Klügl, 2008; Ligtenberg et al., 2010). These methods test the reliability and robustness of the outcomes of the AMB. Filatova et al. (2013: 2) state that "*Sensitivity analysis, verification, and validation become especially vital when ABMs are applied in a policy context to inform management challenges*". As this policy context is an important part of the research conducted in this thesis, it is thus important that the developed canal cruise ABM is validated in a proper way.

The complete validation process of an ABM consists of the verification, the validation and the sensitivity analysis, in this order (Cooley & Solano, 2011). Verification tests whether the model is doing what it is supposed to be doing, thus conceptual model has to be implemented adequately and the model is supposed to be bug free (Gräbner, 2018). The verification takes place after the model is built and before the validation of the model, usually it also takes place during the model building process. The verification involves two steps: analysing what the model is doing and comparing this to what the model is supposed to be doing (Gräbner, 2018).

Ligtenberg et al. (2010) break down the validation of the behavioural performance of the simulated system into three levels: the first level validates how well the ABM represents the real world at the level of the global outcomes, the elements of validation are the generated patterns and the accomplished goals. In this study the generated patterns of the flow of tourists can be compared to the real situation of crowdedness in the city centre: are the most crowded places the same in both 'worlds'? The second level validates the representation of the processes within an agent-based model, and the elements of validation are the created beliefs, the created preferences and the created proposals. The third level of validation is knowledge representation, with the elements of validation being the facts and the rules that an agent needs to carry out their task. This verifies if these facts and rules sufficiently represent the knowledge used by the real-world agents, in this case the actual tourists.

Klügl (2008) affirms that there are indeed all kinds of different ways to validate models, but classifies these different ways into two dimensions: face validity and empirical validity. The author (2008: 39) defines face validity as "*showing that processes and outcomes are reasonable and plausible within the frame of theoretic basis and implicit knowledge of system experts or stake-holder*." and empirical validity as follows: "*empirical validity derived from empirical validation uses statistical measures and tests to compare key figures produced by the model with numbers gathered from the reference system*". Due to a lack of useful statistics about pedestrian tourist in Amsterdam to use as a ground truth, and a timeframe which is not sufficient to execute a full ABM validation, there will be mainly made use of face validation in this thesis. Klügl (2008) emphasizes the importance of face validation during the design of an ABM and identifies three different methodological elements within this validation type, to be executed in this order:

1. **Animation assessment**: assessment of the animation of the overall simulated system to check if the simulation behaves like the original system. Shows the simulated system from a bird perspective, thus the dynamic aspects must emerge in an easy way detectable by a human expert. The observations can be on an individual level following the behaviour of a specific agent, but it is also used to assess general flows in the model.
2. **Immersive assessment**: follows the route of one particular agent to assess if the behaviour of the simulated agent is appropriate. If the simulation software and interface allow participation, the human expert assesses the reactions of other agents on the behaviour of the participation-controlled agent.
3. **Output assessment**: assessing the plausibility of the output values of the simulation. As well, assessing the relations between those values and the dynamics and trends of the different output values from multiple model runs. Can be applied on the macro level and on the micro level.

Another important step in the model validation process is the sensitivity analysis. A sensitivity analysis shows the effect of the different parameters and their values; calibration then determines the appropriate values (Klügl, 2008). Ten Broeke, van Voorn & Ligtenberg (2016) selected three common goals in ABM research for which sensitivity analysis is used: the first one is to gain insight in how patterns and emergent properties are generated in the ABM; the second goal of sensitivity analysis is to examine the robustness of emergent properties; the third goal is to quantify the variability in ABM outcomes resulting from model parameters. Furthermore, they selected three methodologies to execute a sensitivity analysis, one of which will be used in to perform a sensitivity analysis on the canal cruise model: sensitivities based on one-factor-at-a-time or OFAT. Within this methodology one parameter is changed at a time while keeping all the other parameters fixed (ten Broeke et al., 2016). The OFAT method reveals the relationships between the varied parameter and the output, improving the understanding of the model mechanisms. Extreme values are assigned to the altered parameter to see the different results.

2.2 Modelling tourist movements

2.2.1 Pedestrian movements

In the Visitors Survey Amsterdam Metropolitan Area, carried out by Amsterdam Marketing, it is stated that 78% of the cities visitors explore Amsterdam by foot (Amsterdam Marketing, 2016). Therefore this research will only focus on walking tourists, and the pedestrian movements will be modelled. Haklay, O'Sullivan, Thurstain-Goodwin, & Schelhorn (2001) state that there are multiple approaches to the modelling of pedestrian models. The authors identify models on different geographical scales: the microscale movement in which obstacle avoidance could be measured, to mesoscale of individuals planning shopping trips with multiple stops, and up to the macroscale of general flows of people between places. Antonini, Bierlare, & Weber (2004) have the same view on this and identify two different approaches to pedestrian movements: pedestrians as a flow and pedestrians as a set of individuals or agents. They state that *"The complexity of pedestrian behaviour comes from the presence of collective behavioural patterns (as clustering, lanes and queues) evolving from the interactions among a large number of individuals"* (Antonini et al., 2004:2). However, Helbing, Molnár, Farkas, & Bolay (2001) argue that even though pedestrians have indeed preferences, aims and destinations on a personal level, the dynamics of pedestrian crowds are unexpectedly predictable. After years of analysing pedestrian behaviour by investigating video films and combining it with results from other pedestrian studies, they have formulated four main observations about pedestrians' movements:

1. Pedestrians do not like to take detours to their next destination and they mostly choose the fastest route to get there. Even when the direct route is crowded or when they have to move to the opposite direction of the desired walking direction, they still take favour to the fastest route. As well, they prefer a route that goes mainly straight ahead if it is not significantly longer than alternative curvy routes.
2. Pedestrians choose to walk at their own desired speed, corresponding to what they find the most comfortable or the least energy-consuming. This does not take hurrying into account to make it in time to a specific destination. The desired speed of pedestrians is Gaussian distributed with a mean value of 1,34 meters per second, having a standard deviation of 0,26 meter per second.
3. Pedestrians maintain a certain distance between themselves and other pedestrians and borders such as walls and obstacles. If the pedestrian is in a crowded area or in a hurry this distance is smaller. Resting pedestrians, for example at train stations or lying at a beach, uniformly distribute themselves across the available area if they are not acquainted with other pedestrians in the area. If pedestrians know each other they may form groups that behave in the same way as an individual pedestrian. The more crowded the area is, the smaller the distance in between is.
4. Pedestrians tend to not adjust their movement preferences in every new situation, as they act in an automatic way. A good example of this is when pedestrians already enter a train or elevator when others are still trying to get off, resulting in delays or hindrance.

Despite these general observations about pedestrian movements there is still an uncertainty about the behaviour of pedestrians on the individual level. However, these uncertainties are levelled out if the movements are observed at a macroscopic level such as pedestrian streams and flows (Helbing et al., 2001). The authors argue that pedestrian streams and corresponding spatiotemporal patterns emerge from nonlinear interactions from individual pedestrians. These self-organized patterns appear even without assuming strategic considerations, communication, or the imitative behaviour of pedestrians.

2.2.2 Pedestrian movements in ABMs

Antonini et al. (2004) discuss the modelling of pedestrian movements with the use of ABM. The authors state that all the ABMs are also microscopic models that attribute a kind of intelligence to the agents: simple behavioural rules are implemented in the agents to be able to reproduce more complex collective phenomena through simulation. In ABMs, the behaviour of agents representing individual pedestrians can be modelled as a sequence of specific choices, such as the choice of the destination, the choice of the schedule, the choice of a more broad direction, or the choice of where to go in the next time step (Bierlaire et al., 2003).

Schelhorn, O'Sullivan, Haklay, & Thurstain-Goodwin (1999) describe the outline for their STREETS model, a two stage ABM that they developed to investigate pedestrian behaviour in urban centres. In Haklay et al. (2001) a more extensive explanation of the STREETS model is given. In both articles the movements of pedestrians are described as an outcome of two components. The first component is the configuration of the street network of urban space. The second component is the location of specific attractions such as shops, offices and public buildings on that street network. Figure 3 shows the conceptual model of the STREETS model. The model can be divided in two phases: the 'pre-model' and the ABM. The aim of the pre-model is to create a population of the model that is statistically valid, based on socioeconomic and other (spatial) data about the study area. The agents build in this phase are assigned socioeconomic and behavioural characteristics. Socioeconomic characteristics such as gender, age and income are used to create an activity schedule for each agent. The schedule, a sequence of locations that the agents tend to visit, consists of waypoints on the street network that will be visited using shortest-path determination. This relates to the statement of Borgers & Timmermans (2005: 4) that most models that look into pedestrian behaviour assume that pedestrians have "*a predefined set of destinations to visit, activities to perform or a route to follow through the public space*". By using socioeconomic characteristics as a way to populate the STREETS model, a variety of agents is created whose behaviour is expected to differ. The behavioural characteristics assigned to the agents are for example speed, (visual) range and goal-fixation. Variations in these characteristics allow different behaviours to occur.

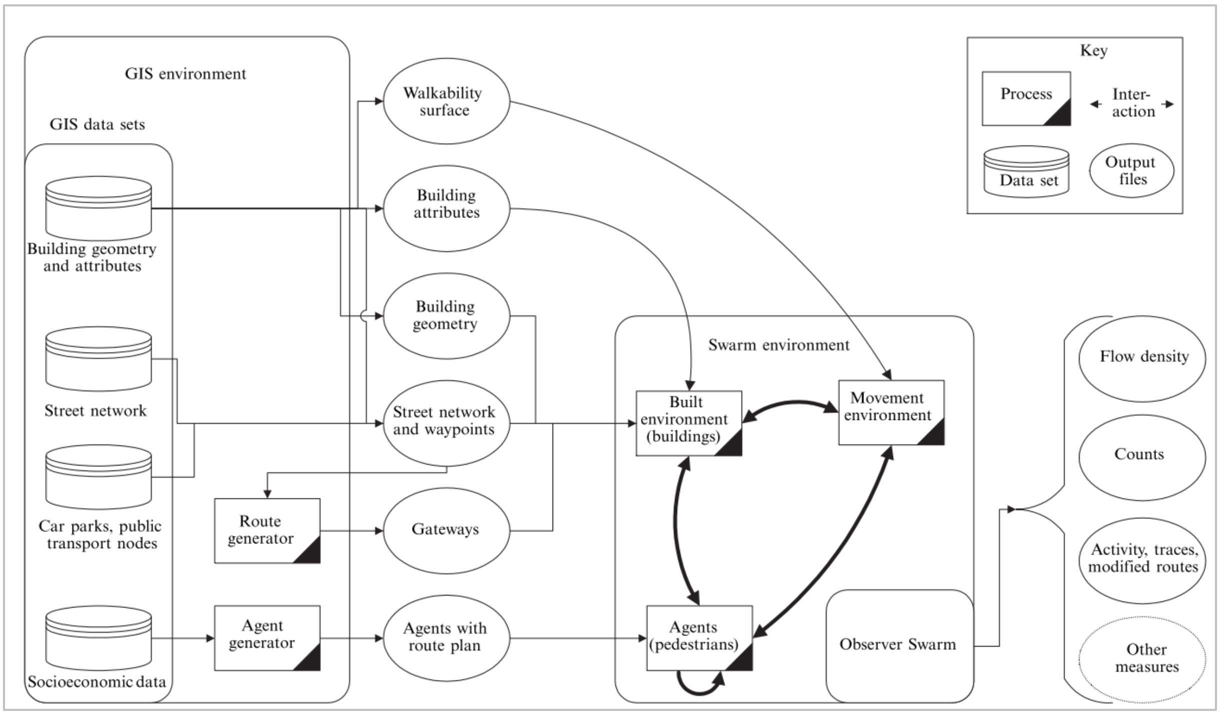

Figure 3 –the overall structure of the STREETS model
Source: Haklay et al., 2001

Phase two of the STREETS model can be started: the aim of the ABM is to simulate the movements of the created population around the urban district. The agents will enter the model via gateways, such as bus stops or car parking's, with a planned sequence of waypoints as their route. The STREETS model is developed completely within the Santa Fe Institutes 'Swarm' simulation environment. Haklay et al. (2001) give a comprehensive description of the modules that are implemented in the simulation environment and used for the STREETS model. The modules create five levels of behaviour on different scales. The 'mover' module', moving agents to the next walkable area, the 'helsman' module, maintaining the correct direction of the agent, and the 'navigator' module, avoiding dead ends, allow each agent to find its own route from waypoint to waypoint according to their schedule. The two other modules, the 'chooser' module and the 'planner' module, respectively enable interaction of the agents with their environment and changes to the initiated plan of the agent. Figure 4 shows the interaction of the five modules with the other components of the ABM.

The approach to agent movement of the STREETS model is modular and loosely hierarchical. The authors Haklay et al. (2001:355) state about this: "*The main purpose of adopting a modular approach is pragmatic, enabling us to cope with the complex, multivariate state of the agents in this environment, as well as supporting the implementation of the model in a relatively clear and robust way.*" The STREETS model and its underlying theory will function as an example to the ABM for this thesis.

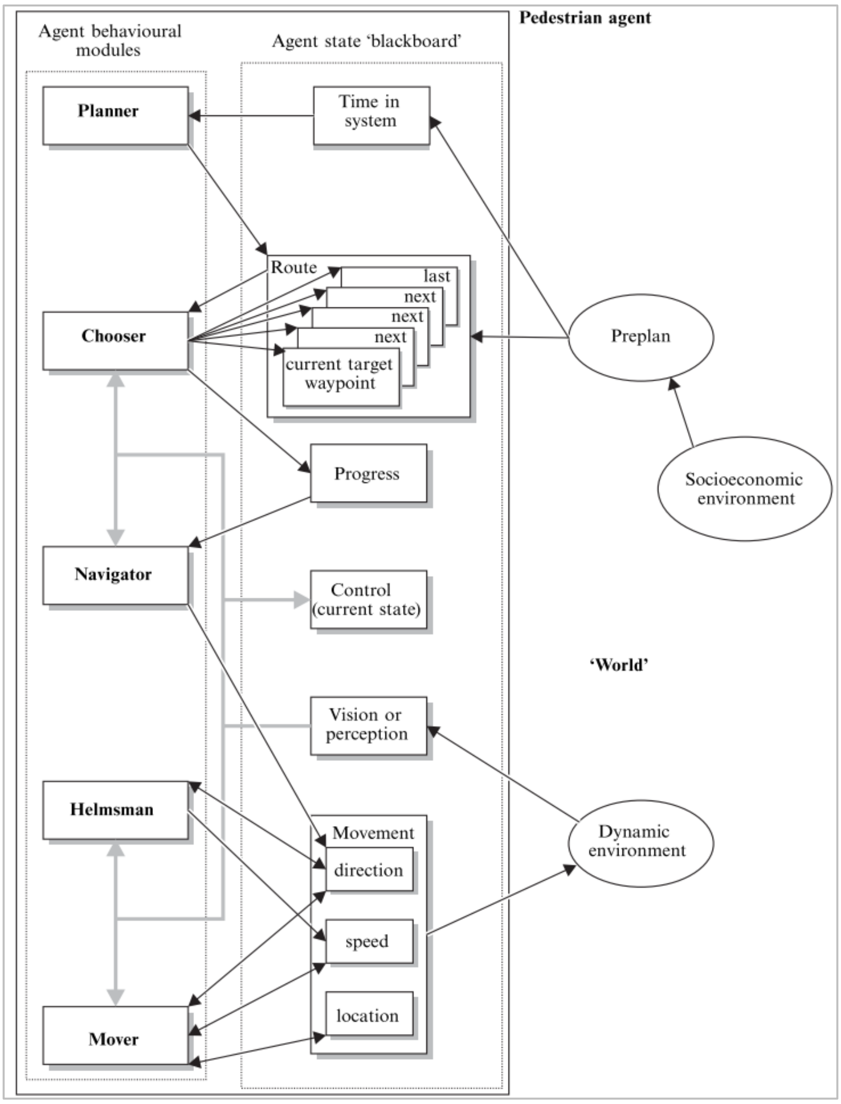

Figure 4 – The interaction between the SWARM control modules and the agent in the STREETS model
Source: Haklay et al., 2001

2.2.3 Tourist movements

The understanding of tourist movements in a specific destination and the influencing factors on the time-space relationships that they have with destinations and attractions is important, as it has extensive implications for policy, transport, infrastructure, product development and tourist management (Edwards & Griffin, 2013). McKercher & Lau (2008) add to this that the understanding of tourist movements within a destination play a fundamental role in understanding tourist behaviour in general. However, as McKercher & Lew (2004) state, there is little empirical or conceptual research done on the modelling of tourist itineraries. The reason for this is that there is a practical problem in the gathering of data: the listing of destinations and stopovers assume that the most direct route is taken between points, but this assumption cannot be made. The research that was done on this topic was with the use of classic data gathering such as participatory and non-participatory observations and questionnaires (Grinberger et al., 2014; McKercher & Lew, 2004). In the last decades however, the development of new digital information technologies made new and advanced tracking methods possible that produce high-resolution spatial and temporal data regarding the movements of tourists (Grinberger et al., 2014).

Most of the research conducted related to tourist movements is about inter-destination movements rather than intra-destination movements. McKercher & Zoltan (2014) assign this to three factors, that did not affect research in the inter-destination tourist movement research field. The first factor is the fineness of data: in inter-destination research the destination is the unit of analysis, whereas in intra-destination research a much more precise unit of analysis is required on the scale of meters. The second factor is the reliability of the tourist as a researcher: with a required fineness of scale it is important how accurate the tourist is with the report of their movements. Both of these issues are resolved with the emergence of new and accurate digital tracking devices. The third limiting factor is the lack of theoretical framework about inter-destination tourist movements. However, Lew & McKercher (2006) have developed a framework for to analyse inter-destination tourist movements based on the geomorphology of the destination, the spatial location of attractions and accommodation nodes, transport routes, mode and accessibility, tourist time budgets, tourist motivation, and destination knowledge. These movements can be modelled in two dimensions. The first one are territorial models, which reflect the impact and perception of distance and intervening opportunities. Figure 5 shows these models: in the different types of models it shows how far tourists move away from their accommodation. The accommodation is the starting point of their explorations within their vacation destination. The rings in the different types of models represent relative distance that tourist move. The larger and wider the rings, the further away from their accommodation they explore intra-destination. How far a tourist will explore is dependent on the destination and tourist characteristics.

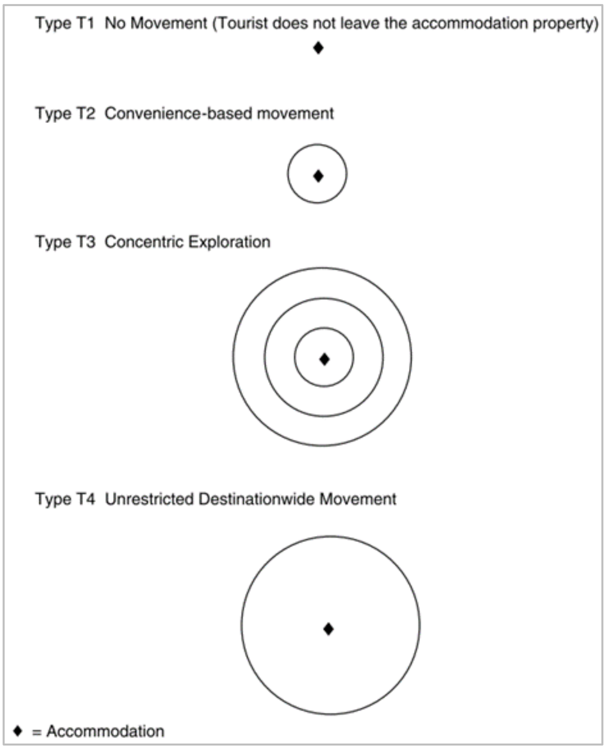

Figure 3 - Territorial models of tourist behavior in local destinations
Source: Lew & McKercher, 2016

The second dimension into which tourists can be modelled is linear. Figure 6 shows that there are three main linear models. The linear path models reflect the geometry of tourists movement away from their accommodation point. They simplify the actual movement patterns that are shaped by the geography of a place.

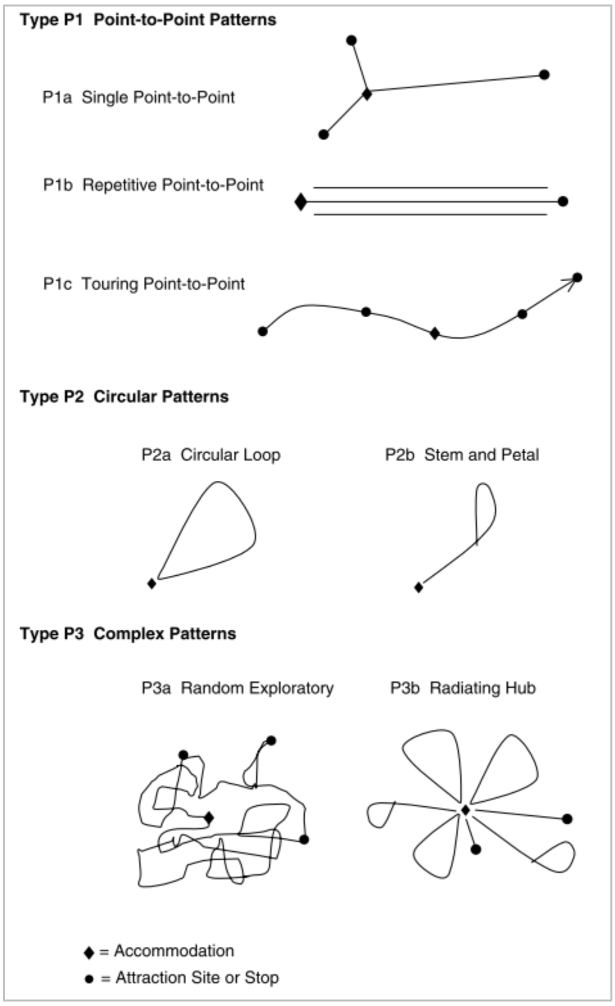

Figure 6 - Linear path models of tourist behaviour in local destinations
Source: Lew & McKercher, 2006.

There are multiple factors identified as of influence on tourist movements. McKercher & Lau (2008) state that the number and spatial organization of attractions and whether they are clustered or dispersed influence whether tourists move widely or narrowly within the destination. McKercher & Lew (2004:40) mention that *"the spatial distribution of tourists, either on a macro scale across destinations, or on a micro scale within a destination is influenced by a number of factors including distance decay, market access, time budget availability, trip characteristics and socio-cultural or demographic characteristics."*. In further research conducted by Lau & McKercher (2006) they divide the factors that influence intra-destination tourist movements into three major aspects:

- **Human 'push' factors**: these are the individual differences such as tourist role, the travel party someone is with, personal motivations and if they have visited the destination before. Tourists have their own 'environmental' or 'tourist' bubble that reminds them of home, in which they tend to stay, dependent on their characteristics. Based on the human characteristics there are four types of tourists identified, that all have their own way of handling this bubble: the *organized mass tourist* mostly confines their activities to their 'environmental' bubble with well-planned itineraries, and fixed time-budget and accommodations, which results in routine movement patterns; the *individual mass tourist* has a more flexible movement pattern as they have more control over time and itinerary, but are still confined by their 'environmental' bubble; the *explorers* have movement patterns that are less confined by their 'environmental' bubble, and are willing to discover new places; the *familiar tourist* is known with the destination and this makes them more adventurous, resulting in high flexibility in their travelling schedule and movement patterns.

- **Physical 'pull' factors**: physical factors from the external physical environment that affect tourist movements can be divided into three aspects: destination configuration, attractions and the transport network. Tourist movements are influenced by the number and distribution of attractions and activities available at the destination: primary attractions have the biggest pull on tourists.
- **Time factor**: time is a limited and fixed resource for tourists and will either encourage or discourage the movement patterns of tourists. The longer the stay, the more places will be visited. Short-stay and first-time tourists will focus on primary attractions: time scheduling and the length of the stay are two big aspects of the movements of tourists.

There has not been a lot of empirical research on tourist movements within a destination. Therefore, in this research the tourist's movements will be based on made assumptions. There are mentioned influencing factors, which will be the base for the movements. It is assumed that each type of tourist has their own way of moving around in the city.

2.3 Tourists types

2.3.1 Visitor profiles Amsterdam

Based on an extensive research conducted to map out the visitors of Amsterdam, Amsterdam Marketing describes four types of tourist that visit the Amsterdam Metropolitan Area (Amsterdam Marketing, 2016) . The four types of tourists all have their own main characteristics such as age, length of stay and interests in activities. The agents in the agent-based model will be based on these characteristics.

The first visitor profile is the **city trippers**. This is the most common group of visitors in Amsterdam and are not of Dutch nationality. 60% of this group's nationality is from one of the seven core markets of Amsterdam (Germany, Great-Britain, United States, France, Italy, Spain and Belgium). On average, this group spends 3.8 days in the city, with 3.9 friends. It is the youngest core visitor group, with an average age of 35. The main interests of this group are culture, highlights and entertainment and 82% visits at least one museum. They give their Amsterdam experience a rating of 8.5, making them the most satisfied group of tourists.

The second visitor profile is the **Dutch same-day visitors**. They do not have an overnight-stay in the city and only spend around five hours in the city. They are generally repeat visitors, as 87% has already been in Amsterdam before and thus quite familiar with destination. The average age of these visitors is 50 and they mostly come with their partner or family. Their main interest varies a lot, but they mostly come for culture (32%), for shopping (13%), or for a specific attraction (10%). This group of visitors rates the city as a 7.9.

The third visitor profile is the **coastal visitors**. It is a small group, but they have a distinctive profile. They spend an average of six nights in the coastal areas of the Amsterdam Metropolitan Area. They are mostly from Germany (49%) or the Netherlands (32%). They are well-known with the area and plan their trip far in advance. They are on average 45 years old and visit the coastal areas with their family and children. 26% of this group makes a day-trip to the city of Amsterdam to go sight-seeing and shopping. As well, restaurants and cafes are in special interest of this group. They rate the Amsterdam Metropolitan Area an average of 7.9.

The fourth visitor profile is the **conference attendees**, which are international overnight visitors whose main reason for visiting is to participate in a conference. They have an average age of 41 an 75% of them is male. They mostly come to Amsterdam alone (51%) of with colleagues (38%). Although their prime reason to come to Amsterdam is to attend a conference, they tend to stay two more days in the city independently from the conference. They are mostly interested in cultural activities; 40% of them visits a museum during their stay. A lot of this group are repeat visitors, but they still go to see the main big highlights. This group of tourists rates the city an average of 8.2.

2.3.2 Visitor profile canal cruises

Additionally to these visitor profiles, the research of Amsterdam Marketing contains a visitors profile of the tourists that take a canal cruises during their stay in Amsterdam (Amsterdam Marketing, 2015). Figure 7 shows from which countries the tourists are that take a canal cruise, the biggest groups are from the UK and Germany. The canal cruise visitors stay in the city of Amsterdam for an average of 3-5 days. Two-third of the visitors is a first-time visitor of the city, but almost 20% has been in the city already 6 - 10 times before. Almost half of the visitors take a canal cruise together with their family or partner, followed by with friends (16,6%) or alone (12,2%). The biggest age group is 21 - 30 years, followed by 31-40 years. The divide between male and female visitors is almost equal: 47,9% is male and 52,1% female (see figure 8). The canal cruise visitor profile also lists other attractions that the visitors tend to visit during their stay in Amsterdam, and it appears that the canal cruise visitors tend to only stay in the city centre, as all these attractions are located there, in random order:

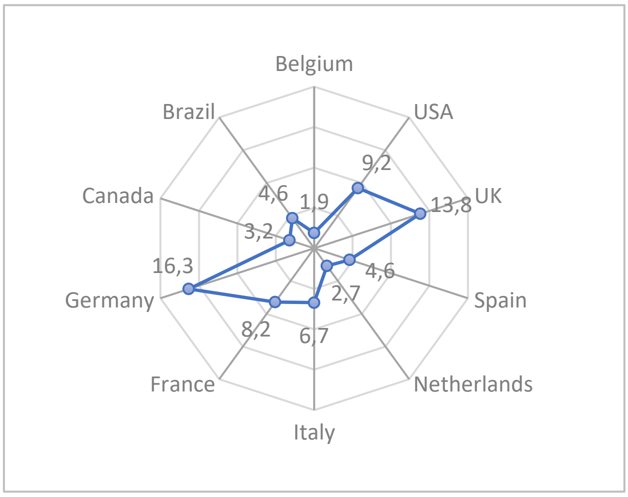

Figure 4 - Percentages of country of origin from tourists that take a canal cruise
Source: Amsterdam Marketing, 2015

- Walking around the red-light district
- The I Amsterdam Letters (Removed since December the 3rd 2018)
- Heineken Experience
- Diamond museum
- Visiting a diamond polishing factory
- Van Gogh museum
- Rembrandt house museum
- De Nieuwe Kerk
- Royal Palace on the Dam square
- De Oude Kerk
- Anne Frank House
- Zaanse Schans

With these characteristics of the canal cruise visitors, it is possible to operationalize the types of tourists visiting the canal cruises for the agent-based model. It is tried, based on this operationalization, to create agents in the model with behaviour that resembles the actual tourists in Amsterdam. This was done in an attempt to generate results and outputs of the canal cruise model that can be said to be plausible. The occurring movement patterns are plausible if they can be related to the real-world situation.

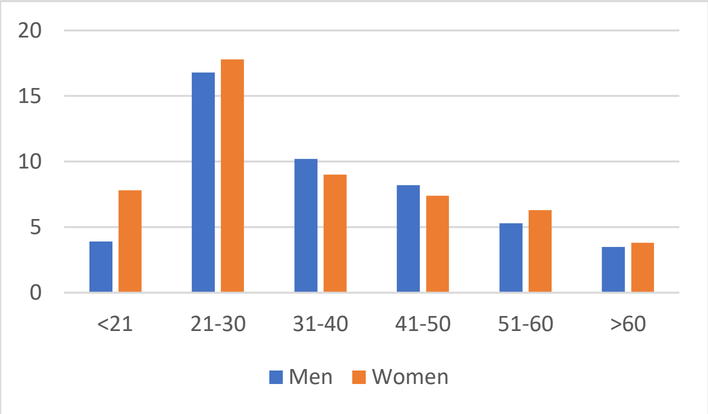

Figure 8 - Percentages of age groups that go on a canal cruise, divided per sex
Source: Amsterdam Marketing, 2015

3 Methodology

3.1 Conceptual design

3.1.1 General model description

In the theoretical framework a comprehensive explanation of the STREETS model as developed by Schelhorn et al. (1999) and Haklay et al. (2001) was given. The canal cruises ABM will be based on the framework of this model with some adjustments to fit our purpose. The purpose of the developed model is to build a simulation that shows the movements of tourists, depending on the locations of the boarding and disembarking docks of the canal cruises. The aim is to find out *if* the locations of the docks are influencing the flows of tourists in the city centre of Amsterdam and in *what way*.

Like the STREETS model, the canal cruises model can be divided in two phases: the 'pre-model' in which a statistically valid population is created, and the actual ABM. The pre-model combines socioeconomic and behavioural characteristics and other data to create realistic agents. In the canal cruise model, the agents represent the different types of tourists in Amsterdam that take a canal cruise and subsequently walk around in Amsterdam to other destinations. These destinations are based on the operationalization of the main tourist types of Amsterdam as discussed in section 2.3.1. In section 3.2.2 a broad description of the agents with its state variables is given. The four kind of agents have a predefined schedule that is corresponding with the type of tourist that they represent.

Besides creating a statistically valid population, other data is also implemented in the 'pre-model'. As stated in the theoretical framework, another important aspect of an ABM is the virtual environment in which the agents will operate. This can be an entirely neutral medium with little to no effects on the agents, or as in the STREETS model, the environment may be as carefully crafted as the agents themselves. For the canal cruise model, the GIS data that is implemented creates the environment of the model. The study area is the city of Amsterdam, but the city will be represented in the model in a simplified way, with the pedestrian roads as a network that the agents can move around on. Added to the pedestrian network are the locations of the canal cruise docks and the locations of the four main type of activities that tourists engage in while in Amsterdam: museums, attractions, restaurants and cafes, and shopping areas. Figures 9, the whole study area, and figure 10, zoomed in on the city centre, show the model at the initial state, with different colours for each type of activity and the docks. As mentioned before, Haklay et al. (2001) argue that the way pedestrians move is the outcome of two components: the configuration of the streets network and the specific locations of attractions. In the canal cruise model thus the used pedestrian network represents the first component of this theory and the locations of the activities represent the second component. In section 3.4 all used datasets and alterations to the data to create the pre-model are discussed further.

Figure 9 - Initial state of whole study area in the model

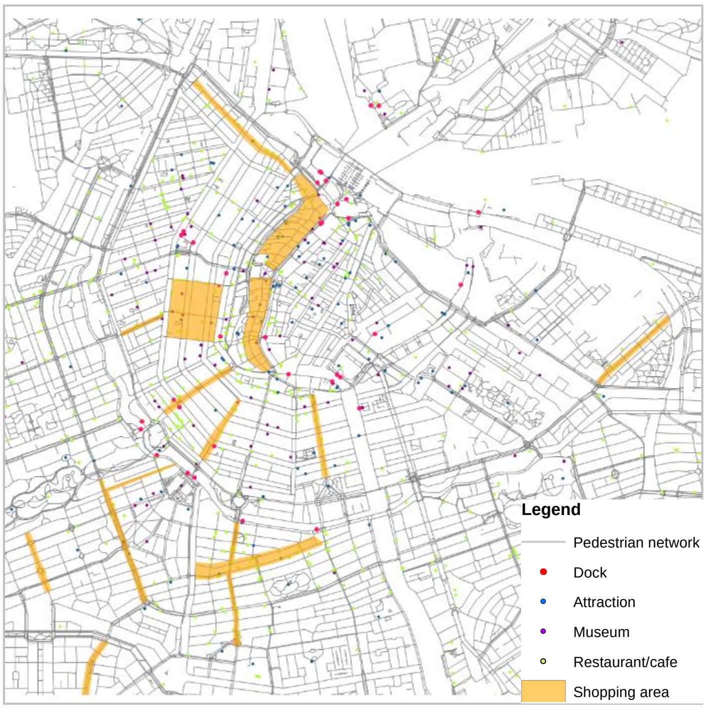

Figure 10 - Initial state of the model, zoomed in on the city center

The second phase is the ABM. The two inputs of the ABM are the created population and the environment consisting of the pedestrian network, the dock locations and the activity locations. In the STREETS model agents enter the environment via gateways. The gateways in the canal cruise model are the boarding and disembarking docks of the canal cruises. Agents enter the model as if they disembark from a canal cruise and start to explore the city by foot. Based on their characteristics they have a predefined schedule of activities to do when they enter the model. Each agent has a random start time, after which it goes to their next waypoint on the pedestrian network as defined by its schedule. When arrived at their goal activity, they stay a certain amount of time at the activity (see section 3.2.4 for the specific time frame for each activity). When this certain amount of time has passed the agent leaves the activity to continue to their next activity as defined by their schedule. For this second activity a certain amount of stay time is given as well. After this time has passed, the agent is ‘free’ to wander around the model to ‘explore’ the city by foot within a specified distance range, corresponding to the type of tourist that they represent. Each run of the model represents one day, and all agents die at the time of 23:00. Each timestep of the model is 10 minutes. Figure 11 contains the conceptual or schematic design of the canal cruise model.

For the development of the canal cruise model GAMA was used: an opensource modelling and simulation engine. In section 3.5 there will be further elaborated on the GAMA software. The GAMA differs from the software that was used to create the STREETS model. Hence, the five modules, creating five levels of behaviour on different scales, as discussed in the theoretical framework are not used in the canal cruise models. However, the functioning of GAMA includes some of the components of the modules of the SWARM software that was used for the STREETS model. For example, the moving skill that moves the agent along the walkable graph resembles the ‘mover’ module and a shortest path optimizer makes sure that the agents walk in the right direction and avoiding dead ends, like the ‘helsman’ and ‘navigator’ module.

To get to the destinations of their schedules the agents move along the pedestrian network according to the AStar shortest-path algorithm. De Smith, Goodchild, & Longley (2018) define the shortest-path optimizer AStar (or A*) as a goal-directed best-first algorithm. To reach the goal in the most preferable way it selects which node to visit next by computing the Euclidean distance of each vertex from the target, adding this to the distance that is already established via the network to this vertex. Generally, the AStar optimizer visits less nodes for a specified origin-goal route than other shortest-path algorithms and is thus faster on average.

With the development of the model the four main observations about pedestrian movements by Helbing et al. (2001) were kept in mind. The first observation, pedestrians do not like to take detours and generally take the fastest route to their destination, is initialized in the model by using the afore mentioned AStar shortest-path algorithm. The second observation, that pedestrians move at their own desired speed, is initialized as the agents act as autonomous pedestrians with a random desired speed as defined in their state variables. The fact that they act autonomously at the same time interferes with the third observation, that pedestrians like to keep a certain distance between themselves and obstacles on the walkable area. In the canal cruise model, the pedestrian network is implemented as a graph, thus making it impossible to implement this observation, as pedestrians on the same road would not be able to cross each other. The fourth observation, that pedestrians do not adjust their movement preferences in every new situation, is on the other hand again implemented in the model by the autonomous nature of the agents.

The canal cruise model counts per road how often it gets passed by agents, creating outputs showing which streets are passed the most. The redder a street gets; the more agents have passed this street along the route of their schedule. This visualization by colour shows which areas of Amsterdam are the most crowded.

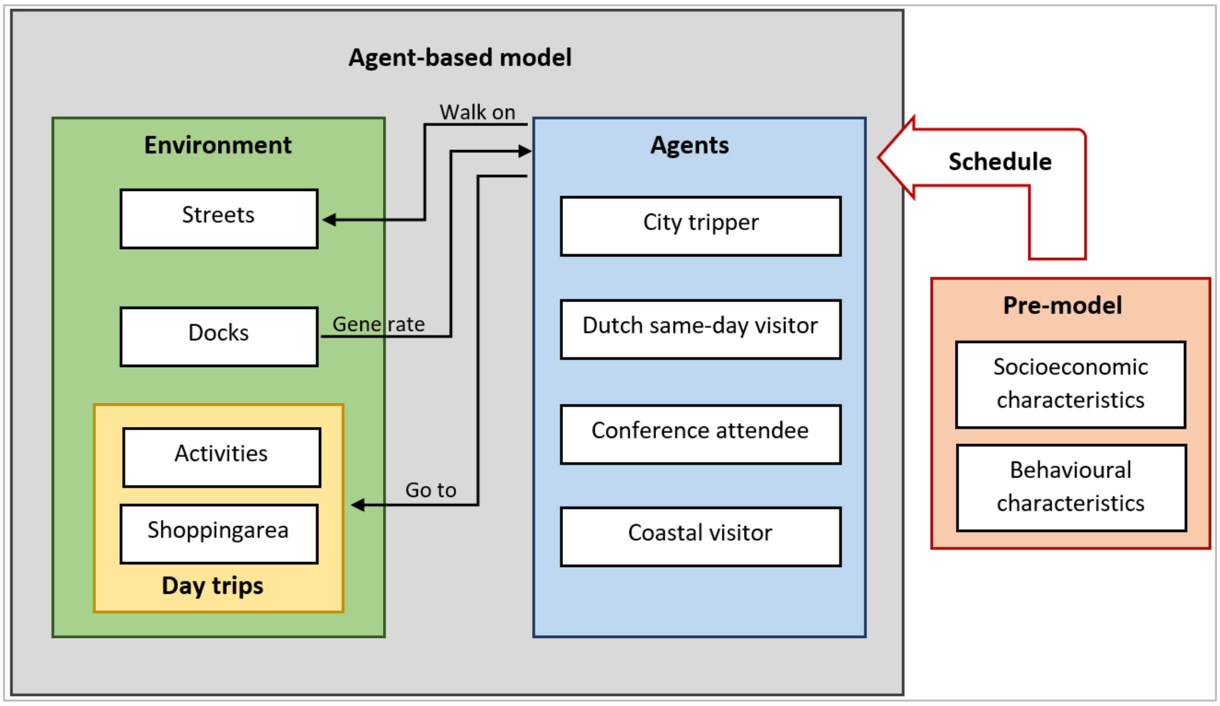

Figure 11 - Conceptual model of the canal cruise model

It can be seen in figure 11 that the ABM consists of the following entities, or species as it is called in GAMA, each with their own state variables and scale factors: city trippers, Dutch same-day visitors, coastal visitors, conference attendees, roads, docks, activities and shopping areas. The first four are the agents representing the tourists. As these entities and their behaviour are the most important for the canal cruise model they will be discussed extensively in the next section.

3.1.2 Agents

As discussed in the theoretical framework, an agent-based model consists of agents that interact with each other and their environment. The agents in the canal cruise model function as individual entities but are part of four types of tourist 'personalities' with corresponding behaviour. These tourist 'personalities' are based on the visitor profiles as identified by Amsterdam Marketing and discussed in section 2.3.1. In this the canal cruise model, there is thus a multi-agent model built, as there are multiple groups of agents. As (Torrens, 2010: 431) says; "*Multi-agent models' are generally built with many individual agents, each of which may play a different role or assume a set of distinct tasks in a model of collective behaviour. 'Multi-agent systems' adopt a synoptic view, often from the bottom-up, to consider individual agency in the context of a larger or collaborative phenomenon. Agents in a multi-agent system usually interact with (or within) an environment that is modelled explicitly in simulation*.".

Based on the STREETS model the different types of agents representing tourists are operationalized on socioeconomic characteristics and behavioural characteristics. The socioeconomic characteristics are used to create a schedule for each agent. These types of characteristics can be linked to the work of Lau & McKercher (2006). These authors state that there are three major factors that play a role in the movements of tourists, as discussed in the theoretical framework: human push factors, physical pull factors and time. The behavioural characteristics are influencing the behaviour of the agents in the model. Table 1 shows the operationalized agents per characteristics type, combined with the work of Lau & McKercher (2006).

Table 1 – Operationalization of the tourist types based on the theory of Haklay et al. (2001) and Lew & McKercher (2006)

	Socioeconomic characteristics			Behavioural characteristics		
Tourist type	**Human push factors**	**Physical pull factors**	**Total time budget**	**Start time**	**Speed**	**Range**
City trippers	-First time visitors: do not explore very broad -In groups of 4	-Locations of museums -Locations of attractions	3.8 days	09:00 – 21:00	1.08 – 1.60 m/s	7 km
Dutch same-day visitors	-Repeat-visitors: explore broader -Duo's or family	-Locations of museums -Locations of shops	5 hours	09:00 – 21:00	1.08 – 1.60 m/s	10 km
Coastal visitors	-Well-known with the region: explore broader -With family	-Locations of shops -Locations of restaurants/cafes	1 day	09:00 – 21:00	1.08 – 1.60 m/s	10 km
Conference attendees	-First time visitors: do not explore very broad -Alone or in little groups	-Locations of museums -Locations of restaurant/cafes	2 days	09:00 – 21:00	1.08 – 1.60 m/s	7 km

The activities are also entities in the agent-based model. These are locations that influence the movements of tourists when they enter the model from the docks of the canal cruises. Based on the characteristics of the agents they are more likely to move towards special types of activities: as an example, city trippers are likely to go to a museum. There are four types of activities: museums, shopping areas, restaurants/café and attractions.

The predefined schedules of the agents are based on the characteristics as described in table 1. Thus, the day of a city tripper agent in the canal cruise model is as follows: the agent enters the model at a random canal cruise dock, next the city tripper agent goes to its first activity which is a randomly selected museum, the agent walks along the graph representing the pedestrian network of Amsterdam to the museum, the agents stays at the museum a certain amount of time, after which it goes to its next activity, which is a randomly selected attraction, at 23:00 in the model the day is over and all agents die. The schedules of the Dutch same-day visitor, the coastal visitor and the conference attendee agents work essentially in the same way, except that the activities are different. The Dutch same-day visitors' first activity is a museum, after which a shopping area is the next activity. A coastal visitor first goes to a shopping area and afterwards to a restaurant or café. And lastly, an agent representing a conference attendee first visits a museum and then goes to a restaurant or café. The randomly selected activities of all the agents have to keep the maximum range of the type of tourist into account. Dutch same-day visitors and coastal visitors are identified as already familiar with the city of Amsterdam, thus exploring broader. This gives them a range of 10 kilometres in the canal cruise model. A city tripper and a conference attendee are not as familiar with the city as the two other types of tourists and thus explore less broad, giving them a range of 7 kilometres in the canal cruise model.

3.1.3 Model assumptions

There are some assumptions to be made regarding the model. These assumptions set rules to the behaviour of the agents and provides initial values for some of the model parameters. The canal cruise model is a representation of the real-world situation but a very simplified version. It is tried to implement the current model in such a way that it generates plausible tourist movement patterns.

Because there are no absolute numbers on how the four types of tourists are divided exactly it is necessary to make assumptions based on the data that is available. There is no official number available yet on the amount of tourists in 2017 or 2018, but Couzy (2018) estimated that there were 20,5 million tourists in the city of Amsterdam in 2017, based on numbers of Amsterdam Marketing and the NBTC (Nederlands Bureau voor Toerisme & Congressen). This means that on average there were around 56.000 tourists in the city per day. A little bit less than half of these visitors are day-visitors (Briene, Meurs, Krins, & Rundberg, 2018). Amsterdam Markting (2018) has stated that approximately one-third of the overnight stays were classified as a business stay. It is important to keep in mind that the city trippers are said to be the biggest group of visitors in Amsterdam, and that the coastal visitors are only a small percentage (Amsterdam Marketing, 2016). This brings us to the following division of types of tourists during one day in Amsterdam, see table 2. Of all tourists visiting Amsterdam, 28% goes on a canal cruise (Amsterdam Marketing, 2016). In the ABM only the tourists that go on a canal cruise are taken into account. Thus, from the estimated numbers of tourist from each tourist group, 28% actually went on a canal cruise (see table 2). This means that 15.680 tourists in total go on a canal cruise each day. If this number is multiplied by 365, 5,7 million tourists should have taken a canal cruise in 2017. As stated before, 5,2 million tourists went on a canal cruise in 2016 (OIS Gemeente Amsterdam, 2017a). Keeping the continuous growth of tourists in mind, the amount of 5,7 million tourists going on a canal cruise in 2017 sounds very probable. For the canal cruise model, it is thus assumed that on average 15.680 go on a canal cruise each day. In the model, a sample size of 5% is used: 784 agents represent the tourists in Amsterdam going on a canal cruise.

Table 2 – Division of the number of tourists in Amsterdam

Tourist type	Number of tourists per day	%	28% going on a canal cruise
City trippers	24.000	42,8%	6720
Dutch same-day visitors	22.000	39,3%	6160
Coastal visitors	2.000	3,6%	560
Conference attendees	8.000	14,3%	2240
Total visitors per day	56.000	100%	15.680

Furthermore, it is assumed that an agent only takes a canal cruise once, considering that in real-life tourists wouldn't do more than one canal cruise during their stay as well. Same goes for the activities: an agent will only visit a certain activity once. There are no restrictions in the model to how agents walk: areas and streets can be visited or passed an unlimited amount of times.

In the predefined schedule of the agents assumptions are also made. First, it is assumed that an agent engages in two different activities per day. In which activities they engage in exactly is based on the operationalization of the tourist types (see the previous section). The assumption that tourists engage in two main activities on one day is based on the proposed itineraries for a one, two or three day visit in Amsterdam by Amsterdam Marketing ("Itineraries | I amsterdam," n.d.). To complete the predefined schedules of the agents, an assumption needed to be made on the stay time at each activity. Appendix B contains tables showing the average staying time for the top 12 museums in Amsterdam, the top 20 restaurants and cafes, and the top 20 attractions. Based on these actual staying times, the following minimum and maximum staying times for the activities in the model are defined, see table 3. Unfortunately, the average staying times in shopping areas cannot be calculated in the same way. This staying time is based on the stated duration times in the proposed itineraries from Amsterdam Marketing.

Table 3 - Staying time at each activity

Type of activity	Staying time in the model
Museum	1 - 3 hours
Attraction	1 - 2,5 hours
Restaurant/cafe	1 - 2 hours
Shopping area	0,5 – 3 hours

The start and end times of the canal cruises are based on the actual opening times of the canal cruises in the summer period. Opening times of the canal cruise companies in this thesis were compared and the average opening and closing times were taken. On average, the opening time for the canal cruises is 09:00 in the morning and they close at 21:00 in the evening. Agents are entering the model through these gateways in these opening hours.

3.1.4 Implementation of the model

The implementation of the canal cruise model was an iterative process. The model was coded in GAMA (see section 3.3 for an extensive description of this software). The model consists of different kind of features or functions, implemented by different pieces of code. The development of the model was divided in very small steps, implementing each feature piece by piece and checking the model after each new piece was added. Sometimes the addition of features required alterations to the already existing code. These steps were repeated until the model was defined as 'done'. After the first 'done' classified model the validation process started, which will be elaborated on more in section 3.5. Figure 12 shows the iterative process of the model development.

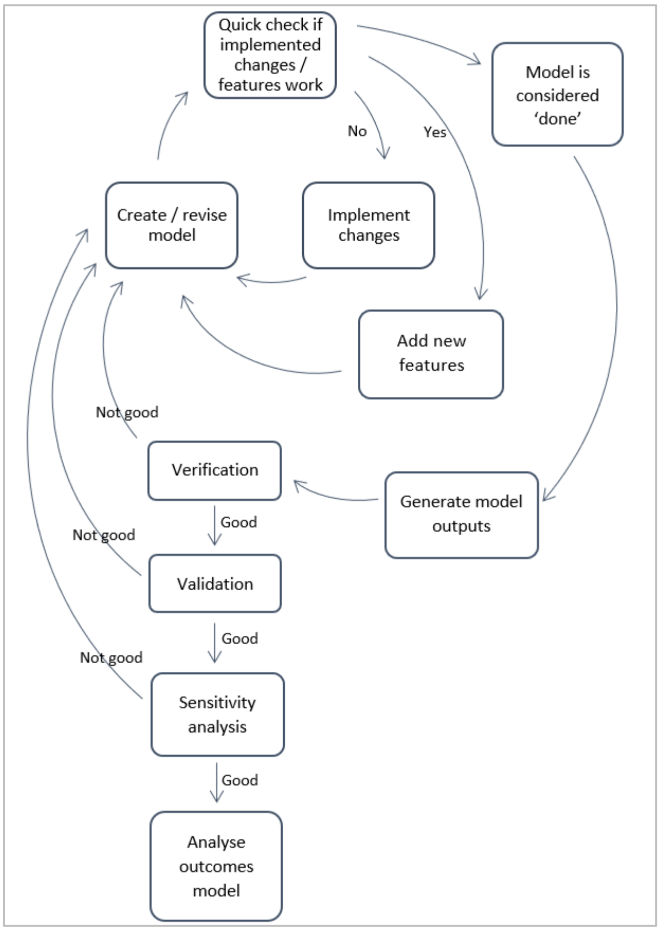

Figure 12 – Iterative process of the model development

The model is implemented in the following way. First the pre-model is set up, this contains for example all initial values of the agents and the time calculation and timesteps of the model are defined. Important time frames are implemented such as the opening times of the canal cruise docks and the minimum and maximum staying times for all the activities. The minimum and maximum walking speed of the agents is set, based on the theory of Helbing et al. (2001) thus resulting in a random speed between 1.06 and 1.60 m/s. Additionally, the range of agents is implemented. Furthermore, the environment of the model is set up in the pre-model. The environment is based on spatial datasets (shapefiles) of the dock locations, the activities and the pedestrian network. The latter is then identified as the graph that agents can move around on with the AStar shortest path algorithm as optimizer. In the initialization section within the pre-model, all species in the model - the roads, the docks, the activities, the shopping areas and the four types of tourists - are created, implementing variables that are important for each species.

The pre-model is followed by the declaration of the different entities, called 'species' in GAMA, that in the 'road' species the code that changes the road by width and colour when passed by agents is implemented. The docks species are implemented as points along the graph, based on the imported shapefile containing the locations of the docks. The activities species are implemented in the same way as the docks, based on a shapefile containing the locations of the activity-points. Different colours for the different types of activities were already defined with the initialisation of the environment in the pre-model. The shopping areas species are implemented independently of the other activities as these are polygons and not points. Next, the four different tourist types are implemented as four different species. These four types of species are constructed in the same way, with different activities accordingly to the predefined schedule of each type of tourist. Figure 13 shows how the city tripper species is constructed. The whole code of the model can be found in appendix C. In figure 13 it can be seen that the skills of the agents are defined and that the attributes, values and parameters are set. Next, the behaviour of and the predefined schedule of the agent is implemented. The agent enters the model at a random time between the opening hours of the canal cruise, going to their first target: the first activity, which is a randomly selected museum. The agent moves to the target along the graph with a random walking speed (a value between the minimum and maximum possible walking speed). If the agent arrives at the target, e.g. the first activity, the 'arrivedAtLocation' Boolean value is set to true. The model decides the time that the agent will leave for their next activity ('end_time_museum') based on the time that they arrived at the museum and the staying time at the museum (a value between the minimum and maximum possible 'stay_time_museum'). If the current hour in the simulation is the same as the set 'end_time_museum', the agent leaves the museum and is assigned a new target: a randomly selected attraction. The agent then moves towards their second activity. If the current hour in the simulation is 23:00 all agents die, regardless if they finished their schedule or not. The other three tourist type species function in the same way, but with different activity schedules.

```
species citytrippers skills:[moving] {
	bool arrivedAtLocation <- false ;
	bool readyToGo <- false;
	point the_target;
	int start_time;
	int stay_time_museum;
	int stay_time_attraction;
	road current_road;
	float range_agents <- 7000 #m;
	int end_time_museum;

	reflex stay when: current_hour = start_time {
		the_target <- any_location_in (one_of (museum));
		}

	reflex at_museum when: arrivedAtLocation = true{
		end_time_museum <- (current_hour + stay_time_museum);
		arrivedAtLocation <- false;
		readyToGo <-true;
		}

		reflex next_activity when: readyToGo = true{
		if current_hour = end_time_museum{
		set the_target <- any_location_in (one_of (attraction));
			}
		}

	reflex dayisover when: current_hour = 23{
		do die;
		}

	reflex move when: the_target != nil {
		do goto target: the_target on: the_graph ;
		if (location = the_target){
		the_target <- nil ;
		arrivedAtLocation <- true;
		road my_road <- road closest_to self;
		if my_road != current_road{
			my_road.nb_passes <- my_road.nb_passes +1;
			current_road <- my_road;
				}
			}
		}

	aspect base {
		draw circle(10) color: #deeppink;
		}
	}
```

Figure 13 – Code of the city trippers species

The last part of the code (see appendix C) implements the experiment, the actual simulation of the canal cruise model. The simulation parameters and the outputs are set. In the output it is defined which species are existing in the simulation.

3.2 Data

The data that was used for the building of the agent-based model is discussed in this section. If and how data has been modified will be elaborated on if necessary.

3.2.1 Areas of Amsterdam

This dataset contains the areas of Amsterdam that will be used in the model and thus the study area. The dataset “Gebieden22” from the Municipality of Amsterdam was downloaded through the maps.amsterdam.nl portal. For this thesis not all of the 22 areas of Amsterdam were used. The decision was made to not include the areas that are far away from the city centre, such as the South-East area and far up in North, as these areas are not focused on tourism. Other areas that are located far away from the city centre are on the other hand included, because they contain one or more of the proposed waterways from the ‘Watervisie 2040’ report to relocate the docks to. Based on these decisions the areas that were used for the model are:

- Bos en Lommer
- Buitenveldert/Zuid-as
- Centrum-Oost
- Centrum-West
- Indische Buurt/Oostelijk Havengebied
- Oud-Noord
- Oud-Oost
- Oud-West/De Baarsjes
- Oud-Zuid
- De Pijp/Rivierenbuurt
- Slotervaart
- Watergraafsmeer

A new shapefile with these thirteen Amsterdam areas was created to use for other datasets as a border: if the data falls within the boundaries of the shapefile it is used.

3.2.2 Pedestrian network

The most important dataset for the ABM is the pedestrian network of Amsterdam. The agents in the model walk along this network as it is used as the graph that they move on. This network dataset is retrieved trough OpenStreetMap (OSM). The complete road network of Amsterdam was downloaded through OSM. The clip tool from ArcMap is used to clip the OSM road network to the used Amsterdam areas, the result is the road network for the study area. However, only the pedestrian network is needed for the model, as the agents will represent walking tourists. The OSM road network contains all different kinds of roads. The following types of roads were selected to create the pedestrian network dataset for the model after multiple considerations: 'cycleway’, 'footway’, 'living street’, 'path’, 'pedestrian’, 'residential’, 'secondary’, 'steps’, 'tertiary' and 'unclassified'.

Naturally, footway, path and pedestrian are included in the network as they are specifically for pedestrians. The tertiary and secondary type of roads were added because important spokes in the city were missing if these would not have been included such as de Vijzelstraat, Rozengracht and van Woustraat. As well, two important shopping streets, de Utrechtsestraat and de Ferdinand Bolstraat were missing in the network without the tertiary and secondary road types. The living street and residential type of roads are included because this generally are roads that pedestrians walk on from or to certain facilities such as shops, hotels and Airbnb's. The cycleways are included in the network as they represent smaller roads that are not for cars. Mostly the cycleways are accompanied by adjacent footways but unfortunately in the city centre of this is not the case and therefore the choice is made to use this type of road for the pedestrian model, even though there might be adjacent footways in some places. The steps type of road was included as these can usually only be climbed by foot and are therefore for pedestrians. Lastly, the unclassified type of road is included in the pedestrian network: it are a lot of smaller streets, especially along the canals in the city centre and therefore important for the needed network.

To make the pedestrian network complete some roads were manually added if they were missing in the OSM dataset. An example is the Amstel from Muntplein to the Blauwbrug, which is important because two of the current docks are along this road. To represent the ferries across the IJ lines were added to the network so that the agents can 'walk' to the North side of Amsterdam along the routes of the ferry's: Distelweg - Pontsteiger, CS - Buiksloterweg, CS - NDSM, CS - IJplein, Pontsteiger – NDSM.

Other types of roads that are included in the OSM dataset such as primary, service and track were not added to the pedestrian network for the model because they are consistently accompanied by an adjacent footway or cycleway, because they are highways or main car roads and inaccessible for pedestrians or because they are found not to be important for the needed pedestrian network.

After selecting all suitable types of roads and adding the missing data the pedestrian network was clipped to the selected areas of Amsterdam, resulting in the final pedestrian network of Amsterdam to be used in the ABM.

3.2.3 Waterways of Amsterdam

To be able to determine the correct places of the current docks and the proposed places for the new docks a dataset containing the waterways of Amsterdam was necessary. This dataset is created with the use of the 'Landuse2017' dataset, retrieved through the maps.amsterdam.nl portal. All different waters were selected to create a shapefile containing all waterways and lakes of Amsterdam. This shapefile was also clipped to the selected areas of Amsterdam, resulting in the final waterways shapefile of Amsterdam to be used in this research. Figure 14 shows the pedestrian network and waterways clipped to the study area of Amsterdam.

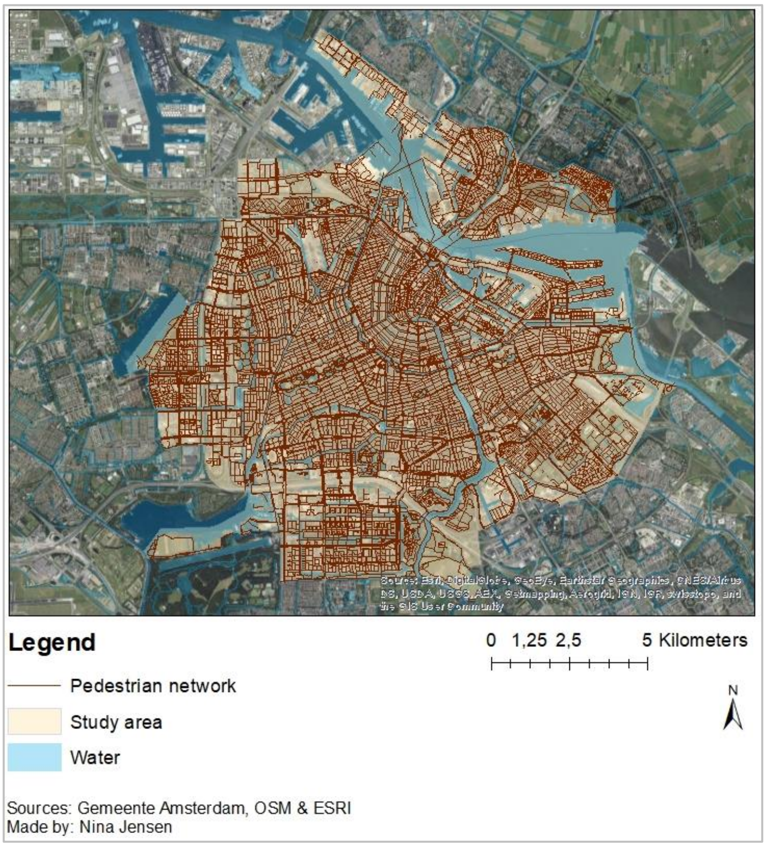

Figure 14 - Pedestrian network within the Amsterdam study area

3.2.4 Activities dataset

In the section before four types of activities were identified that tourists do when in Amsterdam: cultural activities, shopping, entertainment activities and going to a restaurant or café. To create the dataset for the model three datasets from data.amsterdam.nl were used: museums & galleries to represent cultural activities, food & drinks to represent all the restaurants and cafes and attractions to represent the entertainment activities. The dataset containing the activities and their locations is retrieved through the data.amsterdam.nl portal, and consists of activities that are registered by Amsterdam Marketing. As Amsterdam Marketing is one of the main information points for tourists it can be assumed that these activities are a good representation of the activities that tourists visit during their stay in Amsterdam. Duplicates were removed from the datasets so that a specific activity can only occur in one of the activity types, so museums are not included as an attraction. As well, the data was clipped to the study area again. As well, the canal cruises were removed from as an activity because it can be assumed that tourists will not take multiple canal cruises on their trip in Amsterdam.

To represent the shopping activity a dataset was created of the most important shopping areas of Amsterdam. Again, data from Amsterdam Marketing was used: a list of shopping areas within the study area was retrieved through: https://www.iamsterdam.com/en/see-and-do/shopping/shopping-areas and https://www.iamsterdam.com/nl/zien-en-doen/shoppen/beste-van/winkelgebieden. Figure 15 shows a map of all the different activities and the locations of the current docks of the canal cruises. It clearly shows that most of the activities and canal cruises are in the city centre, creating a cluster of activities that attract tourists to the busy city centre.

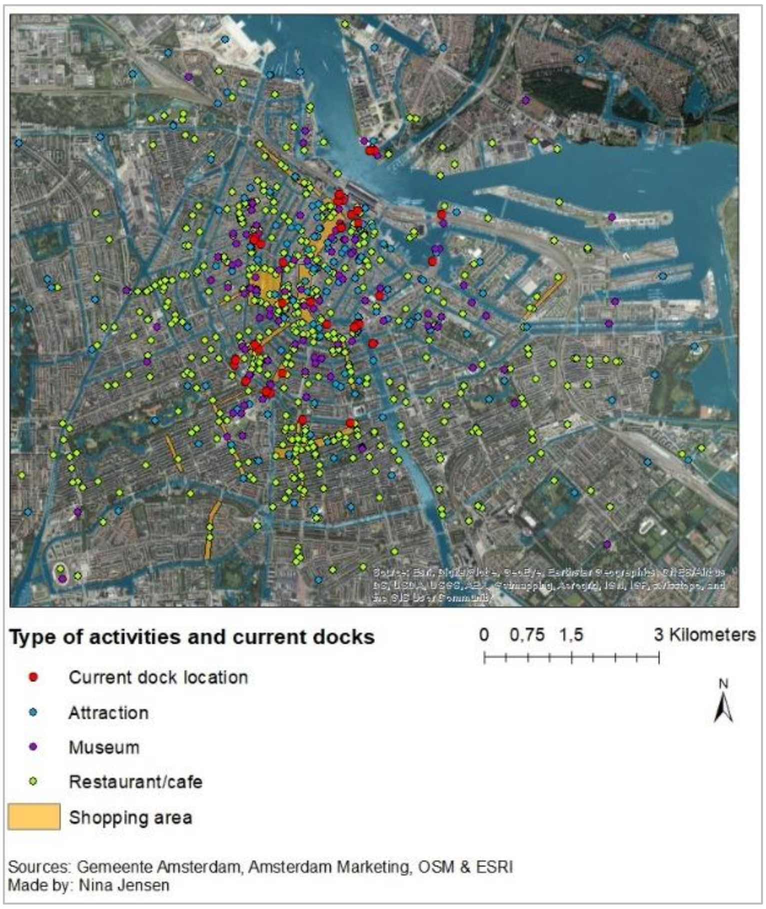

Figure 15 - Location of the activities and current docks within the study area

3.2.5 Current dock locations

Another essential dataset for the ABM is the locations of the current boarding and disembarking docks of the canal cruises. Again, this data was retrieved through Amsterdam Marketing; all locations of the companies offering canal cruises on their website were digitized as a spatial dataset. A list of the included canal cruises and their locations can be found in the appendix. Figure 16 shows all current canal cruise docks within the study area. The figure also shows which docks are located in the city centre and are thus not foreseen to stay on that location if the plans of the Municipality of Amsterdam as discussed before will be executed. It can be seen that almost all the current locations are not eligible to stay on their current locations. Only a few docks along the Stadhouderskade, a dock in the Zouthavens and two on the North side of the IJ are not located in the city centre. This shows that the measure of the Municipality of Amsterdam to ban all canal cruise docks out of the city centre is a rather big decision. It will not only affect tourists, but also the canal cruise companies and the inhabitants of Amsterdam. As well, it changes the streetscape in both the city centre, where the docks are removed, and the new areas outside the city centre where the docks will be relocated to. In total, there are currently 34 boarding and disembarking docks, of which only seven are located outside of the city centre. Thus, accordingly to the plans of the Municipality, 27 docks should be removed or relocated.

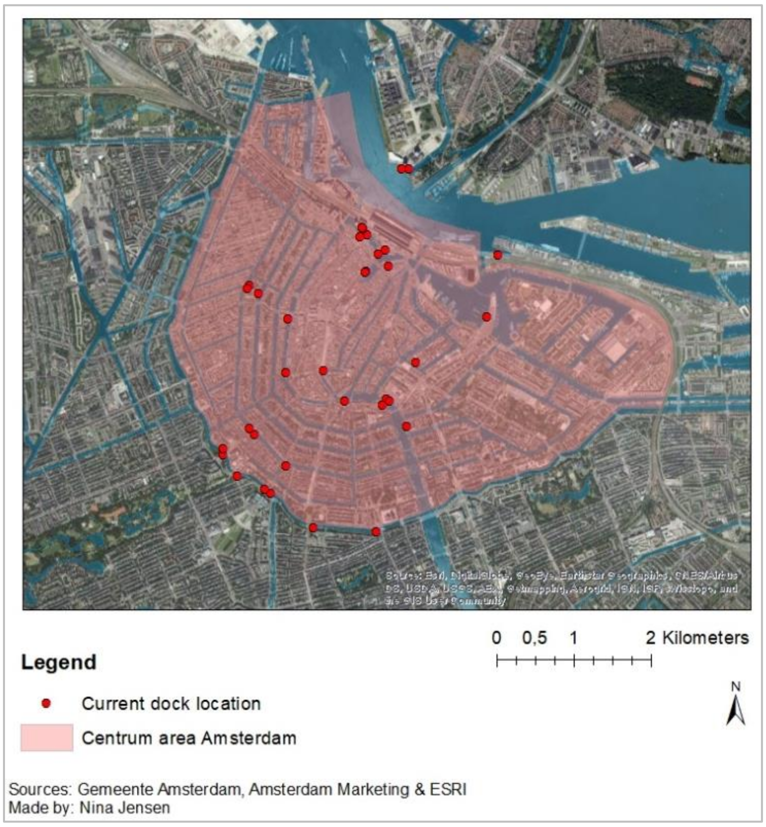

Figure 16 – Locations of the current docks in 2019 and the city centre area of Amsterdam

3.2.6 New dock locations

In the "Watervisie 2040" report by de Gemeente Amsterdam (2016) multiple waterways outside of the city centre are proposed to place canal cruise dock along (see figure 2). These proposed waterways functioned as input for a shapefile containing possible locations for the new boarding and disembarking docks. The dataset representing the new dock locations with only docks outside the city centre contains the current seven docks that already are outside of the city centre, as discussed in the previous section, and new proposed locations for the docks along the suggested waterways and can be seen in figure 17.

The exact locations of these new docks are based on three criteria. The first criteria is proximity to public transport stops, as it is assumable that when the docks move outside of the city centre tourists are likely to take public transport to the dock locations further away. A shapefile with the public transport stops is retrieved through the maps.amsterdam.nl portal. The second criteria is proximity to the main pedestrian network and important connecting streets (the plus network), of which a dataset is also retrieved through the maps.amsterdam.nl portal. As stated before, 78% of the tourists in Amsterdam explore the city by foot, and even when relocating the docks, this will still be the main way of transport (Amsterdam Marketing, 2016). Therefore, it is important that the new dock locations are in proximity of the main pedestrian network. The third criteria is that there is enough space to be able to place a dock both in the waterway but also at the quay. Figure 18 shows a map with the new docks along the proposed waterways based on the three criteria: a buffer was placed around the public transport hubs of 250 meter, assuming this is a distance that tourists are willing to walk; a multi-ring buffer was also placed around the main and plus pedestrian network at 100, 150 and 200 meter, assuming that tourist mainly take these roads and are thus willing to walk here. Within these two buffers the new dock locations were appointed to areas along the proposed 'Watervisie 2040' waterways where there is enough space to exploit and place the boarding and disembarking docks of the canal cruises.

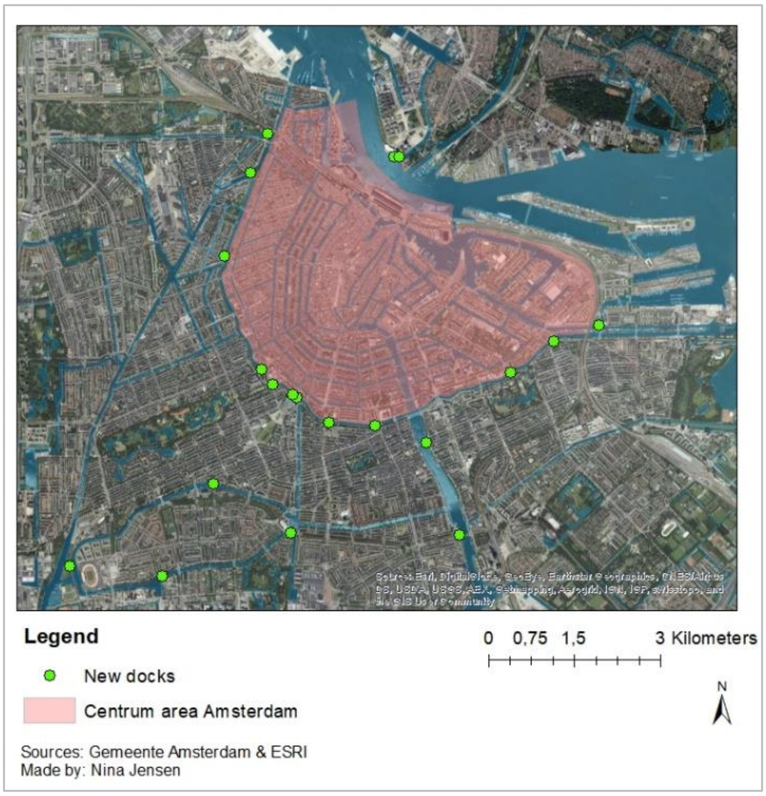

Figure 17 – Locations of the new dock and the city centre area

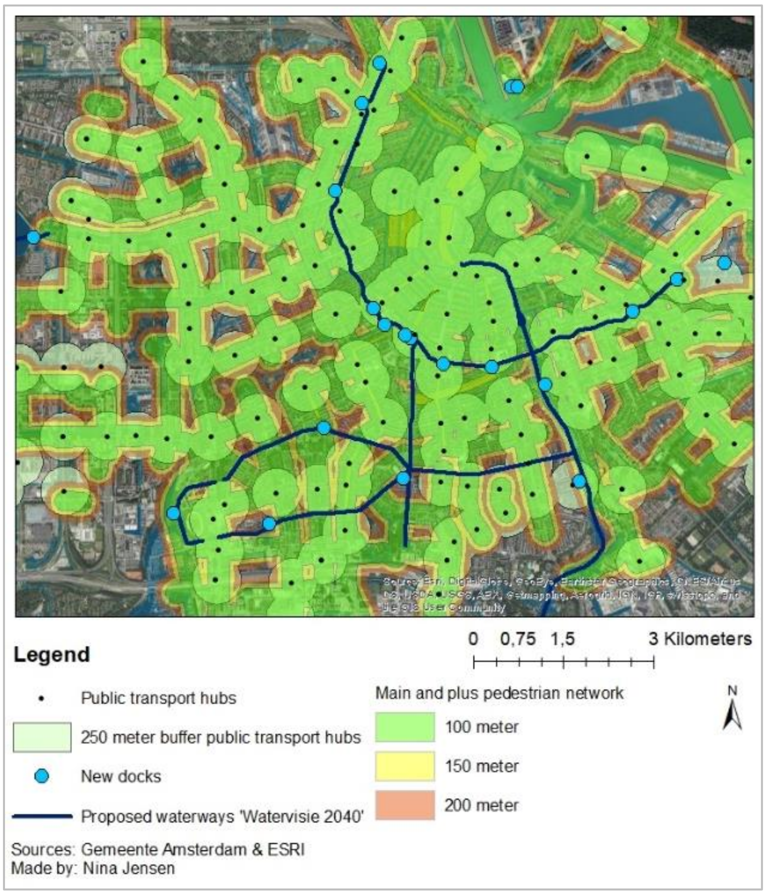

Figure 18 - The new dock locations along the proposed waterways, based on buffers around public transport hubs and the main and plus pedestrian network

3.3 Software

The software that will be used to build the agent-based model is the opensource program GAMA (Gis & Agent-based Modelling Architecture). The GAMA platform provides a complete modelling and simulation development environment for building spatially explicit multi-agent simulations (Taillandier, Vo, Amouroux, & Drogoul, 2012). Its main advantages come from its versality, as it is domain independent, and the simplicity of defining a model. In GAMA you can work with geographical vector datasets, which makes it easy to build the environment that represents the city of Amsterdam. The pedestrian network of Amsterdam will be used as the network graph that the tourist move along to. Furthermore, there will be made use of the GIS software programmes ArcMap and QGIS.

3.4 Model validation

Based on the theory of the validation process as discussed in section 2.1.2 the canal cruise model is validated, in order to be able to draw conclusions from the model results. In figure 12 and section 3.2.4 it was already mentioned that the validation in some parts was already carried out throughout the design and the constructing of the canal cruise model. In this section, it is described how the three steps of the complete model validation – verification, validation and sensitivity analysis – are carried out during the building process and afterwards. As stated before, due to a lack of empirical and statistical data it is not possible to perform a full validation process on the developed model. However, the results can be analysed to see if the model produces plausible outcomes and if movement patterns occur that are related to the real-world situation. Besides generating plausible outcomes, it can be tested if the model is working properly and if it is doing what it is supposed to be doing.

All steps in the validation process are carried out with the current canal cruise dock locations in the model. This way, the model represents the real world and can thus compared and validated, with the new proposed locations in the model this cannot be done. If the canal cruise model with the current locations is working properly and classified as valid, the assumption can be made that the model is also working properly and valid with the new dock locations. Hence, with the use of the model results, the sub and main research questions of this thesis can be answered.

3.4.1 Verification

The purpose of the verification of the model is to check what happens in the model. This step consists of two steps: analysing what the model is doing and comparing this to what the model is supposed to be doing. Every time a new feature or function was added to the code and model the model was ran to check whether the desired effect was met. During this process, the model is frequently debugged to make new features work as planned. At this point, the canal cruise model runs without any errors occurring.

An important aspect of this step in the validation process is to investigate whether the model adequately implements the underlying conceptual model (Gräbner, 2018). In the final version of the canal cruise model all implemented features are working in a proper way. Thus, the main aspects of the conceptual model as shown in Figure 11 and discussed in section 3.1 are included, resulting in a model that thus does what was said in the final conceptual model.

3.4.2 Validation

For the validation of the model the theory of Klügl (2008) is used. As there is a lack of sufficient empirical and statistical data related to this thesis to subject, the canal cruise model cannot be judges on a full empirical validation. There is however a report by the Municipality of Amsterdam about how residents perceive the crowdedness in their neighbourhood. This report is based on a survey among almost 4500 Amsterdam residents from all neighbourhoods (OIS Gemeente Amsterdam, 2018). The outcomes of the canal cruise model are compared to these statistics about which areas in Amsterdam are considered the most crowded. For this comparison the model with the current canal cruise dock locations is used, as this is representing the situation at this time. However, as this is not sufficient for a full validation, this section will mainly focus on the face validity of the canal cruise model, and this will be assessed first.

The first step of the validation is the assessment of animation. Four models were ran simultaneously at the same screen, to see if the outcomes vary a lot. Looking at the running model, agents are seen moving along the graph as intended. Agents enter the model at the docks, or gateways, and move towards their goal accordingly to their predefined schedule. The more timesteps have passed, the more agents emerge in the model. Assessing the animation, the model is working properly and a general flow of pedestrians can be identified. Looking from a birds' perspective, it is easily seen that the agents tend to stay closer to the city centre and do not roam around the model very broad, resulting in red and thicker roads in the inner city centre. The agents cluster in the city centre and spread unevenly across the model: the further from the city centre, the less agents there are. The first impression therefore is that the model and the agents seem to behave in a valid way, representing the real-world.

The second step of the validation process is the immersive assessment. In this assessment the route of one particular agent is followed to see if the agent is behaving as it should. For this validation step, one agent of each type of tourist (city tripper, Dutch same-day visitor, coastal visitor, and conference attendee) is randomly selected and followed throughout one model run. This way, it is possible to see if they follow the predefined schedule associated with the type of tourist they are. The exact activity the agents engage in is looked up in the dataset of the activities. Table 4 shows the agents that were followed. Their starting time, when they enter the model from their dock, the amount of time they take to their first activity, the amount of time spent there, the time they take to get to their next activity, and whether they 'die' at the end of the day is tracked. It is striking that the randomly selected itineraries of each agent resemble what actual tourists would do in Amsterdam. It is likely that indeed a coastal visitor would go to the Beethovenstraat shopping area, as they are more familiar with the city already and explore more broadly during their visit to Amsterdam. The schedules of the agents thus can be labelled as valid. This is an important step in the development of the model, as the predefined schedule of the agents is the main stimulator of the agents in the model.

Table 4 - The executed schedules of four tracked agent in the canal cruise model

Type of tourist	City tripper	Dutch same-day visitor	Coastal visitor	Conference attendee
Speed	1.36 m/s	1.45 m/s	1.17 m/s	1.59 m/s
Range	7 km	10 km	10 km	7 km
Start time	11:00	13:00	10:00	15:00
First stop	Museum: Amsterdam Museum	Museum: Hash, Marijuana & Hemp Museum	Shopping area: Beethovenstraat	Museum: Het Grachtenhuis
Time to get there	1:10	1:10	1:40	1:00
Starting time first stop	12:10	14:10	11:40	16:00
Staying time first activity	3 hours	2 hours	0,5 hour	3 hours
Time leaving first activity	15:10	16:10	12:10	19:00
Next stop	Attraction: Begijnhof	Shopping area: Leidsestraat	Restaurant/café: Thijs	Restaurant/café: Brasserie Marie
Time to get there	0:20	0:20	1:00	0:20
Starting time second activity	15:30	16:30	13:10	19:20
Dead at 23:00	Yes	Yes	Yes	Yes

To check whether the route and the behaviour of the agents is valid, the schedule is checked for each to see if the amount of time the agents needs to get from the first activity to their second activity is the same as it would be in the real-world. This is based on the distance between the activities as said on Google Maps and the walking speed of the agent. Table 5 shows the route of the agents, the distance, the time the route should take and the time that it took in the model. It shows that three out of four routes are representing the real-world situation in a proper way, as the travel time is almost the same. The deviant travel time of the city tripper could be explained by the 10 minute time steps.

The model only shows the location of the agent per 10 minutes; thus the agent could have left the Amsterdam Museum at 15:19 and arriving somewhere between 15:20 and 15:30. The measured 20 minutes could therefore actually be shorter and closer to the actual travel time between the activities. The proper working of the AStar shortest path optimizer was already examined within the verification, this assessment of the routes confirms that the shortest path optimizer is working the correct way.

Table 5 - The checked routes of the four tracked agents based on the actual distance and routes

Agent	Route	Actual distance	Time the route should take (walking speed x distance / 60)	Time it took the agents in the model
City tripper	Amsterdam Museum → Begijnhof	210 m	1.36 x 210 = 285,6 / 60 ≈ 5 minutes	20 minutes
Dutch same-day visitor	Hash, Marijuana & Hemp Museum → Leidsestraat	1 km	1.45 x 1000 = 1450 / 60 ≈ 24 minutes	20 minutes
Coastal visitor	Beethovenstraat → Restaurant Thijs	3 km	1.17 x 3000 = 3510 / 60 ≈ 59 minutes	1 hour
Conference attendee	Het Grachtenhuis → Brasserie Marie	650 m	1.59 x 650 = 1033,5 / 60 ≈ 17 minutes	20 minutes

The third step of the face validation is the output assessment. In this step the plausibility of the outputs of the model are judged. In this thesis this step will be combined with a small empirical validation, as the outputs are compared to the report of the Gemeente Amsterdam on the perceived crowdedness in Amsterdam neighbourhoods. In this way, the plausibility of the outputs can be assessed based on the real-world situation.

On first look, the outputs of the model show plausible patterns. Overall, the main patterns occurring in multiple model runs do not shows a lot of differences; the overall pattern stays the same. This way, the model is assessed on a macro level; observing the general patterns and flows of agents. On a micro level, it is seen that some streets outside of the city centre are passed more times in one output than another. This shows that the outputs do indeed differ from each other. The generated output of the canal cruise model with main occurring patterns is not surprising: as expected the most crowded areas are within the city centre. This can be related to the fact that all the gateways of the agents are located in the city centre and the main part of the activities are also clustered in these areas. Thus, it can be reasoned that the outputs of the model are plausible, making the canal cruise model valid on this part.

Next, the outputs of the canal cruise model are compared to the most crowded neighbourhoods in Amsterdam. Figure 19 shows how residents rate their neighbourhood varying from very quiet to very crowded, the darker areas are the most

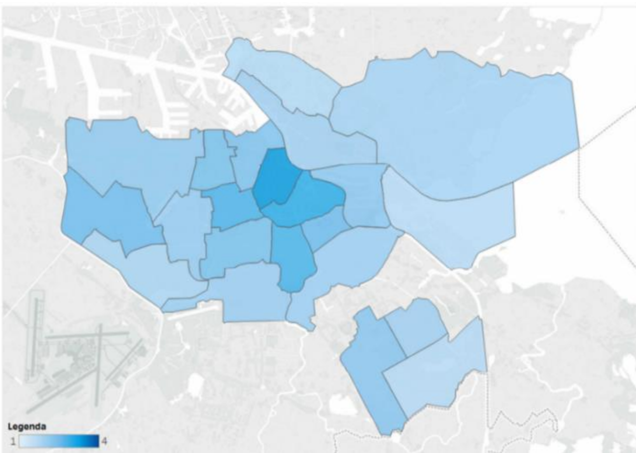

Figure 19 - How residents judge the crowdedness in their neighbourhood on average: 1 = very quiet, 4 = very crowded Source: OIS Gemeente Amsterdam, 2018

perceived crowded areas (OIS Gemeente Amsterdam, 2018). The centre areas are perceived the most crowded, followed by surrounding neighbourhoods such as Oud-West / de Baarsjes, de Pijp / Rivierenbuurt and Oud-Oost. However, the results from the report do not only take crowdedness caused by tourists that go on a canal cruise into account. The causes of the crowdedness that are mentioned in the report are foreign tourists, Dutch visitors, large groups of people, Amsterdam residents, and suppliers of shops and delivery vans (OIS Gemeente Amsterdam, 2018).

Figure 20 shows four outputs of the canal cruise model as an example that were made to assess the outputs in the face validity. It is very clear to see in the model outputs that the most passes streets and thus crowded areas are in the city centre. From the city centre, the more crowed places 'flow' to the neighbourhoods that are located next to the city centre, such as de Pijp and Oud-West. If these results are compared to figure 19, the crowdedness is spread out in the same way. Therefore, it can be stated that based on the output assessment combined with a small empirical validation the outputs are plausible. However, it is important to keep in mind that the crowdedness perception of the residents in the report does not only include tourist going on a canal cruise.

Based on the face validation as proposed by Klügl (2008) consisting of animation, immersive and output assessment, the model is valid on these aspects. With the model outcomes of the current dock locations being valid, it can also be assumed that the patterns occurring in the model with the new dock locations are also valid.

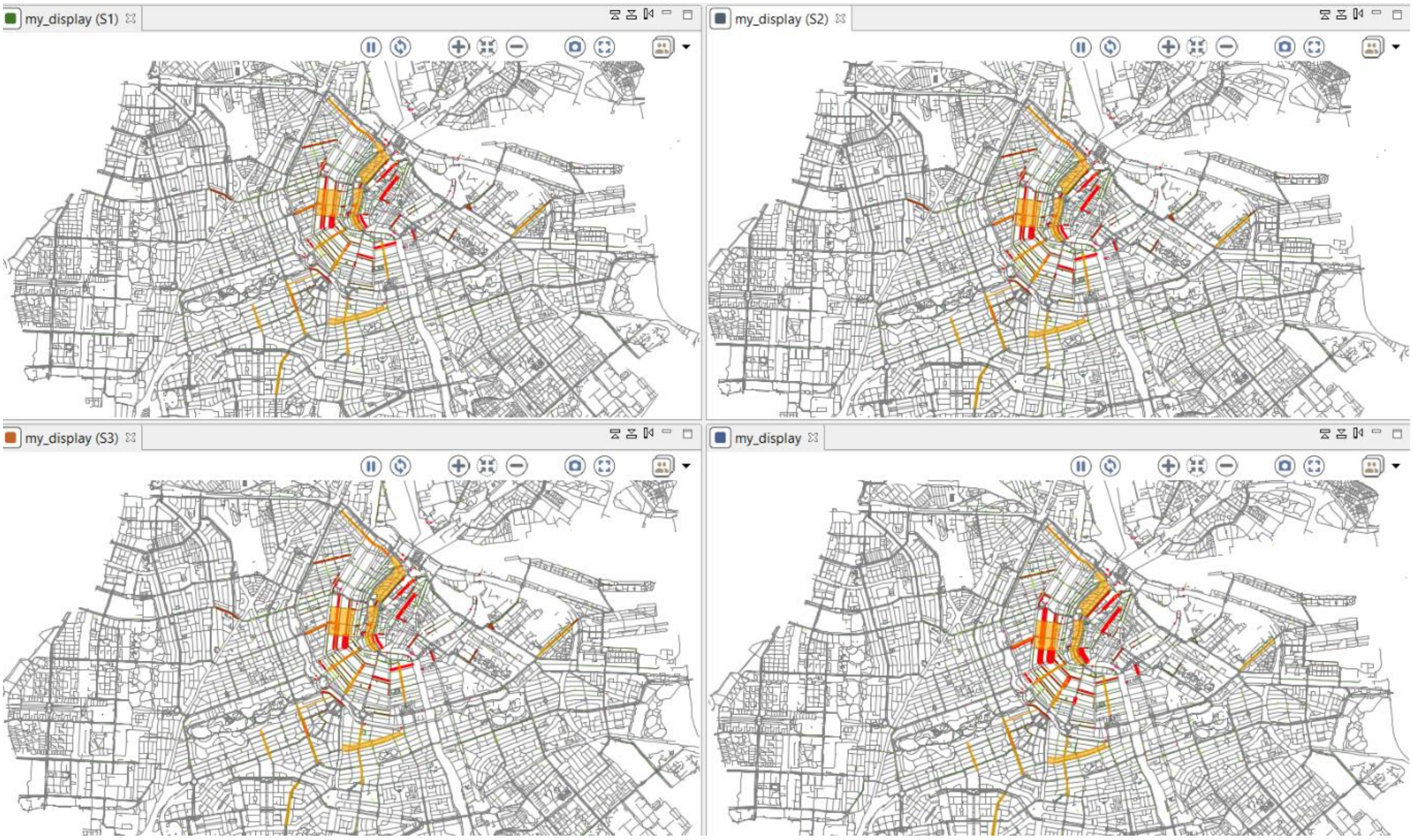

Figure 20 – Four example outputs of the model for the output assessment

3.4.3 Sensitivity analysis

The final step in the validation process is to carry out a sensitivity analysis to test the robustness of the outcomes of the model and to calibrate the different variables in the model. After the calibration the canal cruise model is ready to generate definite outputs that will be analysed in the results chapter of this thesis.

There are four parameters in the canal cruise model that will be altered in the sensitivity analysis. This is done using the OFAT method, as discussed in the theoretical framework. In this method, one parameter is changed at a time while keeping the other parameters fixed. When changing a parameter, it is the most useful to use extreme values, as this shows the different results in a distinct way. The parameters that were subjected to a sensitivity analysis are:

- The initial values of the agents
- The order of the activities in the schedule of the agents
- The range of agents
- The opening hours of the canal cruises

To test the sample size of the canal cruise model by changing the initial values of the agents. First a sample size of 5% (784 agents) was used. However, the bigger the sample size the more reliable the results will be. McKercher & Lau (2008: 372) state about this that *"A larger sample would likely result in more patterns being identified, while a different spatially organized destination might also produce different patterns.".* As the produced patterns are important in this thesis it is thus relevant to have a larger sample size. The model is ran with a sample size of 50%, representing 7.840 agents. However, it is not the best way to perform the canal cruise model; details disappear as a lot of roads are passed a lot of times, resulting in a large red city. A sample size of 10% was then used, bringing 1.568 agents into the model. This result displays the higher-level patterns and flows occurring, without losing details. It shows a more diverse result in comparison to the 5% sample size, confirming the belief that a 10% sample size is the right fit for the canal cruise model. Figure 21 shows 10 % sample size, with 1568 agents, versus 50% sample size in figure 22 with 7840 agents. The 50 % sample size makes the outcomes more profound but also harder to read. Additionally, the computational time is way longer, making it less suitable to use in this thesis.

Figure 21 – Model run with 10% sample size

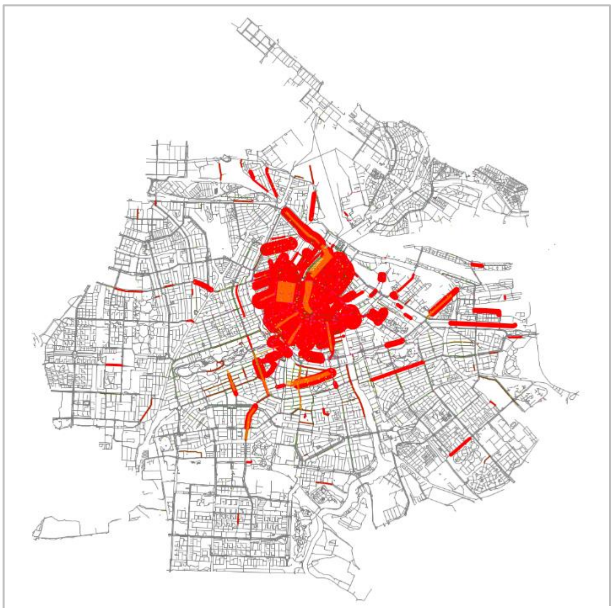

Figure 22 – Model run with the 50% sample size

Next to the sample size, the order of the activities that occur in the predefined schedules of the agents are switched. This shows if the specific order has a big influence on the outcomes of the canal cruise model or not. This is an important step, as the schedule and the order of the targets of the agents is mainly based on assumptions, although substantiated by the operationalization of the tourist types. It is important to see how these assumptions influence the model, and if the order of the activities of the schedule matter. The patterns occurring could be influenced by the clustering of specific activities and the range of the agents. For the sensitivity analysis the city trippers will thus start their day with an attraction, followed by a visit to a museum; the Dutch same-day visitors will start by going to a shopping area and then to a museum; the coastal visitors' first activity will be a restaurant or café followed by going to a shopping area; and the conference attendees start their day with a restaurant or café and then a museum. Figure 23 shows the outcome of a model run with the activities of the agents turned around in the predefined schedule. As can be seen, the outcomes do not vary from the outcomes with the activities scheduled in the original way (see figure 20). This means that the specific order of the agents' activities does not matter for the outputs of the canal cruise model. No alterations had to be made to the model based on this altered parameter in the sensitivity analysis.

Figure 23 – Model run with the switched predefined schedules of the agents

For the parameter of the range of the agent extreme values were used to see the influence of this parameter on the model. First, the range was made broader, up to 20 kilometres for all agents. This resulted in no clear changes to the general patterns and flows of the model. However, when the range of the agents was largely limited, to 1 kilometre for each agent, the results of the model showed some changes. Streets were not passed as frequently and the outputs weren't as straightforward. Most crowded areas were located in the city centre. This sensitivity analysis shows that the chosen ranges for the agents are appropriate, and no changes need to be made.

The last specification of the model that was examined is the scale factor width and scale factor for the colour, which changes the roads in the model according to how many times it was passed by agents. This is not really a parameter of the model but it is more related to the usability of the model. However, this is an important aspect of the model as it improves the readability of the outputs and is thus subjected to a kind of sensitivity analysis. The scale factor width was not altered, as the making the roads way thicker made the outcomes hard to read. The initial value of the scale factor colour was 8, blending colours from green to red. However, changing this value made the outputs more profound but also diverse as not all crossed roads turned red fast anymore. Therefore, the scale factor colour was set to 20 to improve the readability of the outputs of the canal cruise model.

4 Results

In this chapter the outputs of the canal cruise model with both the current dock locations (scenario 1) and the new dock locations (scenario 2) will be analysed. First, each scenario will be discussed individually, after which the two results will be compared to investigate the effect of the locations of the docks.

4.1 Results of the model with scenario 1

The outputs of fifteen model runs with the current locations of the canal cruise docks are combined to find the most occurring patterns of crowded places in Amsterdam. The number of passes on each road are counted within the canal cruise model, resulting in the top-most crossed streets for each individual output. Each time a road turned out red in an output, thus passed relatively more than the other, non-red, roads it was put in an excel sheet with a value of 1. All the output results were added up to come to a csv-file containing the relatively more passed streets by agents in the 15 model outputs. If a street, for example the Prinsengracht, is passed often and thus occurring red in all 15 model outputs, it has a value of 15 in the created csv-file.

Figure 24 shows the combined outputs of all 15 canal cruise models that were run with the current locations of the canal cruise docks. The more red a street is on the map (a value of 15), the more it was passed by agents in all 15 model outputs. Combining the results of the model runs, displays the most crowded areas caused by tourists that go on a canal cruise in Amsterdam. It is necessary to combine the multiple outputs to come to a proper result: if a street is passed multiple times in all models, it is assumable that this would also happen in the simulated real-world.

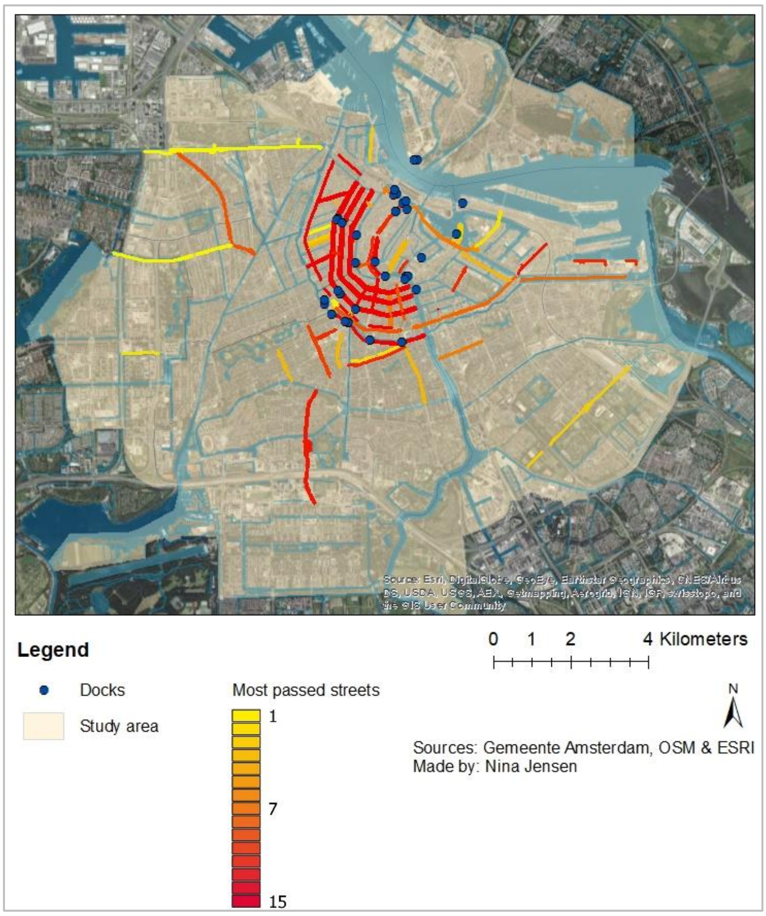

Figure 24 – Combined model outputs with the current dock locations, resulting in the most passed streets by agents

In the results that can be seen in figure 24, with the current dock locations as gateways for the agents, a few things stand out. First of all, all of the canals (Prinsengracht, Keizersgracht, Herengracht, Singel) are passed a lot by agents in every model run, resulting in a value of 15 for each of these roads. As most of the canal cruise docks are located along one of those canals this is not an unexpected result: most agents will enter the model straight onto one of the canals and walk on them to their target activity according to their predefined schedule. Second of all, it can be seen that the most crossed streets are within the city centre; agents thus are more in the city centre than outside of it. This could result in crowded areas if all tourists stay within a particular neighbourhood. The third observation made is that some streets located far out of the city centre are passed often by the agents in the model runs. As well, no streets in the Oud-Noord area or in the Buitenveldert/Zuid-as area are crossed relatively more than other streets. This is notable, as there are two canal cruise docks located in the Oud-Noord area. An explanation for this observation could be that there are not many activities located in the Oud-Noord area, so agents move to the city centre as soon as they enter the model. Another observation of the results is that areas that are known to be crowded with tourists are indeed occurring to be crowded in the model as well: the Jordaan and the Museum Square are areas that are passed often by the agents. The last observation made is that a lot of the relatively often passed streets are shopping areas. This can be attributed to the fact that people do not only visit these areas as an activity from their schedule, but that other agents are also passing the streets within the areas to go to their own activity.

4.2 Results of the model with scenario 2

The result of the second scenario was retrieved in the same way as scenario one: the outputs of fifteen model runs with the new locations of the canal cruise docks are combined to find the most occurring patterns of crowded places in Amsterdam. Again, the number of passes on each road are counted within the canal cruise model, resulting in the top-most crossed streets for each individual output. Another csv-file was created for the outcomes of scenario 2, resulting in a list of relatively often passed streets in the model outputs with a value of 1 - 15.

Figure 25 shows the combined outputs of all 15 canal cruise models that were run with the new locations of the canal cruise docks. In this figure, it is also the case that the more red a street is, the more it was crossed in every model run. These combined model runs give an insight into the most crowded areas in Amsterdam, caused by the tourists in Amsterdam that go on a canal cruise. This second scenario is not a real-world situation but more an exploratory prognosis of what would happen if the canal cruise docks were relocated outside of the city centre. However, as the canal cruise model with the current dock locations was found to be valid with plausible occurring patterns, it can be assumed that the results of the combined outputs of the model runs with the new dock locations are also plausible results.

From the results of the canal cruise model with the new docks locations in figure 25 some observations are made that stand out. The first observation made is that the most passed streets are still located within the city centre. All canals (Prinsengracht, Keizersgracht, Herengracht, Singel) have been passed more often than other streets in all model runs, even with no docks located along them anymore. The second observation that is standing out from the results of the model runs is the fact that more streets outside of the city centre are relatively often passed by the agents in the model runs. It can be seen that especially de Pijp / Rivierenbuurt area on the south side of the city centre is more crowded with tourists. Also standing out is the fact that roads that are located close to the new dock location are crossed more often, this applies to both streets inside and outside of the city centre. This can be attributed to the fact that these streets functioning as passage routes for the agents to go to the activities according to their predefined schedule. It is however surprising that this is not applicable to all new dock locations: near the new dock locations located at the Sloterplas, the Zuider Amstelkanaal and the Stadiongracht there are no roads that are passed significantly more often. This may be due to the AStar shortest path optimizer; the agents follow the shortest path to their target activity and this can be different for each agent entering the model via a dock. The agents do not take main pedestrian roads, that would maybe have the preference over the shortest path via small roads, into consideration. Both the Oud-Noord and Buitenveldert / Zuid-as area do not accommodate roads that are passed significantly more than others. As well, a lot of the shopping areas in the model are accompanied by roads that are often passed by the agents. This could be for the same reasons as stated for scenario 1.

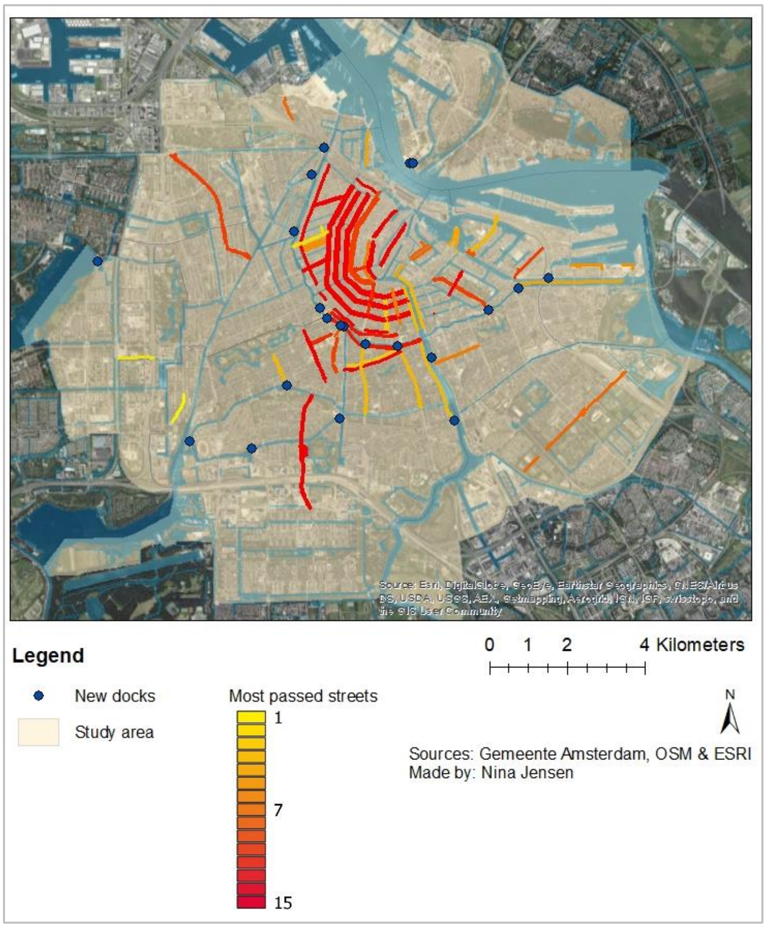

Figure 25 – Combined model outputs with the new dock locations, resulting in the most passed streets by agents

4.2 Comparing the two scenarios

If the results in figure 24 and figure 25 with both the current and new dock locations are compared there are both similarities and differences between the two scenarios. Figure 26 shows which streets are passed more or less frequent in the outputs with the new dock in comparison to the outputs with the current docks. If a street was passed a lot by the agents in all 15 model outputs of scenario 1, but in scenario 2 the same street was only passed often by agents in 5 model output there is a decline of -10 in figure 26.

The first main finding when comparing the results as showed in figures 24 and 25 ,is that in both scenarios the city centre contains the relatively most passed streets. With both options for the canal cruise dock locations the city centre is the most crowded area in Amsterdam. So, on first sight the relocation of the canal cruises does not solve the problem of crowdedness within the city centre. However, there are indeed some shifts in regard to the passed streets in the city centre, which can be seen in figure 26. Streets that were passed more than other streets in almost all model runs with the current dock locations are less often passed in the model runs with the new dock locations, such as Zwanenburgwal and the Prins Hendrikkade. As well, other streets in the city centre are passed more often in the model runs with the new docks. There is some diffusion to the east side of the city centre as the Plantage Middenlaan and Kattenburgerstraat are crossed more often in the outputs of the model runs with the new dock locations. It is interesting that these are long streets that could be seen main passage roads to the outskirts of the city centre. However, it is also striking that all the canals are passed often within the new dock locations model runs, even though there are no more direct docks located along them. The canals thus clearly function as important spokes in the pedestrian network.

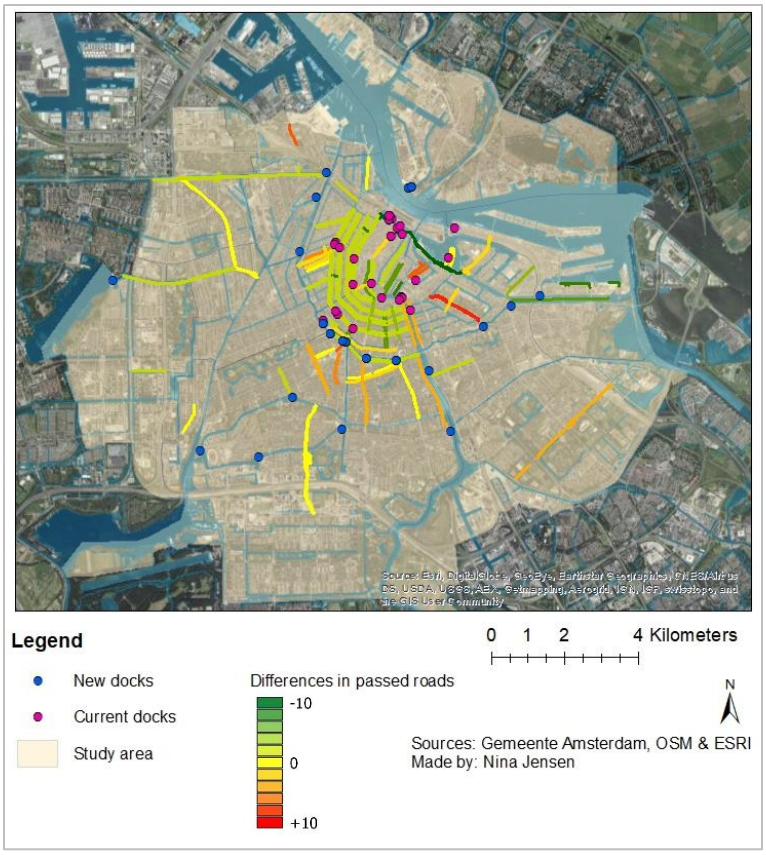

Figure 26 – Comparison of the roads that were relatively often passed in scenario 2 regarding scenario 1

When looking at the passed streets that are located outside the city centre it is found that the same streets are often passed in both the model runs of the current docks and the new docks. However, the difference is that the same roads in the model with the new dock locations are passed significantly more often than other streets in more of the model runs: e.g. they are more yellow and orange on the map in figure 26. It is interesting that the Pijp / Rivierenbuurt area nearby the south side of the inner-city centre is a lot more crowded with the new dock locations. The agents representing tourists seem to move more along the pedestrian network located close to the city centre. It is however striking that roads in the west of Amsterdam were passed more significantly with the current canal cruise locations in the model than with the new canal cruise locations.

In both models results the Oud-Noord area and Buitenveldert / Zuid-as area do not contain roads that are passed relatively more than other roads. For the Oud-Noord are this is remarkable as there are even two canal cruise docks located in this area. An explanation could be that there are little activities located that agents can engage in. For the Buitenveldert / Zuid-as area this not as unexpected as there are no docks located nearby and there are also few activities or shopping areas that agents have on their predefined schedule. It is notable that the locations of the shopping areas seem to have a considerably effect on the most passed streets: in both model runs the shopping areas contain streets that are often passed, and they show little differences in this. As already stated in section 4.1 this could be due to the fact that the shopping areas function as an activity but can also be passed by agents that are just passing along the roads on their way to their target activity. As well, shopping areas often have other activities located in the nearby, attracting agents, giving another reason for agents to pass through the shopping area.

Summarized, there are indeed some shifts in the most significantly passed roads between the model runs with the current dock locations and the model runs with the new dock locations. There seems to be a slightly better spread of the tourists around the city. Roads inside the city centre are passed less and streets outside the city centre are passed more often. The spread of tourists could help in battling the over-crowdedness in the city centre caused by tourists. However, the city centre of Amsterdam is the most crowded area in both model run results. An explanation for this could be that still most of the activities that tourists engage in, including the shopping areas, are located in the city centre. Even when an agent enters the model from a dock outside of the city centre the chance that an activity or shopping area located in the city centre is on their predefined schedule is rather large. This could explain why the Pijp / Rivierenbuurt area is more crowded in the model runs with the new dock locations: there are a lot of activities and shopping areas located and the area is functioning as a passage route as well for agents that entered the model through docks in the neighbourhood. This is in line with the theory of McKercher & Lau (2008)that whether tourists move widely or narrowly within a destination is an outcome of the numbers and spatial organization of attractions and whether they are clustered in particular areas or dispersed through the whole destination.

5 Conclusion

In this section the conclusions of this thesis and the conducted research are presented. First, the findings will be summarized by answering the three sub research questions. This is followed by answering and discussing the main research question of this thesis.

5.1 Sub research question 1

The first sub research question is as follows:

> *How can the movement behaviour of tourists in Amsterdam be operationalized and modelled in an ABM?*

For this research an ABM was developed that simulates the tourists in Amsterdam that go on one of the most popular activities: a canal cruise that sails through the unique canals of Amsterdam. To be able to develop an ABM with plausible outcomes that can be related to the real-world situation, it is important that the agents in the model resemble the actual tourists. The operationalization of these tourist was an important aspect of the conducted research. An extensive literature review about tourist behaviour and movement patterns of tourists and pedestrians in general, as most tourists explore Amsterdam by foot, was done. The operationalization of the tourists that go on a canal cruise is based on the theory of Lau & McKercher (2006) and reports on tourists in Amsterdam by Amsterdam Marketing (2015, 2016). Lau & McKercher (2006) Identified three main factors that influence tourist movements within a destination: human 'push' factors, physical 'pull' factors and time. The review of the reports by Amsterdam Marketing led to the identification of four types of tourists that visit Amsterdam: city trippers, Dutch same-day visitors, coastal visitors and conference attendees. These four types of tourists have their own characteristics that fall within the push and pull factors of the theory by Lau & McKercher (2006).

The canal cruise model is set up based on the STREETS model and underlying theory of Haklay et al. (2001) and consists of two phases: the pre-model and the ABM. The population of the model is created in the pre-model and based on socioeconomic and behavioural characteristics of the actual population that is represented by the agents. In the canal cruise model, the characteristics of the four types of tourists derived from the operationalization are used to populate the model with four different kind of agents. These four types of agents all have their own pre-defined schedule according to their push and pull factors. The environment of the model consists of a pedestrian network, the dock locations (according to scenario 1 or 2) and the locations of activities (museums, attractions, restaurants and cafés, and shopping areas) in Amsterdam.

In short, the ABM works as follows: an agent enters the model through a random canal cruise dock at its starting time (a random time between the opening hours of the canal cruises). The agent moves to their first activity according to their predefined schedule based on which tourist type it is. After the staying time of the first activity is finished the agent moves to their predefined second activity. Each model run lasts a day.

5.2 Sub research question 2

The second sub research question is as follows:

> *What are the tourist movement patterns in the city based on the following two scenarios and what are the differences between the two scenarios?*

<u>*Scenario 1:*</u> *The current canal cruise dock locations in the inner-city centre*
<u>*Scenario 2:*</u> *The new canal cruise dock locations outside of the city centre along the waterways as proposed in the 'Watervisie 2040'*

The developed canal cruise model aims to simulate the tourist movement patterns in Amsterdam from the tourists that go on a canal cruise. 15 model outputs were generated for each scenario. Per output, the roads that were passed often by the agents in the model run were documented in a csv-file. The 15 model outputs are combined to come to a map showing the roads that are relatively more passed in all the model runs.

In scenario 1 it is clear that tourists mainly move around in the city centre: this area seems to be the most crowded. All streets along the canals are passed often by the agents in every model run, which is not surprising as most of the current canal cruise locations are located along these roads. Other crowded areas emerging in the model are the Jordaan and the Museum Square, which are known to be crowded by tourists in the real-world as well. If there are no activities in an area for agents to go to, there are no roads that are often passed observed. Shopping areas are an activity itself, but they also often have other activities located nearby. This results in the observation that shopping areas are often passed by agents, regardless if they are located within the city centre or not. Roads far outside of the city centre seem to be passed more randomly and certainly not in every model run.

In scenario 2 the combined model outputs still show that the city centre has the most passed roads and thus is the most crowded area caused by tourists that go on a canal cruise. However, streets outside of the city centre are passed more often by the agents in the model runs. Especially de Pijp / Rivierenbuurt area has more relatively often passed roads. Roads nearby the new dock locations are also passed more often by the agents as they are functioning as passage routes for the agents to move to their target activity.

Comparing the results from the two scenarios it can be stated that the city centre is still the most crowded area. However, there is a shifting of the most passed roads by the agents towards the outside of the city centre: the roads in the city centre are passed less often and the roads outside of the city centre are passed more often. Also, within the city centre tourists are more spread out because of a diversion to the east side of the city centre. The fact that the city centre is still the most crowded area can be assigned to the specific locations of the activities that tourists engage in while in Amsterdam. Most of the activities are clustered in and nearby the city centre, thus always attracting agents back to the city centre even when they entered the model through a dock outside of the city centre.

5.3 Sub research question 3

The third sub research question is as follows:

> *To what extend can the developed ABM be validated based on verification, validity and sensitivity of the model and how plausible are the found patterns?*

An important aspect in the development of an ABM is the validity. The validation process consists of the verification, the validation and a sensitivity analysis. Due to a lack of empirical data, a full validation of the canal cruise model was not possible. However, a lot of steps of the process were completed to be able to say something about the plausibility of the model results. For the validation process only the current dock locations were used, as these represent the real-world situation and can thus be compared and validated. It is assumed that if the model is found to be valid with the current dock locations, the results are also valid if run with the new dock locations. The model is verified as it is doing what it is supposed to be doing according to the conceptual model, and bug-free. A face validation was done with positive outcomes for the validity of the model within the ability of the validation process. The generated crowded areas in the model outputs were compared to the outcomes of a survey among Amsterdam residents about their perception of crowdedness in their neighbourhood. The outcomes of the model resemble the most crowded areas as perceived by Amsterdam residents, but it is important to keep in mind that the survey does not only take tourists into account.

A sensitivity analysis was performed to test the robustness of the model and to calibrate the different parameters in the model. Four parameters were tested such as the opening times of the canal cruises and the range of the agents. It was investigated if the specific order of the activities in the predefined schedule was influencing the model outcomes to test the underlying assumptions made regarding the agents schedules. Adjustments were made regarding the sample size in the model and to the usability of the model outputs.

Based on the feasible validation process, the results of the model outputs and occurring patterns are found to be plausible. They can be related to the actual situation of crowdedness in the city of Amsterdam. The results of the model can therefore be used to answer the main question of this thesis.

5.4 Main research question

The main research question of this thesis is as follows:

> *To what extent can an ABM simulate the influence of the locations of the canal cruise docks on the crowdedness in the city centre of Amsterdam caused by tourists?*

An ABM is a good tool for the testing of policies as it enables policy makers to analyse the effects of planned measures with multiple scenarios before actually implementing them. The body of scientific literature about policy testing with the use of ABM is mainly about land use models and within the agricultural sector. By using ABM for policy testing in the urban field, this thesis has contributed to the expanded use of ABM outside of the beaten track of the rural approach. As well, this thesis has proven the applicability of ABMs to test urban policies with multiple scenarios.

Before being able to develop an ABM that simulates the influence of the canal cruise locations on the crowdedness, it was necessary to carry out an extensive literature review. The literature review provides an insight into AMBs in general, the validation of such models and the processes that are simulated within the canal cruise model: tourist and pedestrian movement patterns. The theoretic background together with the operationalization of the tourists in Amsterdam function as a solid base for the development of the canal cruise model. A proper analysis of the generated outcomes of the model make it possible to draw some conclusions of the results.

Based on the outputs of the canal cruise model with the two different scenarios and a comparison between those results, the main findings of this thesis are as follows: by relocating the canal cruise docks outside of the city centre it is likely that the tourists that go on a canal cruise will spread out to the neighbouring areas of the city centre. This spread will reduce the current pressure of tourists causing crowdedness within the city centre to some extent. However, the city centre will remain the most crowded area in Amsterdam even with the relocation of the docks. This can be addressed to the fact that the activities that tourists engage in are mostly located within the city centre and have a considerable influence on the behaviour and movements of the agents in the canal cruise model. This result of the model can be endorsed by the theory of McKercher & Lau (2008): the spatial distribution of activities in a city determines whether tourists spread wide across the city or cluster at specific areas. As well, it should be restated that this thesis only takes the tourists into account that go on a canal cruise during their stay in Amsterdam, representing 28% of the total number of tourists in Amsterdam.

6 Discussion and reflection

6.1 Discussion of the ABM and improvements

This research has aimed to examine the influence of the canal cruise locations on the crowdedness in the city centre of Amsterdam caused by tourists through the use of ABM. The results generated from the model outputs with the two different scenarios are deemed plausible based on a validation process of the model within the scope of what was possible without empirical data. The findings are a good exploration of the effects of the imminent policy devised by the Municipality of Amsterdam. The results from this thesis are probable, but further research should be done taking other processes into account that are of influence on the effect of this policy measure. In further research the role and point of view of other stakeholders involved in the relocation of the docks should be considered. It can be assumed that the canal cruise companies are not willing to relocate their docks without resistance. As well, residents of the neighbourhoods that the docks are relocated to might not be content with the attraction of tourists, causing crowdedness, to their neighbourhood.

This could explain why less research was done using ABM for policy testing in the urban field: a lot of stakeholders and processes are influencing the simulated situation. Therefore, using ABM in the urban field might be more time-consuming than using it to test policies in the agricultural sector. But, a lot of people are affected by new policies in urban areas, making it worthwhile to examine the effects of multiple scenarios before implementing a policy with the use of an ABM.

As stated in the conclusions, the specific locations of the activities have a big influence on the way tourists spread around the city. In the canal cruise model only the museums, attractions, restaurant and cafes and shopping areas are taken into account, but the locations of additional influences such as hotels and other places of interest also play a role in tourist movements. Furthermore, the new dock locations in the canal cruise model are a rough approach and in no way a definite proposition for the new locations. In further research an extensive multi-criteria analysis could be done to determine the best locations for the new docks. Other placement of the new docks could deliver different results on the spread of crowdedness caused by tourists. As well, it is uncertain if the same number of tourists will go on a canal cruise if the docks are not located close-by other activities, resulting in the fact that the tourists will remain in the city centre.

The developed model is based on qualitative assumptions to simulate a real-world situation, which should be taken in consideration regarding the results. The current model is working properly and doing what it is supposed to be doing but there are some improvements that could be implemented in further research. To make the model even more realistic more rules could be added to the ABM such as a maximum number of visitors at a specific activity according to the actual maximum number of visitors possible. As well, the opening times of the activities and the departure and arrival times of the canal cruises should be integrated in the model. The functioning of the behaviour of the agents could be expanded, including interaction between agents resulting in changes in the predefined schedules.

It is desirable that empirical data is collected regarding the movements of tourists in Amsterdam. This could be done through a study in which the movements of actual tourists are tracked with GPS, enabling the execution of empirical validation of the canal cruise model.

6.2 Movement patterns in the model

Regarding the movement patterns as discussed in the theoretical framework, some things can be said about the canal cruise model. The results of the model runs can be related to the work of Lew & McKercher (2006). As stated in section 2.2.3, the authors have developed a framework to analyse inter-destination tourist movements based on variables such as the geomorphology of the destination, the spatial location of attractions and accommodation nodes and transport routes. The movements of tourists within a destination can be divided into two dimensions: the territorial models and linear models.

The authors take the tourist accommodation as the starting point in the models, but in this research the gateway dock is the starting point. The developed model created the 'type T3: concentric exploration' pattern within the territorial model's dimension (see figure 27). The territorial models reflect the impact and perception of distance and intervening opportunities on how far tourists move away from their starting point. This could be argued because the agents in the model do not specifically stay close to the dock that they entered the model through. The agents will move around in the city of Amsterdam to go to their target activity according to their predefined schedule. However, they do not move unrestricted (type T4: unrestricted destination-wide movement) as they are restricted by their range and dependent on the locations of the activities, located mostly within the city centre.

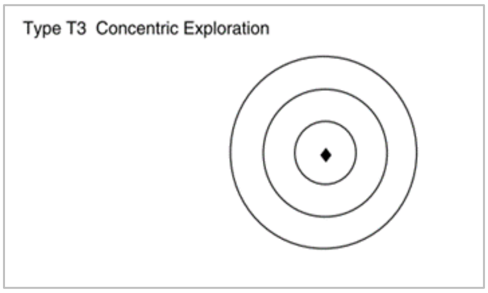

Figure 27 – The emerging movement pattern within the territorial models
Source: Lew & McKercher, 2006.

For the linear models, reflecting the geometry of tourists movement away from their accommodation point, it is more difficult to say something about the patterns emerging in the canal cruise model. Currently the model is programmed in such a way that only point-to-point patterns are generated (see figure 28). In the real-world situation this could be different, or a mix of the patterns, as tourists do not strictly move from target point to target point but also wander or take detours to come across other places of interests.

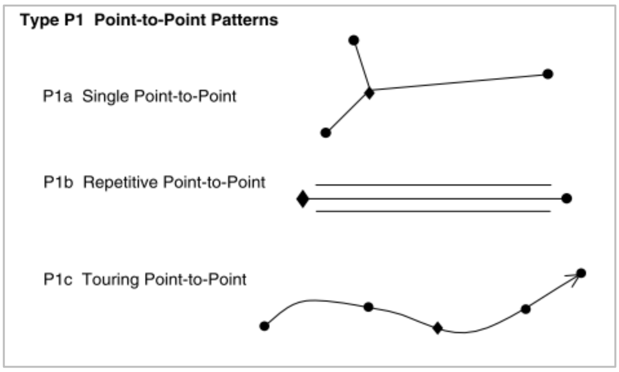

Figure 28 – The implemented movement patterns within the linear models
Source: Lew & McKercher, 2006.

6.3 Reflection

Reflecting on this this thesis, I can say that the canal cruise model in its current form represents the ideas I had when I started working on this topic. Even though the learning curve of the GAMA simulation engine, with its own agent-based language coded in java, was steeper than I expected. The start of the model was set up quite fast, but the implementation of more complicated features was difficult and sometimes took more time than I anticipated on. Following the mid-term report it was suggested that I would start small with the model, to expand it step-by-step. However, this made it complicated to implement new ideas, as it was not ideal to completely alter the model, which would result in starting from scratch again. In the end I created a model and wrote a thesis that I am proud of and I look back on a process in which I learned a lot.

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8 Appendices

8.1 Appendix A

The current canal cruise companies as promoted by Amsterdam Marketing, with the locations of their boarding and disembarking docks, and whether the dock is located within the city centre.

Canal cruise company	#	Location	Within city centre
Stromma	1	Prins Hendrikkade 47	Yes
	2	Stationsplein 45F	Yes
	3	Stationsplein 4	Yes
	4	Prins Hendrikkade 37	Yes
	5	Damrak 16, pier 5	Yes
	6	Prinsengracht 279	Yes
	7	Keizersgracht 526	Yes
	8	Leidse bosje 2	Yes
	9	Stadhouderskade 520	No
Amsterdam Circle Line	10	Stationsplein 53	Yes
	11	Prinsengracht 263-267	Yes
	12	Prinsengracht 444	Yes
	13	Prinsengracht 598	Yes
	14	Amstel 1	Yes
	15	Singel 357	Yes
	16	Singel 250	Yes
Boat Amsterdam	17	Amstel 51F	Yes
Blue Boat Company	18	Stadhouderskade 550	No
	19	Stadhouderskade 501	No
	20	Overhoeksplein 3	No
Rederij P. Kooij	21	Rokin t/o no. 125	Yes
	22	Amstel t/o no. 30	Yes
	23	Sint Nicolaasbrug 1	Yes
Rederij Plas	24	Damrak 28A: Steiger 3	Yes
City Sightseeing Amsterdam	25	Stationsplein 10	Yes
	26	Passenger Terminal Amsterdam	No
	27	NEMO	Yes
	28	Overhoeksplein	No
	29	Nieuwe Uilenburgerstraat 173	Yes
	30	Amstel 194	Yes
	31	Westerkerk	Yes
Lovers	32	Prins Hendrikkade 25	Yes
	33	Leidsekade t/o 97	No
	34	Leliegracht 51	Yes

Locations of the proposed new boarding and disembarking docks for the canal cruises, including the already existing docks that are located outside of the city centre.

Canal cruise company	#	Location
Stromma	1	Stadhouderskade 520
Blue Boat Company	2	Stadhouderskade 550
	3	Stadhouderskade 501
	4	Overhoeksplein 3
City Sightseeing Amsterdam	5	Passenger Terminal Amsterdam
	6	Overhoeksplein
Lovers	7	Leidsekade t/o 97
NEW	8	Ruysstraat – Amstel
	9	Berlagebrug
	10	Apollo hotel
	11	Noorder Amstelkanaal – Reinier Vinkeleskade
	12	Zuider Amstelkanaal – Stadionkade
	13	Stadiongracht
	14	Singelgracht – Zeeburgerstraat
	15	Mauritskade - Alexanderplein
	16	Singelgracht – Tweede Hugo de Grootstraat
	17	Nassaukade – Jacob Catskade
	18	Haarlemmerpoort
	19	Sloterplas

8.2 Appendix B

The average staying times of the top activities for the museums, restaurant and cafes and attractions in Amsterdam, according to Amsterdam Marketing and TripAdvisor. The average time that people spend at a certain activity is looked up on Google Maps.

Top 12 major museums according to Amsterdam marketing	Average staying time according to Google Maps: up to … hours
Rijksmuseum	3
Stedelijk museum	2,5
Van Gogh museum	3
Anne Frank house	2
Hermitage Amsterdam	3
Amsterdam museum	2
Nemo	3
The National Maritime Museum	2,5
Eye Filmmuseum	3
Foam	1,5
Rembrandt House Museum	2
Tropenmuseum	3
Average staying time total	1 - 3

Source: https://www.iamsterdam.com/en/see-and-do/things-to-do/museums-and-galleries/top-12-museums-in-amsterdam

Top 20 highest ranked restaurants/cafes according to TripAdvisor	Average staying time according to Google Maps, in hours
Graham's Kitchen	2 – 3,5
De Silveren Spiegel	3
Chez Lorraine	0,5 – 1
Zaza's	2,5
Bhatti Pasal	1,5
Senses Restaurant	3
Café Sonneveld	1 – 1,5
The Chicken Bar	1,5
Restaurant Adam	Unknown
Benny's Chicken	Unknown
PIQNIQ	0,75 – 1,5
The Happy Bull	1
Rob Wigboldus Vishandel	0,25 – 0,75
Bistrot des Alpes	2
Gartine	1 - 1,5
Café Broer	1 – 2,5
Pastai	1 – 2
Ciel Bleu	Unknown
Restaurant Vinkeles	Unknown
Blue Pepper Restaurant	2,5
Average staying time total	1 – 2,5

Source: https://www.tripadvisor.com/Restaurants-g188590-Amsterdam_North_Holland_Province.html

Top 10 attractions according to TripAdvisors ‘Travelers Favorites’	Average staying time according to Google Maps, in hours
Vondelpark	Unknown
A’DAM Lookout	0,75 – 2
ARTIS Amsterdam Royal Zoo	1,5 – 3,5
Heineken Experience	Unknown
Begijnhof	0,75
Dam Square	1
Ripley’s Believe it or not	2
Portugese Synagoge	Unknown
Albert Cuypmarkt	0,25 – 1
Hortus Botanicus	2
average staying time total	1 – 2

Source: https://www.tripadvisor.com/Attractions-g188590-Activities-a_allAttractions.true-Amsterdam_North_Holland_Province.html

8.3 Appendix C

The code of the canal cruise model:

```
model crowdedcanalcruises

global   {
	int number_of_citytrippers <- 672;
	int number_of_dutch <- 616;
	int number_of_coastal <- 58;
	int number_of_conference <- 224;
	float step <- 10 #mn;
	graph the_graph;
	float min_speed <- 1.08 #m / #sec;
	float max_speed <- 1.6 #m / #sec;
	float range_of_agents <- 7000 #m;
	int current_hour update: (time / #hour) mod 24;
	string optimizer_type <- "AStar" among: ["NBAStar", "NBAStarApprox", "Dijkstra",
	"AStar", "BellmannFord", "FloydWarshall"];

	int min_stay_museum <- 1;
	int max_stay_museum <- 3;
	int min_stay_attraction <- 1;
	int max_stay_attraction <- 2;
	int min_stay_shops <- 0.5;
	int max_stay_shops <- 3.0;
	int min_stay_restcafe <- 1;
	int max_stay_restcafe <- 2;
	int end_time_museum <- nil;
	int end_time_attraction <- nil;
	int end_time_restcafe <- nil;
	int end_time_shops <- nil;
	int opentime_cruise <- 9;
	int closetime_cruise <- 21;

	list<activity> museum;
	list<activity> restaurant_cafe;
	list<activity> attraction;

	file shape_file_roads <- file("../includes/roadsamsfinal.shp");
	file shape_file_docklocations <- file("../includes/dockshuidig.shp");
	file shape_file_activities <- file("../includes/activitiesamsfinal.shp");
	file shape_file_shoppingareas <- file("../includes/shoppingareas.shp");

	geometry shape <- envelope(shape_file_roads);

	init {
	create road from: shape_file_roads;
	the_graph <- as_edge_graph(road) ;
	the_graph <- the_graph with_optimizer_type "AStar";

	create dock from: shape_file_docklocations;

	create activity from: shape_file_activities with: [type::string(read ("Activity"))]
	{
		if type="Restaurant/cafe" {
				color <- #greenyellow;
			}
		if type="Attraction" {
				color <- #gamablue;
			}
		if type="Museum" {
				color <- #darkmagenta;
			}
		}
		museum <- activity where (each.type="Museum");
```

```
			restaurant_cafe <- activity  where (each.type="Restaurant/cafe");
			attraction <- activity where (each.type="Attraction");

		create shoppingarea from: shape_file_shoppingareas;

		create citytrippers number:number_of_citytrippers {
			location <- any_location_in (one_of (dock));
			start_time <- opentime_cruise + rnd (closetime_cruise - opentime_cruise);
			stay_time_museum <- min_stay_museum + rnd (max_stay_museum -
		min_stay_museum);
			range_agents <- range_of_agents;
			speed <- min_speed + rnd (max_speed - min_speed);
			}

		create dutch number:number_of_dutch {
			location <- any_location_in (one_of (dock));
			start_time <- opentime_cruise + rnd (closetime_cruise - opentime_cruise);
			stay_time_museum <- min_stay_museum + rnd (max_stay_museum -
min_stay_museum);
			range_agents <- range_of_agents;
			speed <- min_speed + rnd (max_speed - min_speed);
			}

		create coastal number:number_of_coastal {
			location <- any_location_in (one_of (dock));
			start_time <- opentime_cruise + rnd (closetime_cruise - opentime_cruise);
			stay_time_shops <- min_stay_shops + rnd(max_stay_shops - min_stay_shops);
			range_agents <-range_of_agents;
			speed <- min_speed + rnd (max_speed - min_speed);
			}

		create conference number:number_of_conference {
			location <- any_location_in (one_of (dock));
			start_time <- opentime_cruise + rnd (closetime_cruise - opentime_cruise);
			stay_time_museum <- min_stay_museum + rnd(max_stay_museum - min_stay_museum);
			range_agents <- range_of_agents;
			speed <- min_speed + rnd (max_speed - min_speed);
			}
		}
}


species road  {
		int nb_passes;
		 aspect base {
			draw shape color: #grey;
			}

		aspect show_nb_tot{
		int scaleFactorWidth <- 1;
		int scaleFactorColor <- 20;
		draw shape +(nb_passes / scaleFactorWidth) color:( blend(#red, #green,
nb_passes/scaleFactorColor));
			}
		}

species dock {
		rgb color <- #red;
		aspect base {
			draw circle (15) color: color;
			}
		}

species activity {
		string type;
		rgb color;
```

```
	aspect base {
		draw circle (10) color: color;
		}
	}

species shoppingarea {
	string type;
	rgb color <- #orange;
	aspect base {
		draw shape color: color ;
		}
	}


species citytrippers skills:[moving] {
	bool arrivedAtLocation <- false ;
	bool readyToGo <- false;
	point the_target;
	int start_time;
	int stay_time_museum;
	int stay_time_attraction;
	road current_road;
	float range_agents <- 7000 #m;
	int end_time_museum;

	reflex stay when: current_hour = start_time {
		the_target <- any_location_in (one_of (museum));
		}

	reflex at_museum when: arrivedAtLocation = true{
		end_time_museum <- (current_hour + stay_time_museum);
		arrivedAtLocation <- false;
		readyToGo <-true;
		}

	reflex next_activity when: readyToGo = true{
		if current_hour = end_time_museum{
		set the_target <- any_location_in (one_of (attraction));
			}
		}

	reflex dayisover when: current_hour = 23{
		do die;
		}

	reflex move when: the_target != nil {
		do goto target: the_target on: the_graph ;
		if (location = the_target){
		the_target <- nil ;
		arrivedAtLocation <- true;
		road my_road <- road closest_to self;
		if my_road != current_road{
			my_road.nb_passes <- my_road.nb_passes +1;
			current_road <- my_road;
			}
		}
	}


	aspect base {
		draw circle(10) color: #deeppink;
		}
}

species dutch skills:[moving]{
	bool arrivedAtLocation <- false ;
```

```
	bool readyToGo <- false;
	point the_target;
	int start_time;
	int stay_time_museum;
	int stay_time_shops;
	road current_road;
	float range_agents <- 10000#m;
	int end_time_museum;

	reflex stay when: current_hour = start_time {
		the_target <- any_location_in (one_of (museum));
		}

	reflex at_museum when: arrivedAtLocation = true{
		end_time_museum <- (current_hour + stay_time_museum);
		arrivedAtLocation <- false;
		readyToGo <-true;
		}

	reflex next_activity when: readyToGo = true{
		if current_hour = end_time_museum{
		set the_target <- any_location_in (one_of (shoppingarea));
			}
		}

	reflex dayisover when: current_hour = 23{
		do die;
		}

	reflex move when: the_target != nil {
		 do goto target: the_target on: the_graph ;
		if (location = the_target){
		the_target <- nil ;
		arrivedAtLocation <- true;
		road my_road <- road closest_to self;
		if my_road != current_road{
			my_road.nb_passes <- my_road.nb_passes +1;
			current_road <- my_road;
			}
		}
	}

	aspect base {
		draw circle(10) color: #deeppink;
		}
}

species coastal skills:[moving]{
	bool arrivedAtLocation <- false ;
	bool readyToGo <- false;
	point the_target;
	int start_time;
	int stay_time_shops;
	int stay_time_restcafe;
	road current_road;
	float range_agents <-10000#m;
	int end_time_shops;

	reflex stay when: current_hour = start_time {
		the_target <- any_location_in (one_of (shoppingarea));
		}

	reflex at_museum when: arrivedAtLocation = true{
		end_time_shops <- (current_hour + stay_time_shops);
		arrivedAtLocation <- false;
		readyToGo <-true;
```

```
		}

	reflex next_activity when: readyToGo = true{
		if current_hour = end_time_shops{
		set the_target <- any_location_in (one_of (restaurant_cafe));
			}
		}

	reflex dayisover when: current_hour = 23{
		do die;
		}

	reflex move when: the_target != nil {
		do goto target: the_target on: the_graph ;
		if (location = the_target){
		the_target <- nil ;
		arrivedAtLocation <- true;
		road my_road <- road closest_to self;
		if my_road != current_road{
			my_road.nb_passes <- my_road.nb_passes +1;
			current_road <- my_road;
			}
		}
	}

	aspect base {
		draw circle(10) color: #deeppink;
		}
}

species conference skills:[moving]{
	bool arrivedAtLocation <- false ;
	bool readyfornext <- false;
	point the_target;
	int start_time;
	int stay_time_museum;
	road current_road;
	float range_agents <-7000 #m;
	int start_time_museum;

	reflex stay when: current_hour = start_time {
		the_target <- any_location_in (one_of (museum));
		}

	reflex next_activity when: arrivedAtLocation = true{
		start_time_museum <- (current_hour + stay_time_museum);
		arrivedAtLocation <- false;
		readyfornext <-true;
		}

		reflex next when: readyfornext = true{
		if current_hour = start_time_museum{
		set the_target <- any_location_in (one_of (restaurant_cafe));
			}
		}


	reflex move when: the_target != nil {
		do goto target: the_target on: the_graph ;
		if (location = the_target){
		the_target <- nil ;
		arrivedAtLocation <- true;
		road my_road <- road closest_to self;
		if my_road != current_road{
			my_road.nb_passes <- my_road.nb_passes +1;
			current_road <- my_road;
```

```
				}
			}
		}


		aspect base {
			draw circle(10) color: #deeppink;
			}
}

experiment my_experiment type: gui {
		parameter "number of citytrippers" var:number_of_citytrippers;
		parameter "number of dutch visitors" var:number_of_dutch;
		parameter "number of coastal visitors" var:number_of_coastal;
		parameter "number of conference attendees" var:number_of_conference;

		parameter "Shapefile for the roads:" var: shape_file_roads category: "GIS" ;
		parameter "Shapefile for the dock locations:" var: shape_file_docklocations
category: "GIS" ;
		parameter "Shapefile for the activities" var: shape_file_activities category: "GIS";
		parameter "Shapefile for the shopping areas" var: shape_file_shoppingareas category:
"GIS";

		parameter "opentime canal cruises" var: opentime_cruise min: 8 max: 12;
		parameter "closetime canal cruises" var: closetime_cruise min: 18 max: 21;
		parameter "range of agents" var: range_of_agents;

		output {
			display my_display {
				species road aspect:base;
				species road aspect: show_nb_tot;
				species dock aspect:base;
				species activity aspect:base;
				species shoppingarea aspect:base transparency: 0.4;
				species citytrippers aspect:base;
				species dutch aspect:base;
				species coastal aspect:base;
				species conference aspect:base;
			}
		}
 }
```