Geographical Information Management and Applications

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Master Thesis

Overcrowded Dutch natural areas: an agent-based exploration of visitor conflicts

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Preface

This document represents the results of a year-long study into the behaviour of visitors in natural areas, which I have conducted as part of the master's programme Geographical Information Management and Applications (GIMA). As someone who enjoys spending time visiting nature, whether it be in the Netherlands, or anywhere else in the world, it has been an interesting opportunity to study in detail a topic that is so close to my interests.

For me, one of the main highlights of studying this topic, is that is has allowed me to have very interesting conversations with experts from four Dutch nature management organisations. I want to thank these experts for their time, valuable insights, and most importantly, their enthusiasm.

I also want to say a special thank you to my fellow students, who have been of great help in supporting me in my research. Thank you for the endless hours we spent together working on our theses, as well as for the activities we undertook outside of our studies. I also want to thank my family and friends, who have been with me throughout this period. Thank you to those who have joined me on one of the many walks and cycling trips in Dutch natural areas I have been on during the past year.

Finally, I want to thank my supervisor, Arend, for his support, feedback, and guidance throughout the project.

I hope you will enjoy reading this thesis.

Christian Booms

Houten, November 2021

Abstract

Nature-based recreation and tourism brings forward a wide variety of benefits. However, high recreational pressure can also result in various negative impacts, both on nature itself, as well as on the experiences of those visiting natural areas. Visitors can start to experience crowding, which can reduce the quality of their nature visiting experience, and visitor conflicts can be experienced. In order to facilitate sustainable nature-based recreation and tourism, organisation involved in managing natural areas therefore engage in visitor management, which aims at ensuring the quality of the visitor experience and nature itself. Visitor management is becoming increasingly important to natural areas around the world, as visitor numbers are increasing. This is also the case in the Netherlands, where an historic increase in the number of visits to natural areas has been reported since the start of the COVID-19 pandemic. For visitor management to be effective, information about visitor behaviour is required. For many natural areas, it is the case that little information about visitor behaviour is known, however. Agent-based modelling allows for the estimation of visitor behaviour that is hard to measure using other methods. Many agent-based models, however, rely on the assumption that human decision-making is rational, and are not based on existing models of human psychology. The Consumat approach to simulation modelling is identified as an exception but has not been applied to the context of visitor behaviour yet. In this thesis, it is investigated how an agent-based model, based on the Consumat framework, can be used to simulate and explore the spatiotemporal behaviour of visitors in natural areas, in order to gain insights into visitor conflicts. The Amerongen Forest in the Netherlands has been selected as the research area for this thesis, and GAMA has been used to develop the model. The behaviour of hikers, cyclists, mountain bikers, and horse riders was simulated, and encounters between these different types of visitors were recorded. The model output suggests that many encounters in the research area occur near the main entrances to the area, along frequently used marked hiking trails, and near landmarks situated on these trails. Furthermore, encounters between visitors of different activity types are suggested to occur in places where there is an overlap or intersection between the networks of various activity types. The inclusion of the concepts of familiarity and satisfaction allows for the further exploration of visitor behaviour. A sensitivity analysis was performed, and scenarios were developed. Furthermore, through expert interviews, it was determined that, generally, the outcomes of the model can be regarded as plausible. However, further research, and in particular, empirical research into the behaviour of visitors in natural areas, is required in order to further calibrate and statistically validate the model.

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1. Introduction

1.1. Crowding natural areas

Nature-based recreation and tourism are increasingly being recognised for the wide variety of benefits that they bring to society (Winter, Selin, Cerveny, & Bricker, 2020). Being in contact with nature provides people with both physical and mental health benefits (Frumkin et al., 2017). Furthermore, people visiting natural areas supports local economies, and helps people to develop a consciousness regarding nature conservation and the natural and cultural heritage of an area (Winter et al., 2020). However, as populations have grown, the use of natural areas for recreation purposes has also increased, especially in natural areas near highly urbanised areas (Derks, Giessen, & Winkel, 2020; Winter et al., 2020). Additionally, since the start of the COVID-19 pandemic, the number of visits to natural areas has increased in many countries, especially during lockdowns (Derks et al., 2020). Such an increase in recreative pressure can result in various negative impacts, both on nature itself, as well as on the experiences of those visiting natural areas (Lawson, 2006; Winter et al., 2020). Visitors can start to experience crowding, which can reduce the quality of their visiting experience, and visitor conflicts can be experienced. Most commonly, a visitor conflict is described to occur when the behaviour of a visitor or group of visitors interferes with the goals of another visitor or group of visitors (Carothers, Vaske, & Donnelly, 2001). In order to ensure that nature-based tourism and recreation is sustainable, it is therefore important that organisations involved in managing natural areas engage in visitor management, which should focus on maintain the quality of both the natural area itself and the experiences of the visitors (Candrea & Ispas, 2009).

In the Netherlands, a historic increase in the number of visits to natural areas since the start of the pandemic has been reported (e.g., Koek, 2020; NOS, 2020). This development represents an accentuation of a trend that has already been present before the pandemic. Together with an increase in visitor numbers, the value of businesses dependent on nature tourism and recreation in the Netherlands has increased over the last couple of years, as well as consumer expenditure related to nature tourism and recreation (Horlings et al., 2020). Thereby, nature-related tourism and recreation is the most substantial ecosystem service in terms of economic value.

However, Dutch foresters and other public officials report that the growing number of visitors of natural areas is also causing problems, both for nature itself and among visitors (NOS, 2020). Littering seems to be one of the main problems, but there are also reports about visitors coming into conflict with each other, mainly about the existence of mountain bike tracks, sometimes resulting in dangerous situations. The increasing recreative pressure is a development that is present on the agendas of organisations involved in managing nature and recreation in natural areas. Nationaal Park Utrechtse Heuvelrug, for example, relates two out of six of their ambitions for the upcoming years to managing this pressure (Oosterman & Dik, 2018).

In the Netherlands, the spread of COVID-19 and the corresponding increase in recreative pressure on natural areas has resulted in the launch of multiple crowding monitors. The goal of these crowding monitors is to redirect visitors to places that are less crowded, reducing the recreative pressure in the places that are crowded, as well as reducing the risk of transmitting COVID-19. The Province of Utrecht, for example, launched a crowding monitor as part of a pilot project (Druktemonitor Utrecht, 2021).

1.2. Simulating visitor behaviour in natural areas

These crowding monitors are examples of regional scale computer applications that can be used for visitor management purposes. Effective visitor management requires information about how visitors interact with their environment (Candrea & Ispas, 2009; Cole & Daniel, 2003). An important aspect of these interactions are the spatiotemporal distribution and flow of visitors. Cole and Daniel (2003) argue that obtaining information about the spatiotemporal behaviour of visitors from verbal reports is relatively unreliable. Instead, they argue for the direct observation of visitor behaviour and the use of travel simulation models.

Lawson (2006) identifies four ways in which simulation models of visitor use can facilitate the management of sustainable tourism in protected natural areas. First of all, they can be used to describe existing visitor behaviour. Important here, is that they can be used to estimate visitor behaviour that is difficult to observe otherwise. As the number of people entering an area is often relatively easy to measure, this is especially useful for estimating visitor behaviour that takes place in the interior of a natural area. Simulation models can for example estimate the locations of areas that get easily crowded, potentially leading to conflicts among visitor groups. Next, Lawson (2006) indicates that simulation models can also be used to monitor indicators that are otherwise hard to measure, estimate the impact of different management scenarios, and help design studies about the attitude of visitors to visitor management.

Simulation tools have been used in the management of natural areas since the mid-1970s (Cole & Daniel, 2003). Earlier models were often developed by identifying travel routes and assigning these randomly to visitor groups based on frequencies of use derived from surveys and related to travel modes and group sizes. More recent models, especially those developed after the turn of the century, are often individual-based models (Cole & Daniel, 2003). In these models, autonomous agents traverse a route, making decisions along the way. These decisions are generally based on behavioural rules that are derived from surveys. These models allow for complex decision-making. Most of the models described by Cole and Daniel (2003), as well as by Lawson (2006), focus on natural areas in the USA. These models often focussed on natural areas that are relatively large and remote, compared to the recreational areas that are present in the Netherlands. A notable example of such a model is the Recreation Behavior Simulator (RBSim), as described by Gimblett, Richards, and Itami (2001), that was also applied to the Australian context. An example of a model developed for the Dutch context is the Multi Agent Simulation of Outdoor Recreation, or MASOOR, which has, for example, been applied to the Dwingelderveld National Park (Jochem, Van Marwijk, Pouwels, & Pitt, 2008).

RBSim and MASOOR are examples of agent-based approaches to system modelling. In literature, models following such an approach are described as agent-based models (ABMs), or with the related term of multi-agent systems (Jochem et al., 2008). Central to these models are agents, computer representations of, in the cases of RBSim and MASOOR, human visitors to natural areas. Agent-based models allow for the simulation and measuring of the behaviour of agents, as they try to fulfil their goals in a complex system (Clarke, 2014). Furthermore, in the context of recreational behaviour, agent-based modelling has been found to be an effective approach to modelling encounters between agents as they occur in space and time (Gimblett et al., 2001).

Richetin et al. (2010), however, point out that most agent-based models described in literature are not based on existing models of human psychology, but rather, they rely on the assumption that human decision-making is purely rational. They point to the Consumat approach to social simulation as described by Jager (2000) as a notable exception. The Consumat framework has previously been translated to agent-based models in various fields of research, where it has proven to result in more realistic outcomes when compared to using agents that are not grounded in the Consumat approach (Brouwers & Verhagen, 2003). The Consumat approach has, however, not been applied to the topic of visitor behaviour in natural areas yet, but is described as being easily applicable to new contexts (Pacilly, Hofstede, Lammerts van Bueren, & Groot, 2019).

1.3. Objective and research questions

The aim of this study is to develop an agent-based model that allows for the simulation and exploration of the spatiotemporal behaviour of different visitor groups in a natural area in the Netherlands to gain insights into the occurrence of visitor conflicts. Furthermore, this study aims at reflecting on the plausibility of the outcomes produced by the model and on the usability of agent-based modelling in visitor conflict management. Furthermore, this thesis aims at incorporating realistic decision-making processes in this simulation model, by grounding the model in the Consumat framework. By doing this, this thesis will try to provide some of the spatial knowledge required for the management of visitor conflicts in natural areas.

The main question of this study is as follows:

"How can agent-based behavioural modelling, based on the Consumat framework, provide insights into visitor conflicts in Dutch natural areas?"

To answer this question, various sub-questions will have to be answered. First of all, in order to know what conflicts occur between visitors of natural areas, it is necessary to know more about the behaviour of these visitors. When it comes to behaviour, a distinction can be made between the flows of movement of visitor groups through a natural area, based on their preferences and abilities (e.g., Pouwels, van Eupen, Walvoort, & Jochem, 2020) and interactions that take place between visitor groups. Interactions might lead to visitor conflicts (Carothers et al., 2001), so it is important to gain insight into what interactions occur and when they lead to visitors experiencing a conflict. The corresponding questions, that will be answered through a literature review, are:

> *"What factors influence the spatiotemporal behaviour of visitors in natural areas?"*
>
> *"What interactions take place between visitors of natural areas and when do these interactions lead to visitor conflicts?"*

The knowledge gained from answering these questions, will be used to design a conceptual model of visitor behaviour and visitor conflicts, which will be based on the Consumat framework. This conceptual model will then be translated into an agent-based model. The Amerongen Forest in the Netherlands will serve as the research area for this model. Through the analysis of model outputs, this study tries to provide insights into how agent-based modelling can provide insights into visitor behaviour and the occurrence of visitor conflicts. Expert interviews have been conducted to determine the plausibility of these outputs. The corresponding questions are:

> *"How can an ABM be used to simulate the spatiotemporal behaviour of, and measure the occurrence of conflicts between, visitors in a natural area?"*
>
> *"What information about the occurrence of crowding and visitor conflicts may be derived from the visitor behaviour simulated by the developed model?"*
>
> *"What is the plausibility of the outcomes of the developed model?"*

1.4. Outline of thesis

In the next chapter, the theoretical framework of this study is presented. This chapter begins with a discussion of the spatial behaviour of visitors of natural areas, including their wayfinding as it is described in literature. Next, the causes and effects of visitor conflicts are discussed. Then, it is described how the behaviour of visitors in natural areas has been modelled previously. Finally, the Consumat approach to social simulation is introduced. Based on the theoretical framework, a conceptual model has been developed, which is presented in Chapter 3, Methodology. It is then explained how this conceptual model was translated into an ABM, in which the behaviour of hikers, cyclists, mountain bikers, and horse riders in the Amerongen Forest is simulated. It is also described how model output has been analysed and validated. In the chapter thereafter, the Results chapter, these model outputs are presented. Model output includes information about the flow of visitors through the case study area, as simulated by the model, encounters that take place and their impact on the satisfaction of visitors. Results of a sensitivity analysis and scenarios are also presented, as are the outcomes of expert interviews that were conducted as part of the validation of the model output. The methodology used and the results presented in this study, as well as the limitations of the study are discussed in the fifth chapter, the Discussion. Finally, the research questions are answered, and recommendations are given, in Chapter 6, the Conclusion.

2. Theoretical Framework

This chapter will start with an overview of existing theory on the spatial behaviour of visitors of natural areas. The section thereafter will focus on the causes and effects of visitor conflicts. Next, an overview will be given of what simulation modelling techniques are used to study visitor behaviour in Section 2.3. Finally, the theoretical framework will finish with a description of the Consumat approach to simulation modelling in Section 2.4 and a short conclusion.

2.1. The spatial behaviour of visitors of natural areas

As outlined in the introduction, visitor management in natural areas requires accurate information about the spatiotemporal distribution and flow of visitors, as well as the factors that influence this (Cole & Daniel, 2003). Spatiotemporal visitor travel patterns have typically been the focus of studies on visitor behaviour in natural areas (e.g., Beeco & Hallo, 2014). With an increase in recreative pressure, effective management is becoming increasingly important (Bishop & Gimblett, 2000). An important reason for this, is that recreative pressure can diminish the visitor experience (Lawson, 2006). Literature identifies a wide variety of factors that can influence the flow of movement of visitor groups through natural areas. This chapter will, first of all, give an overview of the methods that can be used to study visitor behaviour. This will be followed by a discussion of visitor wayfinding and, finally, an overview of the most important factors that have been found to influence visitor behaviour.

2.1.1. Studying visitor flows of movement

Many different studies have been performed to get insight into visitor behaviour patterns. Cole and Daniel (2003) and Lawson (2006) give descriptions of the techniques that have been used in these studies. Traditionally, studies on visitor behaviour in natural areas made use of verbal reports of visitors and visitor surveys (Cole & Daniel, 2003). Visitors are asked about the activities they are going to undertake or undertook while visiting a natural area. While these techniques can provide valuable information about visitor behaviour, there are concerns about the validity of information derived from these methods. Cole and Daniel (2003) point out that actual behaviour does not always equate stated behaviour. Visitors might forget what route they travelled while visiting a park, forget what they did at different locations along the route, or lie about visiting restricted areas. Cole and Daniel (2003) conclude that "… verbal surveys are not likely to adequately answer the who, where, when doing what questions that are essential to understanding visitor flow in parks and protected areas" (p. 272). As accurate information about actual visitor behaviour is essential to visitor management, it might therefore be necessary to look beyond verbal reports and surveys alone for this information.

Cole and Daniel (2003) argue for the use of monitoring and simulation modelling to gain insights into visitor behaviour that can complement insights gained from traditional verbal methods. In particular, simulation models can help provide insights into visitor behaviour and associated problems such as crowding in areas that are otherwise hard to monitor, such as the interiors of natural areas. This is regarded as one of the main advantages of the use of simulation models (Cole & Daniel, 2003; Lawson, 2006). Encounters between visitors in the interior of a natural area are difficult to monitor directly. They can, however, be predicted effectively by monitoring visitor numbers at area entrances, which are easier to monitor, and by using simulation models. Furthermore, simulation models provide the opportunity to test the impacts of various potential management alternatives, or fine-tune existing ones (Cole & Daniel, 2003; Lawson, 2006). The potential impact of, for example, entrance quotas or the creation of new hiking tracks on visitor conflicts can be estimated using simulation models in a cost-effective way, and without the risk that is accompanied by real-world management changes. Section 2.3 will go into more detail about the development and use of simulation modelling techniques in visitor behaviour studies.

More recent developments in studying visitor behaviour include the use of GPS tracking devices to more accurately record visitor movement (Lawson, 2006). The use of camera systems and mobile phone tracking techniques provide alternatives to GPS tracking that are also being used to track tourism travel routes (Xia, Arrowsmith, Jackson, & Cartwright, 2008). Participatory mapping techniques and volunteered geoinformation are also increasingly being used to study visitor behaviour (Riungu, Peterson, Beeco, & Brown, 2018). These relatively recent techniques can provide researchers with more accurate tracking data than traditional methods (Xia et al., 2008).

2.1.2. Wayfinding, cognitive mapping, and familiarity

Before going into detail about what factors have been found to influence visitor behaviour using these techniques, it is important to first take a closer look at the decision-making process that visitors engage in when visiting natural areas. When discussing visitor route choice, Davies (2016) distinguishes between choices made pre-trip and on-site decisions. Choices made pre-trip are those concerning aspects such as what area to visit and when, how to get there and what activities to perform there. These choices depend on push and pull factors, which described by Davies (2016) in more detail. However, this thesis focusses on visitor behaviour taking place while visiting an area. For this behaviour, the concept of wayfinding is an important one.

Wayfinding can be described as the "… cognitive psychological process for finding a pathway from an origin to a specified destination" (Xia et al., 2008, p. 445). This process is different for each individual and is influenced by the purpose of the trip and environmental factors. Deciding on what path to follow and following this path are both part of the process of wayfinding. When describing movement along a path, important factors to consider are the route that is followed, the mode of movement (e.g., walking or moving by car) and the related velocity of movement, as well as time aspects, such as arrival and departure times (Xia et al., 2008).

The decision-making part of wayfinding centres around the selection of a path from a set of alternatives. In order to do this, visitors need to make use of their cognitive map (Xia et al., 2008). A cognitive map is a representation of the environment in the mind of an individual, which the individual uses to navigate through their environment. Destination characteristics, or more specifically, landmarks, are used by visitors for cognitive mapping purposes. Landmarks are distinct environmental features which can be natural (e.g., a recognisable tree) or artificial (e.g., a recognisable building). People can improve their cognitive map through their own experience of the environment, as well as through the use of route maps. Jackson (1998) explains that by moving through an environment, people remember routes and decisions made while traversing a route, as well as landmarks that were present on the route. Cognitive maps can therefore be regarded as reflective of one's spatial knowledge and one's spatial ability (Xia et al., 2008). Furthermore, this indicates that one's familiarity with an area will influence one's cognitive map and highlights the important role that landmarks play in the process of wayfinding.

Xia et al. (2008) further studied the relationship between wayfinding, familiarity, and landmarks by developing four conceptual models of wayfinding and applying these to a case study. In the first model, the visitor is familiar with their environment; their cognitive map is fully comprehensive. In this situation, which can for example occur when someone frequently visits the same location, the visitor decides on the path to take prior to their trip. Landmarks are used to recognise the paths that they have decided to follow. Further wayfinding decision-making does not take place.

In the second model, visitors have partial environmental familiarity; their cognitive maps are also partial. These visitors have some global knowledge about the area that they are traveling through, but they are not familiar with specific paths. In this case, their path will be divided into segments. The information that these visitors have will be used to identify and make use of landmarks that they come across during wayfinding, to find their way from segment to segment until reaching their destination. Visitors may add to their cognitive map using their past experiences of similar wayfinding processes. Furthermore, visitors may make use of maps or other sources of information about their environment outside of their own experiences to add information to their cognitive map.

In the third and fourth models, the visitor is unfamiliar with the environment. They do not have a cognitive map about the area they are travelling through and are not familiar with the available path alternatives. What differentiates the third and fourth model from each other, is that wayfinding aids are not available in the third model, while they are available in the fourth model. In the first case, visitors will start wandering around and wayfinding will depend mostly on an individual's motivation for their trip, and less on landmarks. However, landmarks will be used to construct a cognitive map, which happens while these visitor travel through an area. Behaviour may be influenced by environmental characteristics, such as the presence of a waterfall, or crowds of people, which can attract or deter people depending on their motivations. In the second case, visitors will move from one landmark to the other, without having planned their route in advance. In this situation, signs or other navigation aids may also be used by visitors to find their way through an unfamiliar area.

Xia et al. (2008) applied their models to a case study of the movement of visitors of the Koala Conservation Centre on Philip Island, Australia. The majority of visitors consisted of first-time visitors, of which most made use of the available wayfinding aids. In their case study, they found signposts and crowds of visitors to be important landmarks. On the other hand, familiar visitors did not rely on signposts to navigate the area. Finally, people that were part of the second model, mostly tried to follow paths that looked different from the paths they were familiar with.

2.1.3. Factors influencing the distribution and flow of visitors in space and time

When it comes to factors influencing the distribution and flow of visitors through natural areas, one can distinguish between factors related to tourist characteristics and factors related to destination characteristics (Lew & McKercher, 2006). The previous paragraph has already given some insights into how these characteristics can influence visitor behaviour, with familiarity being a personal or tourist characteristic, and landmarks being part of the characteristics of a destination. This section will go over the most important factors that have been found to influence on-site visitor behaviour, starting with tourist characteristics, and finishing with destination characteristics.

Tourist characteristics

Different authors have tried to classify visitors based on personal characteristics (Cottrell, Lengkeek, & Van Marwijk, 2005). Elands and Lengkeek (2000) developed a typology of tourist experiences, based on the five modes of tourist experience identified by Cohen (1979). The five modes described by Elands and Lengkeek (2000) are amusement, change, interest, rapture and dedication. These modes will be described in more detail below.

Elands and Lengkeek (2000) describe amusement visitors as visitors focussed on having fun. These are visitors that are looking for a short break from their everyday life, but within an environment that is not too unfamiliar. Change visitors are looking for an escape from their everyday life, they want to relax and recharge their battery. Interest visitors are looking for interesting locations and stories and want to be informed about them, they want to experience attractions and they want their imagination to be stimulated. Rapture visitors want to discover themselves by having new experiences and finding their own boundaries. Finally, dedication visitors are looking for authenticity and want to incorporate previously unknown things in their life.

Cottrell et al. (2005) applied this typology in their study of day-use visitor experiences at the Duivelsberg, a forest preserve in the Netherlands. In this study, dedication visitors came forward as the visitors that were most satisfied with the area, while amusement visitors were least satisfied. Change and rapture visitors were the most common visitor types present in this area. They further discovered that interest visitors spend the most time in the research area, followed by rapture visitors. Rapture and interest visitors were also more likely to follow specific trails. Interest visitors were more likely to be first-time visitors than the other visitor types, while amusement visitors were more likely than other visitors to only visit the area in the weekend. Finally, different visitor types also visited the area with different purposes and by different means of transportation. Most amusement visitors, for example, visited the area by car, and came for the pancake restaurant. Rapture, interest and dedication visitors, on the other hand, more frequently visited the area for hiking.

The relationship between activity type and visitor behaviour was studied in further detail by Beeco and Hallo (2014). Using GPS trackers, they studied the behaviour of mountain bikers, horse riders, runners, and hikers in a forest in South Carolina, USA, and found that activity type was an important predictor for visitor behaviour. They more specifically looked at the time these different visitor groups spent in the forest, the distances they travelled, how far they travelled from their starting point, and how many different areas they visited inside of the research area. Mountain bikers showed the most dispersed spatial behaviour, followed by horse riders, runners, and finally, hikers, while horse riders spent the most time in the area. Activity came forward as the most important factor influencing use distribution. Personal characteristics, such as how skilful the participants of the study further influenced the use of the forest, but mainly for runners and mountain bikers, and less for horse riders and hikers. Greater knowledge of the destination resulted in greater use distribution regardless of activity type.

Destination characteristics

As outlined at the start of this chapter, GPS tracking can provide valuable insights into the behaviour of visitors in natural areas. One study making use of this method, is that of Pouwels et al. (2020), who more specifically looked to identify landscape features that influence visitor densities in the New Forest area in the United Kingdom. Visitor densities were found to be relatively high near car parks, which often act as entrances to natural areas. Furthermore, they found that visitors often stay on the same side of a road as the carpark, meaning they are not likely to cross roads. Visitors were also attracted to open landscapes, with a wide field of view, but at the same time, other visitors might be attracted to woodlands. Heyman, Gunnarsson, Stenseke, Henningsson, and Tim (2011) also found that visitors value open forest, but at the same time preferring a mix of open and closed forests. In their study, closed forests were valued more by frequent visitors, while infrequent visitors had a preference for open forests. Furthermore, trail width and connectivity has also been found to be related to trail use, with wider and more connected trails being used more (Zhai, Korça Baran, & Wu, 2018).

Orellana, Bregt, Ligtenberg, and Wachowicz (2012) also used GPS tracking to study movement behaviour of visitors. They specifically looked at what they called Movement Suspension Patterns (MSPs) and Generalized Sequential Patterns (GSPs). MSPs show locations where people move relatively slowly or stop, indicating that there is something of interest to visitors at these locations. GSPs show the order in which the locations found using the MSPs are visited. Their study shows that 77 percent of the GSPs contained four or less MSPs. Orellana et al. (2012) studied the behaviour of visitors of the Dwingelderveld National Park in the Netherlands. From their analysis, it came forward that car parks, located at the entrances of the area, were visited frequently, as well as the visitor centre located near one of the entrances. Visitors also stopped at attractions, which Orellana et al. (2012) describe as "… places mainly associated with natural and cultural leisure activities, where people go to experience and enjoy the landscape and features in the park" (p. 680). Examples of such attractions include a radio telescope, sheep farm and wetland areas, where people often stopped near benches. Furthermore, amenities were visited frequently, amenities being "… places with information facilities and services for visitors" (p. 681). Information points and signposts are examples of amenities that are visited frequently, although people stopped here relatively shortly. On average, the tea house, another amenity, was the place where people stopped for the longest time. GSPs indicated that people often decide to start at the entrance that is closest to the attraction they want to visit. GSPs further showed that the order in which places are visited is diverse. This would contradict findings of other studies. The study of Van Marwijk (2009), for example, shows that the majority of visitors of the Dwingelderveld follow predefined routes.

Finally, another important factor that has not been discussed yet are interactions between visitors. Interactions between visitors can lead to visitor conflicts, especially when these visitors have different recreation goals (Carothers et al., 2001). Visitor conflicts can have a further impact on visitor behaviour. The next section will go into detail about the causes of visitor conflicts and the effects of visitor conflicts on visitor behaviour.

2.2. Visitor conflicts

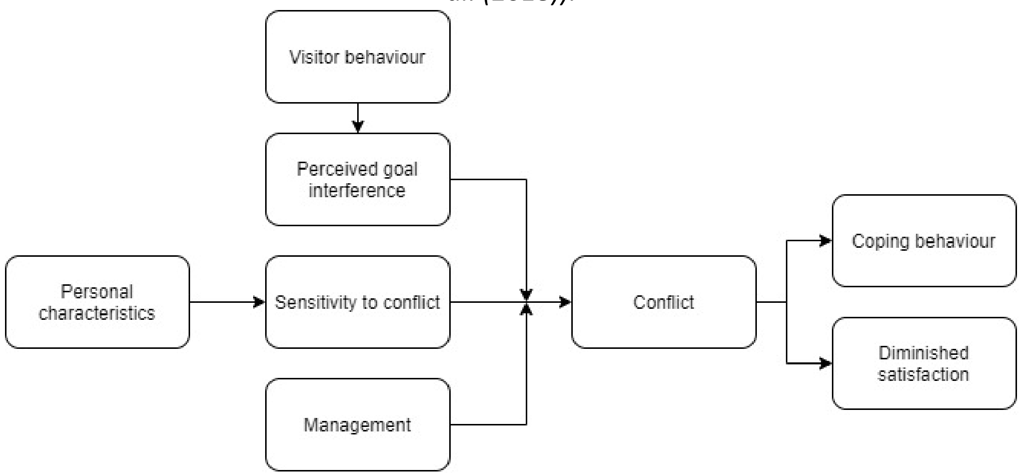
Visitor conflict is described in literature as "… a complex and multidimensional construct" (Wolf, Brown, & Wohlfart, 2018, p. 470). There is an absence of a clear agreed-upon definition of what visitor conflicts are (Kleinlangevelsloo, 2005). The most commonly used definition of visitor conflict is centred around the concept of goal interference, described in the goal interference theory developed by Jacob and Schreyer (1980). Goal interference conflicts are also referred to in literature as interpersonal conflicts. Carothers et al. (2001) state that, "… for interpersonal conflict to occur, the physical presence or behavior of an individual or a group of recreationists must interfere with the goals of another individual or group" (p. 47). According to this definition, conflicts can be regarded as a form of dissatisfaction resulting from the behaviour of another individual or group. These individuals or groups can be engaged in the same activity, resulting in in-group conflicts, or in different activities, resulting in out-group conflicts (Kleinlangevelsloo, 2005). Furthermore, a conflict might be experienced by both individuals or groups involved in a conflict, but more often it happens that conflicts are one-sided (Carothers et al., 2001). One-sided, or asymmetrical conflicts occur when an encounter only interferes with the goals of one of the involved individuals or groups.

The social value conflict theory presents another view about the origins of visitor conflicts. Social value conflicts occur as a result of differences between the norms and values of different visitors (Carothers et al., 2001). These conflicts do not require physical contact between visitors. Social value conflicts have found to be less common than interpersonal conflicts in situations where the values of visitor groups are more similar, such as is the case for hikers and mountain bikers (Carothers et al., 2001). However, in situations where there are larger value differences, such as in the case of hunters and non-hunters, and when visitors are separated by natural barriers, social value conflicts can be more common than interpersonal conflicts (Vaske, Donnelly, Wittmann, & Laidlaw, 1995).

As is the case with the definition of visitor conflicts, there is an absence of an agreed-upon way of measuring visitor conflicts (Kleinlangevelsloo, 2005). Kleinlangevelsloo (2005) discusses a variety of measurements that are being used in visitor conflict studies. Most measures centre around either measuring the predisposition of people towards meeting other people engaged in a range of different activities or asking people about their experiences with other people interfering with their goals. The last way of measuring conflicts fits with the goal interference approach to explaining visitor conflicts. Scholars will often decide on a measure that is specific to the purpose of their research or the context of the visitor conflict that they are studying.

Various scholars have created models of visitor conflicts. Figure 2.1 presents a simplified model of visitor conflicts that is based on the models of Marcouiller, Scott, and Prey (2008) and Wolf et al. (2018). This model identifies a variety of factors that can cause visitor conflicts. The model also indicates the possible reactions to visitor conflicts and the role of visitor management in dealing with visitor conflicts. These aspects of visitor conflicts will be described in more detail in this section.

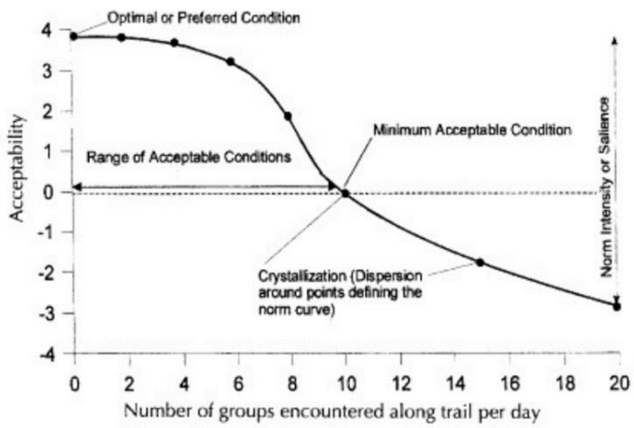
Figure 2.1: *Goal interference model of visitor conflict (based on Marcouiller et al. (2008) and Wolf et al. (2018)).*



2.2.1. Causes of visitor conflicts

Visitor conflicts can have their origins in a variety of phenomena. Crowding is regarded as one of these phenomena. Zwarteveen (2018) explains that crowding has objective and subjective dimensions. Objectively, it can be described as the density of people present in a certain area. Traditionally, this view of crowding and the idea of a social carrying capacity were regarded as important phenomena when it came to explaining visitor conflicts (Kleinlangevelsloo, 2005). A negative correlation has long been assumed between crowding and visitor satisfaction. Studies such as those by Manning, Valliere, Wang, and Jacobi (1999) show that the acceptability of a situation decreases as the number of encounters that a visitor has with other visitor groups increases, as a result of crowding. This results in a hypothetical crowding norm curve, which is shown in Figure 2.2.

Figure 2.2: *Hypothetical social norm curve according to Manning et al. (1999)*



More recently, studies have focussed more on the perception of crowding, or the subjective dimension. This subjective dimension is dependent on personal characteristics, as well as on environmental factors (Zwarteveen, 2018). Overcrowding occurs when crowding reduces the quality of the experience of the visitors of a natural area (Zwarteveen, 2018). Especially visitors that come to nature for quietness and that want to enjoy nature undisturbed can have their experience diminished because of this.

Expectations are important when it comes to the perception of crowding and the experience of visitor conflicts (Zwarteveen, 2018). When people expect that an area will be crowded, they are more tolerant towards it. Expectations depend on factors such as the weather, events taking place and how well-known an area is to the general public as well as to the person that has the expectation. Tolerance itself is another important concept, because people also have a certain tolerance level for crowding. Carothers et al. (2001) explain that when people are more accepting of other activities, they are less likely to experience visitor conflicts.

Whether an encounter with another visitor is experienced as a conflict further depends on a wide range of factors that are specific to the type of encounter. Carothers et al. (2001), for example, studied visitor conflicts between hikers and mountain bikers. In their study, inappropriate actions by other visitors often came forward as the cause of a conflict. Examples of such actions include rudeness, passing someone too closely, or mountain bikers riding too fast. Furthermore, they found that hikers were more likely to experience conflicts as a result of the behaviour of mountain bikers than the other way around and that out-group conflicts were more common than in-group conflicts. Similarly, Wolf et al. (2018) studied visitor conflicts between mountain bikers, horse riders, hikers, dog walkers and motorbike riders They also found that rudeness, speed, near collisions and safety concerns can be reasons for conflicts. However, they also found that conflicts could occur as a result of damage done to a trail or trail pollution as a result of the behaviour of other visitors. Furthermore, congestion, trail obstruction, illegal access (especially by motorbike riders), and dogs (especially if they are unleashed), can cause conflicts.

Mann and Absher (2008) confirm that conflicts may both occur because of what they call social conflicts, which result from either direct contact or value differences, and infrastructural or managerial conflicts. Infrastructural or managerial conflicts are described by Mann and Absher (2008) as being caused by "… disturbances of aesthetic perception of the landscape that do not fit into the recreationists' idea about nature or naturalness" (p. 375). Trail pollution would be an example of something that could potentially cause such a conflict. Garbage, vandalism, uniform vegetation and a shortage of signs and viewpoints are other examples of potential causes of such a conflict.

2.2.2. Effects of visitor conflicts

Marcouiller et al. (2008) identify two main impacts of visitor conflicts on visitors, namely a lowered visitor satisfaction and coping behaviours aimed at minimising negative experiences resulting from conflicts. People are prepared to avoid crowded areas and recreate in areas that are less crowded (Zwarteveen, 2018). Visitor expectations again play an important role here. People that are looking for quiet areas and expect certain areas to be crowded are willing to travel to other areas or visit areas at times when they expect it will be less crowded (Zwarteveen, 2018). Li, Zhang, Nian, and Zhang (2017) found that, while the quality of the visitor experience reduces when crowding increases, this does not necessarily result in lower satisfaction. They point to coping behaviours as a possible explanation for this. Visitors might change their behaviour by going to less crowded locations. These visitors might then be replaced by visitors that have a higher tolerance of crowding. People moving to other areas, or deciding to visit the same area at other times of the day, week, or even year, is an example of displacement, one of the four coping mechanisms that Marcouiller et al. (2008) identify. Other coping mechanisms are redefining expectations to the point where they more closely resemble a visitor's situation, rationalising as a way of rectifying the difference between the actual situation and expectations, and engaging in different activities that might be more fitting to the situation.

2.2.3. Dealing with visitor conflicts

Carothers et al. (2001) identify two management strategies that might be effective in dealing with visitor conflicts, namely zoning and education. As part of zoning measures, separate tracks can be created for different activities such as hiking or mountain biking. Zoning rules and specialised tracks can be effective measures, but they are not likely going to stop all conflicts from occurring, as people will not always following zoning rules or tracks (Zwarteveen, 2018). Furthermore, restricting the access to tracks can lead to resistance from the groups that would no longer be allowed to use the track (Carothers et al., 2001). Also, zoning is not likely to solve social value conflicts, as these do not require visitors to encounter each other, but can be used to reduce the occurrence of interpersonal conflicts.

Education can focus on spreading information about the needs of different visitors and using signs to inform user groups of each other's presence (Wolf et al., 2018). As an additional measure, Wolf et al. (2018) indicate that policing could further reduce the occurrence of visitor conflicts. Policing can for example focus on enforcing access restrictions to tracks for certain types of activities, making sure that dogs are on a leash, and making sure that people reduce their speed for safety reasons.

2.3. Modelling visitor behaviour

In section 2.1, simulation models were introduced as a useful tool for studying visitor behaviour, especially in natural areas where there are problems with crowding and measuring visitor behaviour using other techniques is difficult (Cole & Daniel, 2003). This section will give an overview of the development of the use of simulation modelling in visitor behaviour research. This section will start by looking at the development of early simulation models of visitor behaviour. Next, a description will be given of the use of agent-based modelling techniques, a more recently developed modelling technique. Finally, an overview of RBSim (Gimblett et al., 2001) and MASOOR (Jochem et al., 2008), two of the most influential models in the field of visitor behaviour studies, will be given.

2.3.1. Development of models

The development of simulation models in nature management started in the 1970s (Cole & Daniel, 2003; Lawson, 2006). In early models, data on visitor behaviour was often based on trip diaries. Input requirements included data on travel networks, entry points, trails, user groups, encounters between visitors and visitor frequencies related to the time of day or day of the week. The use of these models saw a decline in the 1980s, after which they received more interest in the 1990s. For newer models appearing around this time, surveys were used to derive information about the frequency of use of travel routes, based on visitor characteristics such as activity types and group size. The 2000s saw the development of a new approach to simulation modelling that is used to study visitor behaviour in natural areas, the individual-based approach. In this approach, autonomous agents are modelled. These agents traverse a route through a natural area, making decisions along the way. These decisions are generally based on behavioural rules that are derived from surveys. These models allow for the incorporation of more complex decision-making in simulation models. It is these dynamic approaches to simulation modelling that best represent visitor behaviour (Lawson, 2006). RBSim and MASOOR are examples of agent-based approaches to system modelling (Gimblett et al., 2001; Jochem et al., 2008). In literature, models following such an approach are described as agent-based models, or with the related term of multi-agent system (Jochem et al., 2008).

2.3.2. Agent-based modelling

Central to RBSim and MASOOR, as well as other agent-based approaches to simulation modelling are agents. Agents are computer representations of, in the cases of RBSim and MASOOR, human visitors of natural areas (Gimblett et al., 2001; Jochem et al., 2008). Agent-based models allow for the simulation and measuring of the behaviour of agents, as they try to fulfil their goals in a complex system (Clarke, 2014). Furthermore, in the context of recreational behaviour, agent-based modelling has been found to be an effective approach to modelling encounters between agents as they occur in space and time (Gimblett et al., 2001).

Other important components of agent-based models include knowledge about agent decision-making, adaptive rules about agent behaviour and an environment that agents can interact with (Clarke, 2014). Designing a model therefore includes following multiple steps, starting with gathering information about agent behaviour in the real-world system. Following steps are quantifying this behaviour and coding the behaviour in a modelling environment that can also be used to examine outcomes of the modelling process using maps or other metrics.

2.3.3. RBSim and MASOOR

RBSim, short for Recreation Behaviour Simulator, presents one of the earliest examples of the use of agent-based simulation models to simulate visitor behaviour in natural areas (Gimblett et al., 2001). Gimblett et al. (2001) used RBSim to simulate the behaviour of visitors of the Broken Arrow Canyon in Arizona. In this model, GIS data containing information on the trails of the canyon were integrated with agents, representations of recreationists that behave according to behavioural rules. Agent behavioural rules and parameters were derived from surveys. The model distinguishes between visitors in jeeps, mountain bikers, and hikers. Furthermore, the model is based on information about, among other things, the arrival time of different visitors and visitor age distributions. Together, the behavioural rules allow for the representation of visitor behaviour in the environment based on the GIS data. As described by Gimblett et al. (2001), among other things, behavioural rules can determine how agents "… will react when encountering other agents; at what speed they should travel through a landscape, how often, and for how long they must rest; their recreational goals; the route they will follow through the landscape; and so on" (p. 38). Behaviour is further influenced by the goals of the visitors. Based on the gathered data, typical days were simulated, where visitors randomly enter the area within a given time period and travel through the area for a certain time period, depending on the type of visitor. Encounters between recreationists are displayed in a map, and the model allows one to implement management actions to see what the effect is on the occurrence of these encounters. For example, alternative mountain bike trails were implemented in the model, resulting in a significantly decreased number of encounters between mountain bikers and other visitor types. Finally, Gimblett et al. (2001) indicate that agent-based simulation models can be "… an effective technique for modeling the spatial and temporal aspects of recreation encounters" (p. 42).

RBSim is an example of a model that has been applied to the context of relatively low path density areas in the USA and Australia. MASOOR, on the other hand, has been developed especially for relatively high path density contexts, where visitors have more options when it comes to reaching their goals or destination, such as is in most Dutch natural areas (Jochem et al., 2008). MASOOR is an abbreviation of Multi Agent Simulation of Outdoor Recreation. The model was developed in cooperation with managers of Dutch natural areas, and has also been applied by managers in multiple European countries to estimate the impact of possible management decisions. Jochem et al. (2008) applied MASOOR to the Dwingelderveld National Park, the Netherlands. Their study found that the behaviour simulated by MASOOR showed a clear correlation with behaviour tracked using GPS trackers in the same area. However, it was also discovered that certain marked trails were more popular than expected, while other paths were not used nearly as frequently as expected.

2.4. The Consumat framework

The focus of this section will be on giving a description of the Consumat approach, an approach to social simulation modelling that was identified in the Introduction as an approach that can be used in agent-based modelling. This section will start with a short introduction of how the Consumat approach came to be, detailing the different theories that it was based on, followed by a general description of the framework. This will be followed by a more detailed description of the key concepts of the framework that together constitute the Consumat approach. Next, an overview will be given of applications of the model in literature. Finally, this section will reflect on the advantages and disadvantages of using this approach as a basis for agent-based modelling.

2.4.1. Origin of the Consumat framework

The Consumat approach has its origin in research to consumer behaviour. Jager, Janssen, and Vlek (1999) were interested in studying consumer behaviour, especially in relation to the commons dilemma, or the tragedy of the commons. Most notably described by Hardin (1968), the commons dilemma describes a situation where the behaviour favourable to an individual is unfavourable to the group that this individual is part of, and the other way around. This behaviour can result in the overexploitation of a collective resource. Because of this, the commons dilemma has received attention in studies to environmental issues and sustainability.

Jager et al. (1999) note that choice behaviour in commons dilemmas has often been studied in experimental settings. They point to the limitations of these experiments, with the most important limitation being that they lack the relatively long time frame, of perhaps a couple of decades, that is often relevant to environmental issues. Choices made by participants of these experiments do not have consequences for the participants after the experiment has ended. Therefore, they argue for the use of computer simulations to study choice behaviour in collective research dilemma situations.

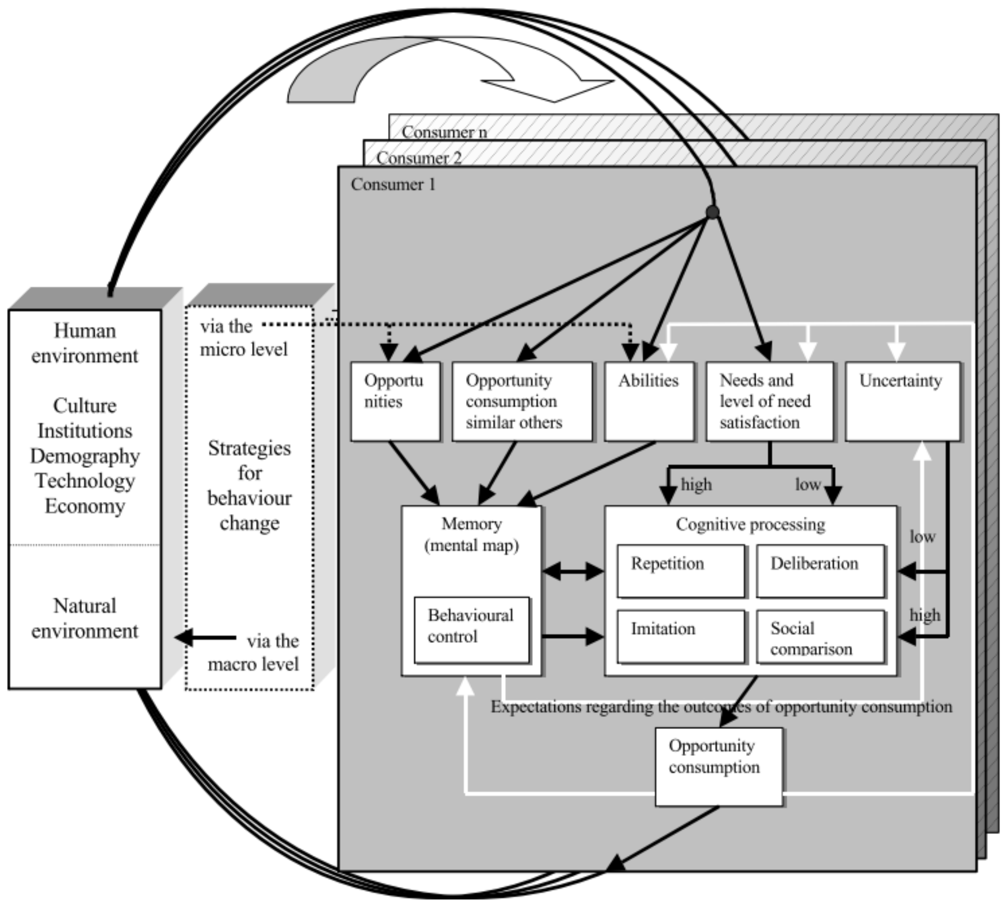
Jager et al. (1999) point out that, up to that point, most computer simulations of consumers in commons dilemmas follow the rational actor principle. This principle assumes that individuals deliberate all choices and picks the options that best satisfy their needs. Jager et al. (1999) also point out, however, that individuals often behave differently from what would be expected based on the rational actor principle. Individuals might, for example, follow other people in their behaviour, or perform habitual behaviour.

A wide range of behavioural theories describing aspects of the decision-making process of consumers exists. There is a certain overlap between many of these theories, as they describe similar processes, and incorporating all these theories into a computer simulation model would make the model very complex. As a response to this, Jager, van Asselt, Costerman Boodt, Rotmans, and Vlek (1997) developed a meta-theory of human behaviour, organising and integrating aspects of a wide variety of theories used in social psychology. A description of the theories they integrated in their meta-theory is given by Jager et al. (1997), Jager et al. (1999) and Jager (2000). This meta-theory of human behaviour formed the basis for the Consumat simulation framework, a conceptual framework of consumer behaviour, that was first described by Jager et al. (1999). In this article, the term 'Consumat' was coined to describe the simulated consumers, i.e. agents, that are part of the computer simulation that Jager et al. (1999) experimented with. The framework was revised by the authors in 2012 (Jager & Janssen, 2012). The next part of this section will give a more detailed description of the framework, based primarily on the revised version, and supplemented with information from previous publications, whenever these provide more detailed information about certain aspects of the framework.

2.4.2. Key concepts of the Consumat framework

Consumat provides a framework that can be used to design rules concerning the behaviour of agents (Jager & Janssen, 2012). The Consumat framework consists of key concepts. These concepts can be viewed schematically in Figure 2.3, which shows the Consumat framework as it was designed by Jager (2000). This paragraph will go through the key concepts that are shown in the figure.

Figure 2.3: *Consumat framework of human behaviour (Jager, 2000)*



Needs

The starting point of the Consumat approach is that humans have needs that they will try to satisfy by performing behaviour. Jager and Janssen (2012) identify three fundamental needs, namely needs of existence, social needs, and personal needs. Needs of existence relate to having means of existence. Depending on the system that is being modelled, this could refer to economical means, or the possession of certain goods. In the case of economical means or goods, agents can have a stock.

Social needs relate to individuals wanting to be part of a collective and be similar to others. People are more likely to be influenced in their decisions by individuals that they have more in common with than individuals that they have less in common with. In this, the expectation is reflected that similar individuals are more likely to make decisions that will satisfy similar needs. Satisfaction will increase when the group that performs similar behaviour is larger and the similarity between the individual and the group is greater. Experience also plays a role here, as people are more likely to follow others that have more experience. People can also strive for a feeling of superiority, so their satisfaction might increase from having higher levels of a desired means of existence. Together, the feelings of similarity and superiority allow for the modelling of a wide range of agents, that can be more or less competitive and conforming. Similarity can be determined by looking at factors such as personal characteristics, behavioural decisions and the way people value different needs. As some of these characteristics can change through time, the social network of an agent has both fixed and dynamic elements.

Finally, personal needs are reflective of the personal preference or taste of an individual. Especially when there is a system where multiple needs can be satisfied, personal taste will determine which needs are more valued by an individual than others.

Satisfaction

In the Consumat framework, satisfaction is described as "… the degree to which the three needs of the agents are satisfied by engaging in certain action" (Jager & Janssen, 2012, p. 8). Not only the current utility that agents derive plays a role in this, also any expectations about future utility that can be derived from certain behaviour are incorporated in the level of satisfaction that an agent experiences. The time frame of expected utilities, and the way that this might be discounted over time, depends on the behaviour that is being modelled. Another important concept here, is the ambition level of an agent. Agents will try to improve their satisfaction level through decisions when their it drops below their ambition level. This is when they start to consider alternative opportunities.

Uncertainty

Uncertainty is a concept that is connected to existence and social needs. When it comes to the needs of existence, uncertainty reflects the variance in the information that agents have about the utility of the different behavioural options that they have (Jager & Janssen, 2012). A relevant concept there is that of uncertainty tolerance. When the uncertainty level of an agent is below their uncertainty tolerance, they will start to consider the behaviour of other agents in their decision-making process (Jager et al., 1999). The time perspective of the agent is once again important here. An agent that considers a longer time frame, might feel more certain or uncertain about expected utilities than an agent with a shorter time perspective. Regarding the social uncertainty, the proportion of similar agents making the same decisions is important (Jager & Janssen, 2012).

Behavioural options

Behavioural options refer to the different options to satisfy needs that agents have (Jager & Janssen, 2012). The expected satisfaction that an agent will derive from an option will partly depend on the personal needs, or the taste, of an agent, as well as on the time frame that the agent considers. Concerning the means of existence, certain behavioural options might, for example, generate money, while other options might cost money. Jager et al. (1999) point out that, in the case of a common good, it is possible that certain options might become less available, because goods can become scarce. The exact behavioural options that need to be considered in a model will depend on the system that is being modelled.

Abilities

The abilities that an agent has refer to the extent to which they can pursue different options, influencing the behavioural control that agents have. Important concepts that determine the abilities of an agent have already been discussed. These are the personal traits of an agent, such as their time preference, the ambition level of the agent, and the uncertainty tolerance of the agent. Abilities are also important determinants for agent similarity.

Decision-making
In the decision-making process, the two main driving forces are satisfaction and uncertainty, with decisions being further influenced by behavioural options and agent abilities. Jager and Janssen (2012) indicate that there are two key rules when it comes to the interplay between satisfaction and uncertainty: "… (1) the lower satisfaction is, the more involved one is to process information on behavioural opportunities, and (2) the larger uncertainty is, the more the behaviour of other people is used to identify attractive behavioural opportunities" (p. 12). These two rules can result in four different decision strategies, which will be described below.

When agents are satisfied and certain, they are more likely to repeat their behaviour. This behavioural strategy reflects habitual behaviour. The corresponding strategy, which can also be seen in Figure 2.3., is called repetition.

When satisfaction drops below the ambition level of the agent, they will start optimising their behaviour, more closely following the rational actor principles. In Figure 2.3., this strategy is called deliberation, but in the revised framework, it is called optimising. Following this strategy will mean that an agent will consider all possible behavioural options, even those not yet followed by any other agents.

When satisfaction stays above the ambition level, but uncertainty increases until it has passed the uncertainty tolerance, agents will start to look at the behaviour of similar agents and follow them in their decisions. The corresponding strategy is called imitation. Agents can either follow the behaviour of a majority of similar agents or follow the behaviour of a more limited group of similar agents, if the behaviour of this group has proven to be successful.

Finally, when satisfaction drops beneath the ambition level and uncertainty passes the uncertainty tolerance, agents start comparing themselves to all other agents, even those that are less similar to them. This process is referred to as social comparison in Figure 2.3. and inquiring in the revised framework.

Cognition
The final key concept of the Consumat framework is cognition. According to the framework, agents have the cognitive ability to remember information about the available behavioural options, as well as about the characteristics of other agents, their decisions and the outcomes of these decisions. When it comes to behavioural opportunities, agents can gain information from their past experiences, the experiences of other agents and from information available through other means, such as advertisements.

2.4.3. Applications of the Consumat framework in agent-based modelling
With the creation of the Consumat framework, Jager et al. (1999) created a framework intended to aid the development of human behaviour simulation models. Jager and Janssen (2012) explain that, because of the generic nature of the Consumat framework, it can be used in many different fields of research, as it allows for different levels of detail for different concepts depending on the context. Since its creation, the framework has been used as the basis for many studies of human behaviour, some of which will now be described.

The Consumat framework was originally designed to study consumer behaviour, which is what Jager et al. (1999) focused on in the first publication about the framework. Important early findings include that the optimising strategy resulted in the most satisfaction, that the time perspective of an agent has an important role in determining the extent to which resources are being depleted, and that the ambition level is important in determining the behaviour of an agent. Other early studies that focused on consumption are the studies by Jager, Janssen, De Vries, De Greef, and Vlek (2000), who studied pollution and fishing and by Janssen and Vlek (2001), who studied household energy consumption. The framework was also applied to market dynamics research and studies about the diffusion of practices, such as the adoption of flood management policies (Brouwers & Verhagen, 2003; Hoffmann & Jager, 2005). More recently, the framework has also been applied to studies about the diffusion of practices, such as the use of electric vehicles (Kangur, 2014; Kangur, Jager, Verbrugge, &

Bockarjova, 2017) and natural gas vehicles (Sopha, Klöckner, & Febrianti, 2017), the use of sustainable technologies by households (Moglia, Podkalicka, & McGregor, 2018), crop blight management (Pacilly et al., 2019), and soil conservation efforts (Van Oel, Mulatu, Odongo, Willy, & Van der Veen, 2019).

What most of these studies have in common is that they are based on the Consumat framework and make use of most of the key concepts as they are described in the framework, while adjusting the framework to the topic of the study. For example, a simulation model named STECCAR has been developed, that deals with the car market and the adoption of electric vehicles (Kangur, 2014; Kangur et al., 2017). For this model, four specific needs were identified, rather than the three needs described above. Oskar et al. (2002) added a price mechanism to better simulate market dynamics. In other studies, certain concepts were not used, as they were deemed to be irrelevant to the context. Both Schwoon (2006) and Sopha et al. (2017), for example, only considered imitation and optimalisation as possible decision strategies, as the other two strategies did not seem relevant to the adoption process of fuel cell vehicles and natural gas vehicles. Finally, it is interesting to note that most of the applications do not explicitly use geographical models. The model developed by Pacilly et al. (2019) is an exception to this. They applied the framework to a study about the use of disease resistant crops by farmers in disease control. For this purpose, they developed a spatial model, consisting of a cellular structure in order to construct a network of neighbours for the farmers.

2.4.4. Strengths and weaknesses of the Consumat approach

Of interest to this thesis, is that the Consumat approach has not yet been applied to the topic of visitor behaviour in natural areas. In fact, it has not been applied in studies of the spatiotemporal behavioural patterns of humans in general. However, as the previous section showed, and as was the expectation of Jager et al. (1999) when they created the framework, one of the strengths of the Consumat approach is that it can be used to study many behavioural processes. Pacilly et al. (2019) indicate that the framework can easily be implemented in new contexts, because the framework is already highly formalised, requiring relatively slight adaptations when implemented in new situations.

As mentioned above, the framework is founded upon a great variety of theories of human behaviour, which is another strength of the framework (Jager et al., 1999). Moglia, Cook, and McGregor (2017) indicate that the framework seems to allow for the appropriate incorporation of all elements of decision-making. The Consumat framework is regarded in literature as an established psychologically plausible model that can be used to explore sustainable behaviour (Schaat, Jager, & Dickert, 2017). Schaat et al. (2017) indicate that psychological realism is important when it comes to behavioural modelling, as it can help overcome the problem of oversimplification that social simulation models can be vulnerable to. The consideration of the four different decision strategies as explanatory variables for social dynamics, and the integration of psychological aspects, such as the different needs, and social aspects, such as the role of social networks, is especially important in that regard. Finally, Schaat et al. (2017) point to the increased validity of models based on the Consumat framework, because of the basis of the framework in empirical findings.

When comparing outcomes of agent simulations grounded in the Consumat approach with simulations not grounded in Consumat, Brouwers and Verhagen (2003) found that more realistic outcomes where produced by the simulation based on Consumat. Another study, however, did not see an improvement from using the Consumat approach (Malawska & Topping, 2016). Malawska and Topping (2016) attribute this to the simplicity of the model they developed, especially when it comes to economic and practical constraints to decision-making. This indicates that, depending on the context, the problem of oversimplification might still occur. However, Jager et al. (1999) argue that, while a model developed according to the framework might result in simple rules that might leave something to be desired when it comes to representing actual human behaviour, these rules do capture real behavioural processes. This allows one to study and experiment with these processes and identify relationships that might be difficult to identify without the inclusion of, for example the four different decision strategies. Furthermore, small adaptations to rules can be easily be made to study the impact of different variables on model outcomes (Jager & Janssen, 2003).

Perhaps the main weakness of the Consumat approach is that model outcomes are often hard to validate because of a lack of empirical data about behavioural drivers in human decision-making (Jager & Janssen, 2003). Similarly, parameterisation can be difficult because of the same reason (Jager & Janssen, 2012). It is, for example, not possible to empirically measure values such as the ambition level and uncertainty tolerance of an agent (Malawska & Topping, 2016). To overcome this, Jager and Janssen (2002) argue for the combination of simulation research with empirical research.

2.5. Conclusion

This chapter started with a discussion of visitor behaviour research. First, it has outlined the various methods that are used to study the spatiotemporal behaviour of visitors of natural areas. The wayfinding process has been described as an important process, in which visitors decide how they are going to move through an area. Tourist characteristics and destination characteristics have been described that further influence the behaviour of visitors in natural areas. In the next section, the causes and effects of visitor conflicts have been discussed. Thereafter, it has been described how visitor simulation models can be used to gather more insights into how visitors behave in natural areas. Finally, the Consumat framework has been introduced as a framework of human decision-making, which can be used as an approach to simulation modelling. As described, the Consumat framework was originally developed as a framework of consumer behaviour, and it has not been applied to the context of visitor behaviour. However, it is a common view that the spatiotemporal behaviour of tourists is a type of consumer behaviour. McKercher, Wong, and Lau (2006) describe how visitors consume, or experience, destinations by moving through them and by engaging in activities. In fact, the tragedy of the commons, which was the reason Jager et al. (1999) originally developed the Consumat framework, also plays an important role in the literature discussing sustainable tourism (Briassoulis, 2002). The context of visitor behaviour in natural areas thereby presents an interesting consumer behaviour context to which the Consumat framework has not been applied to yet. In the next chapter, a conceptual model that integrates what has been described about visitor behaviour, visitor conflicts and decision-making processes, is presented.

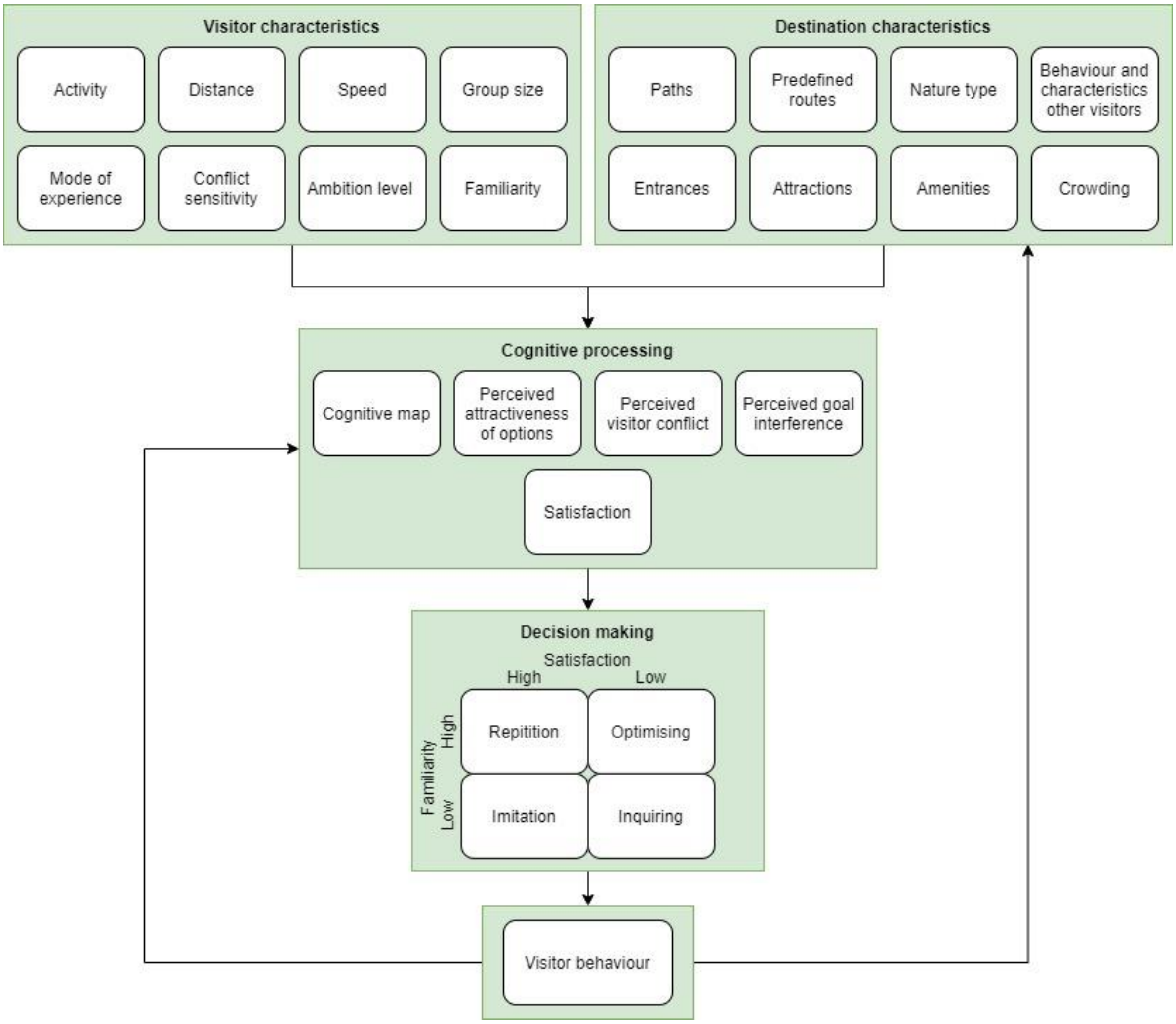
3. Methodology

This chapter will start with the presentation of a conceptual model of visitor behaviour and visitor conflicts based on the Consumat framework and the rest of the theoretical framework, as described in the previous chapter. Next, it is described how this conceptual model has been translated to an agent-based model. Finally, a description is given of how the model has been analysed and validated in the final two paragraphs of this chapter.

3.1. A conceptual model of visitor

Based on the theory discussed in the previous chapter, a conceptual model of visitor behaviour and visitor conflicts was developed, based on the Consumat framework. This conceptual model is presented in Figure 3.1. This model shows how visitor characteristics and destination characteristics together influence the cognitive processing of an agent, which influences their decision-making, resulting in visitor behaviour.

Figure 3.1: *Conceptual model of visitor behaviour and visitor conflict in natural areas*



In the context of this study, needs are represented in this conceptual modal as goals with which visitors enter an area, reflected in their mode of experience. They can achieve these goals by travelling through a natural area, following different paths, stopping at landmarks and engaging in different activities. Their satisfaction is related to the extent to which they achieve their needs, and can be lowered by crowding, encounters with visitors that have different characteristics, such as their mode of experience, activity type, speed, or group size, and visitor conflicts that can result from such encounters. The perception of the visitor plays a role in whether they regard such an encounter as a visitor conflict or not. Behavioural options are represented by the availability of various path alternatives, each with an attractiveness to different visitors, influenced by characteristics of the paths, such as whether they are part of a predefined route or not. The spatial behaviour of a visitor further influences future cognitive processes, as it results in an updated cognitive map, and influences destination characteristics, as it can cause crowding.

It is important to point out that the role that uncertainty plays in the original Consumat framework has been replaced by the concept of familiarity, as described by (Xia et al., 2008). In the context of visitor behaviour, visitors base their decisions on their own knowledge or familiarity with an area, or on information about the area from signs or maps. They might follow other visitors, but it is not described in wayfinding literature that they are aware of the routes that other visitors have taken or are going to take. Therefore, the incorporation of an uncertainty concept defined as the variance in information has about the utility of options or the proportion of similar agents making similar decisions does not seem to fit the context. Instead, information about the utility of behavioural options is best reflected by the concept of familiarity, as described in the wayfinding literature, discussed in Paragraph 2.1.2. Therefore, uncertainty has been replaced with familiarity in the conceptual model. Agents familiar with an area will know about the utility of different routes, based on past experiences, while agents unfamiliar with an area will estimate utility based on whether a route is signed or passes certain landmarks. It is also good to take a look at what the behavioural strategies would look like in the context of visitor behaviour, now that these strategies are based on satisfaction and familiarity, rather than satisfaction and uncertainty:

- **Repetition**
  Agents that are familiar with an area and are satisfied with their regular routes will decide at the start of their route which of their regular routes they will follow.
- **Optimising**
  Agents following the repetition strategy will continue following their route until an event occurs that causes them to become dissatisfied. This can be because of crowding or a visitor conflict. As a result of this, they will start optimising their route, making use of their familiarity with the area to find alternative routes that will bring them more satisfaction.
- **Imitation**
  Agents that are unfamiliar with an area will decide on what route to follow on location. They will follow routes indicated on maps or signs, or they will follow the behaviour of other visitor groups that show similar personal characteristics, grouped together under visitor characteristics in Figure 3.1.
- **Inquiring**
  When agents following the imitation strategy become dissatisfied, they will start following the behaviour of other groups, meaning groups that are not similar to them.

As indicated above, an agent can change its satisfaction based on their experiences and has an ambition level indicating whether their experiences will lead them to choose a different strategy or not. Encounters are However, they are not able to change their familiarity level during their visit. They can expand their cognitive map based on their experiences, but they will not be able to reach the point where their cognitive map is complete. This means that unfamiliar visitors will not engage in repetition or optimising. Similarly, familiar agents will not engage in imitation or inquiring.

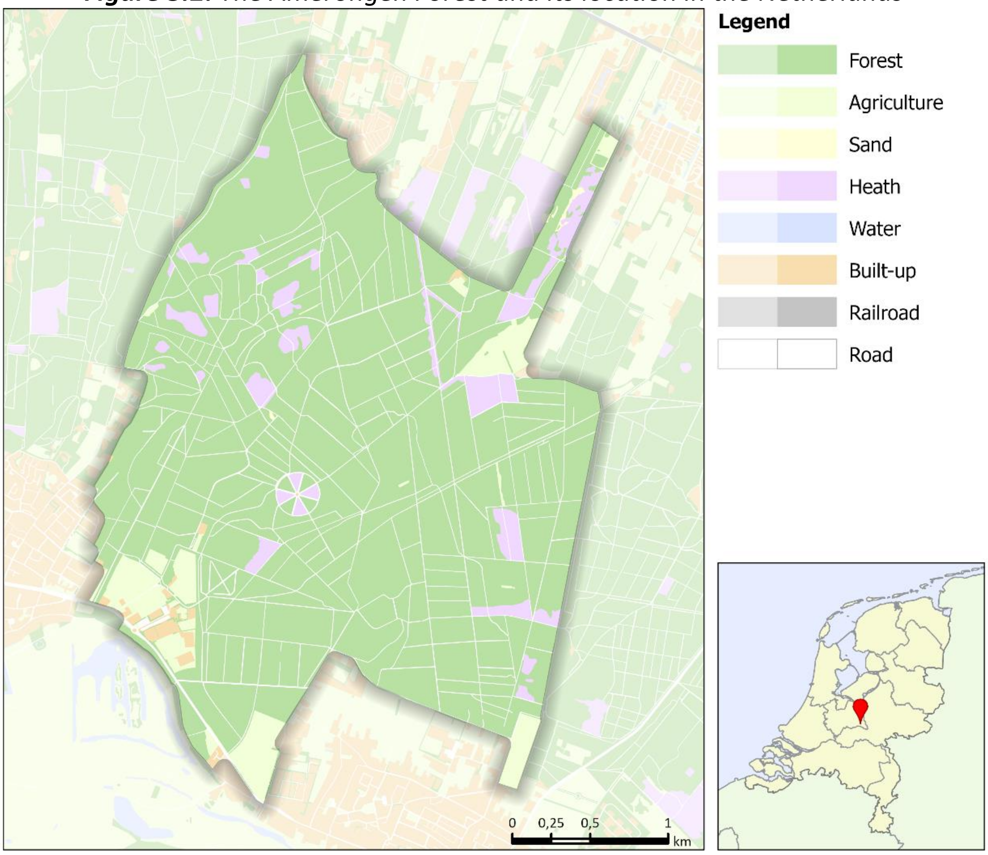
3.2. Translating the conceptual model into an ABM

The conceptual model described in this paragraph has been translated into an agent-based model. The developed ABM, along with the used input data are available via the author. Translating a conceptual model into a functional agent-based model involves a variety of steps, which are described in this section. This description starts with a description of the research area that has been modelled and the software that has been used to design the ABM. This is followed by an overview of the core components of the model, with the paragraphs thereafter focussing on the two main entities of the model: the environment and visitor groups, the core agent of the model. The arrival of the visitors and their behaviour during their stay in the research area is described. The last two sections of this chapter will go over the analysis and validation of this study. For the purpose of validation, expert interviews have been conducted. This is described in detail in Section 3.4, but the outcomes of these interviews will be referred to throughout this chapter, as they are also of relevance when discussing topics such as the calibration of different parameters.

3.2.1. The research area

The Amerongen Forest has been chosen as the research area for this study. The Amerongen Forest is located near the southern tip of the Utrechtse Heuvelrug, primarily situated in the eastern part of the Province of Utrecht, the Netherlands. The research area, along with its location in the Netherlands, is presented in Figure 3.2. The outline of the research area is based on the borders of the terrain owned by Staatsbosbeheer and Utrechts Landschap, the two nature management organisations present in the study area, and the location of path infrastructure relevant to the activity types represented in the model. Terrain borders are presented in Section 3.4, while path infrastructure is discussed in Paragraph 3.3.4. The resulting study area has an area of approximately 950 ha. The area is located in between the towns of Amerongen in the southwest, Elst in the southeast, and Veenendaal in the northeast. The main entrance to the research area is located in the southwest, near Amerongen. Here, a Toeristisch Overstap Punt (TOP) is present, which is a location where parking places are present, and which can serve as the starting point of routes belonging to different activity types. In this research area, dedicated infrastructure is present for hikers, mountain bikers, cyclists, and horse riders, with multiple routes starting at this location. The research area, as well as the nature areas it borders in the east and west and the majority of the rest of the Utrechtse Heuvelrug, is part of Nationaal Park de Utrechtse Heuvelrug.

Figure 3.2: *The Amerongen Forest and its location in the Netherlands*



Source: Eurostat (2020) and Kadaster (2019, 2021).

NTBC-NIPO Research, at the request of the Province of Utrecht, has carried out visitor studies of visitors of the Amerongen Forest, as well as other areas in the Province of Utrecht. Their studies show that between 2012 and 2019, the number of unique visitors from the Netherlands that visited the Amerongen Forest has increased from an estimated 319,000 to 403,000, an increase of around 26 percent over a period of 7 years (NBTC-NIPO Research, 2019; Van der Most & De Vries, 2012). Whereas in 2012, 88 percent of the visitors of this area were from the Province of Utrecht and 59 percent from the local municipality, the Utrechtse Heuvelrug, in 2019 this was 65 percent and 22 percent, respectively. Together with the increase of popularity of the area among visitors from farther away, the area has become increasingly popular among mountain bikers in recent years. In 2015, less than 5 percent of all visitors had visited the area to mountain bike, a number that has increased to 12 percent in 2019 (NBTC-NIPO Research, 2019; Van der Most & De Vries, 2015).

The combination of the increase in visitor numbers that has taken place, along with the presence of a variety of different activity types in the area, and the availability of statistics through the NBTC-NIPO studies make the Amerongen Forest an interesting case study area for this research. Furthermore, it was confirmed by the interviewees that this is an area that can be become busy and is becoming increasingly busier, and where conflicts between visitors are known to occur.

3.2.2. Modelling software

An important step in the development of an agent-based model is to decide what modelling software to use. In this study, the modelling software GAMA has been used. GAMA is a freely available, open-source modelling platform. It is available at gama-platform.org. It has been developed to facilitate the building of spatially explicit ABMs. The version of GAMA used for the development of the ABM presented in this thesis is GAMA 1.8.1.

The programming language used by GAMA is GAML, which has its foundation in object-oriented languages such as Java. GAML can be described as an agent-oriented language, as all entities within the modelling environment are agents, allowing all entities to have behaviour and interact with other agents (Taillandier et al., 2019). In GAML, agents are described in their corresponding species. In their species, it is defined what attributes agents have and what their behaviour is. Compared to higher level object-oriented languages, such as Java, GAML is considered to be more intuitive and easier to use, especially for modellers without much programming experience (Taillandier et al., 2019).

GAMA facilitates building spatially explicit models by allowing GIS-data to be used as input for the spatial dimensions of species. Real-world road network data stored in GIS-datasets can, for example, be represented by a road network species that has the spatial dimensions of the features of the network dataset. The topology of the agents belonging to this species can then be used to construct graphs which other agents can use to navigate an area. A variety of data formats are supported, including CSV and shapefile, formats primarily used in this study. Data generated by the model can also be exported in these formats. This allows output data to be analysed and visualised in other software programs. Microsoft Excel and ArcGIS Pro 2.8.1 were used for this purpose in this study.

3.2.3. The core components of the model

The species to which the agents represented in the model belong can be divided into species that together represent the spatial environment and a species that represents the visitor agents, whose behaviour is the focus of both the model and this thesis. Figure 3.3 gives an overview of all species present in the model, including their relationships with other aspects of the methodology of this study. The spatial or physical environment is represented by the entrance, road network, and waypoint species. The visitor species is the in-model representation of visitor groups visiting the study area in the real-world. The social environment of visitors is represented by the other visitors and the locations of encounters between visitors. Below, a quick introduction will follow of the species that are represented in the model and their most important functions and relationships.

Figure 3.3: *Overview of the entities in the ABM and their relationship with input data, output data and the analysis of the model results*

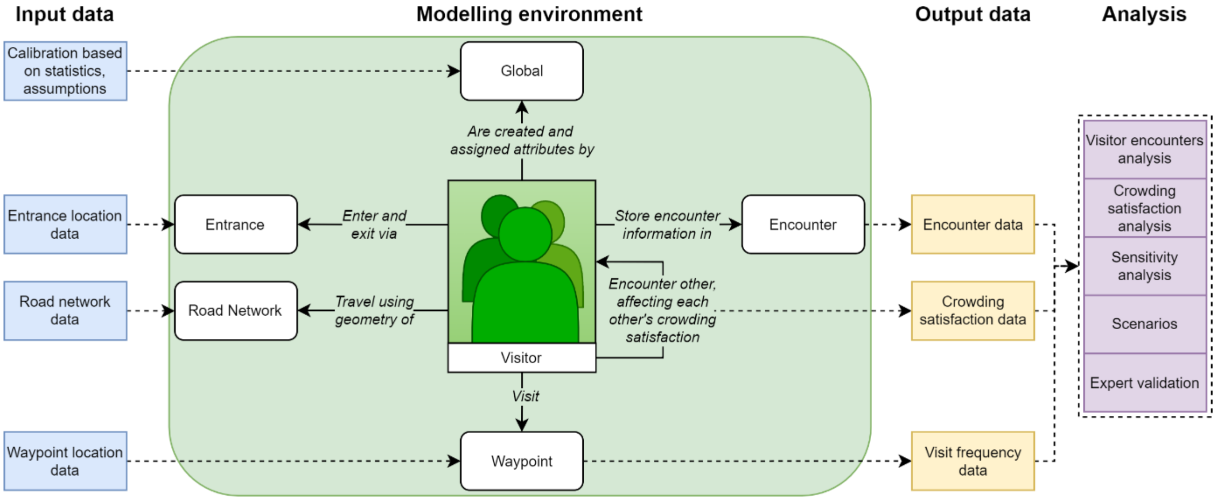


Figure 3.3 shows the general behaviour of the central agent of this model, the visitor species. The visitor species represents visitor groups visiting the study area to hike, cycle, mountain bike or ride horses. These are the four activity types that have been modelled. For hikers, a distinction is made between hikers that follow marked trails and hikers that choose their own path. Each of the visitor groups is assigned individual attributes, such as their activity type, travelling speed and their entrance and exit locations. Visitor attributes are based on available visitor statistics and assumptions, as further described in the paragraph 3.2.6. The creation of visitors and the assigning of their attributes is taken care of by the global species, which will be described in more detail in the next paragraph. Between entering and exiting the study area, visitors travel through the area using the road network. During this process, they visit waypoints, which are locations within the study area that are used by visitors to navigate through the area. Hikers might decide to stop at certain waypoints, called landmarks. The geometries of entrances, the road network and waypoints are supplied by GIS-layers, as described in more detail in paragraph 3.2.5. Finally, visitors might encounter other visitors during their visit to the area. Encountering others will affect a visitor's crowding satisfaction. Information about encounters, crowding satisfaction and hikers visiting landmarks is saved to shapefiles and CSV files that are used in the analysis part of this study. As part of the analysis of the model, a sensitivity analysis has been performed and two scenarios have been developed. This is described in Section 3.3. Finally, expert interviews have contributed to the validation and calibration of the model. These interviews are described in detail in Section 3.4, while also being referred to in other places in this chapter, when discussing the calibration of certain model parameters.

3.2.4. The global species

The main function of the global species is to create all other species and set model parameters. An important model parameter set in the global species is the spatial extent. In this model, the extent was set to match the spatial extent of the research area, as introduced in Figure 3.2.

Apart from the spatial component of the model, the temporal component of the model is also defined in the global species. Here, it is defined that the model runs from 08:00 until 21:00. Each cycle has a duration of 1 second, resulting in the model consisting of a total of 46800 cycles. The model does not simulate a specific date, but rather, it simulates what a typical busy day would look like. The fifth busiest day of a year is often used as a day to base recreational capacity on (Goossen, 2015). The fifth busiest day is often a Sunday at the end of February and such a day receives between 0.5 and 0.6 percent of all hikers visiting an area throughout the year. For the purpose of this model, it was assumed that the modelled day would receive 0.5 percent of the research area's annual visitors.

Finally, all other species shown in Figure 3.3 are created in the global species. Regarding the visitor species, it is interesting to note that it is decided in the global species what attributes visitors will have. Here, it is decided how many visitors will arrive, what activity a visitor group will take part in, where visitors will arrive and when they will arrive. These attributes will be described in more detail when describing the arrival and behaviour of visitors in paragraph 3.2.6.

3.2.5. The environment: roads, entrances, and waypoints

As mentioned above, the physical environment consists of roads, entrances, and waypoints. Their main function is to allow the visitor to move through the research area. The basis of the road network used in the model is the Basisregistratie Topografie (BRT) TOP10NL dataset (Kadaster, 2019). This is the most detailed version of the digital topographical map of the Netherlands published by the Dutch Cadastre. The dataset consists of a variety of topographical elements, of which the road section element (wegdeel) was used to construct the road network. A complete description of the dataset is published by Kadaster (2020). The dataset was also used for the base map of the maps presented in this document.

Road segments that were not going to be used, such as those used by cars, were removed from the dataset. Road segments with dead ends were also removed. Road segments were assigned to the four different visitor activities using Boolean attribute fields, indicating whether each segment was part of, for example, the cycling network or the hiking network. Similarly, this method was used to distinguish between different marked hiking trails. The attributes of the road network, entrances, and waypoints are listed in Table 3.1. Important to note is that some road segments are contained twice, i.e., both ways, in the BRT dataset. This causes problems when asking visitors to travel over them in GAMA, as they will traverse these segments in both directions, instead of one. Duplicate road segments were therefore removed. Additionally, waypoints, landmarks and entrances had to be added, and road segments had to be split wherever these features were not located on a node in the road network. The resulting road network, including entrances, of non-hikers is presented in Figure 3.4, while the road network of hikers is presented in Figure 3.5. Below, processes related to assigning road segments to their activity-specific networks and the placement of waypoints and entrances are described.

Table 3.1: *Attributes of the environment*

Road network	
Attribute	Explanation
Length	Visitors use the length of road segments to calculate the shortest path or optimal path between the entrance or their current waypoint to the exit or their next waypoint.
Activity networks it is part of	Boolean values indicating whether a road segment can be used by mountain bikers, cyclists, horse riders or hikers. If it can be used by hikers, it is also indicated whether it is part of any marked trails.
Encounters	The number of encounters that have taken place on the road segment.
Encounter score	Standardised score that is used in the cognitive map of dissatisfied familiar hikers, the calculation of which is described in paragraph 3.2.9.
Passages	The number of times a segment has been passed by visitors of different activity types.

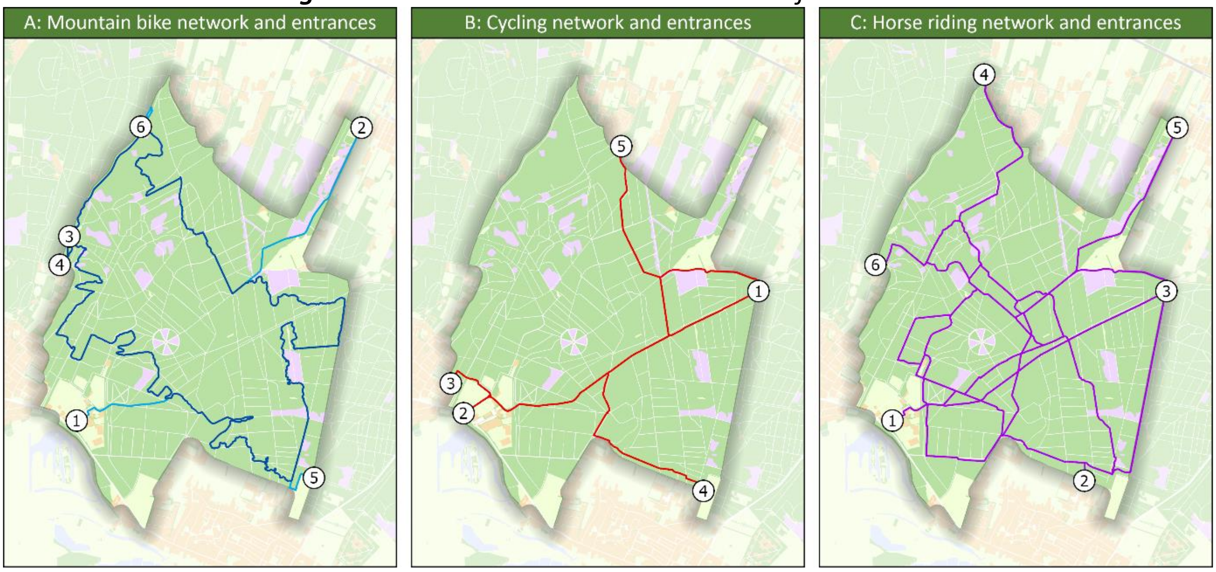
Entrances	
Attribute	Explanation
Activity networks it is part of	Boolean values indicating whether an entrance can be used by mountain bikers, cyclists, horse riders or hikers. If it can be used by hikers, it is also indicated whether it is part of any marked trails.
Arrival frequencies	Number of visitors from each activity type that start at each entrance every hour.
Marked trail distribution unfamiliar hikers	Indicates for every marked hiking trail that starts at the entrance how likely it is that it will be followed by an unfamiliar hiker.

Waypoints	
Attribute	Explanation
Activity networks it is part of	Boolean values indicating whether a waypoint can be used by mountain bikers, horse riders or hikers. If it can be used by hikers, it is also indicated whether it is part of any marked trails.
Landmark	Boolean value indicating whether a waypoint is a landmark or not. Landmarks are locations where hikers might decide to stop.
Waiting chance	When a waypoint is a landmark, there is a certain chance that a hiker will stop there when passing by it.
Visitor frequency	The number of hikers that stop at a landmark is counted.

Bicycle paths

Cycling paths, visualised in Figure 3.4, were assigned based on the cycling paths that are part of the regional cycling network of the Netherlands (Stichting Landelijk Fietsplatform, 2020). In addition to these paths, another cycling path was assigned that connects the two cycling paths that start at Entrance 1. Entrances are situated at the location where the cycling network enters the research area. Because cyclists can travel directly from one entrance to another, no waypoints had to be created.

Figure 3.4: *Route networks and entrances of non-hikers*



Source: MTBroutesNL (n.d.), Stichting Landelijk Fietsplatform (2020), and Stichting Ruiteren & Mennen in Nederland (2021).

Mountain bike trails

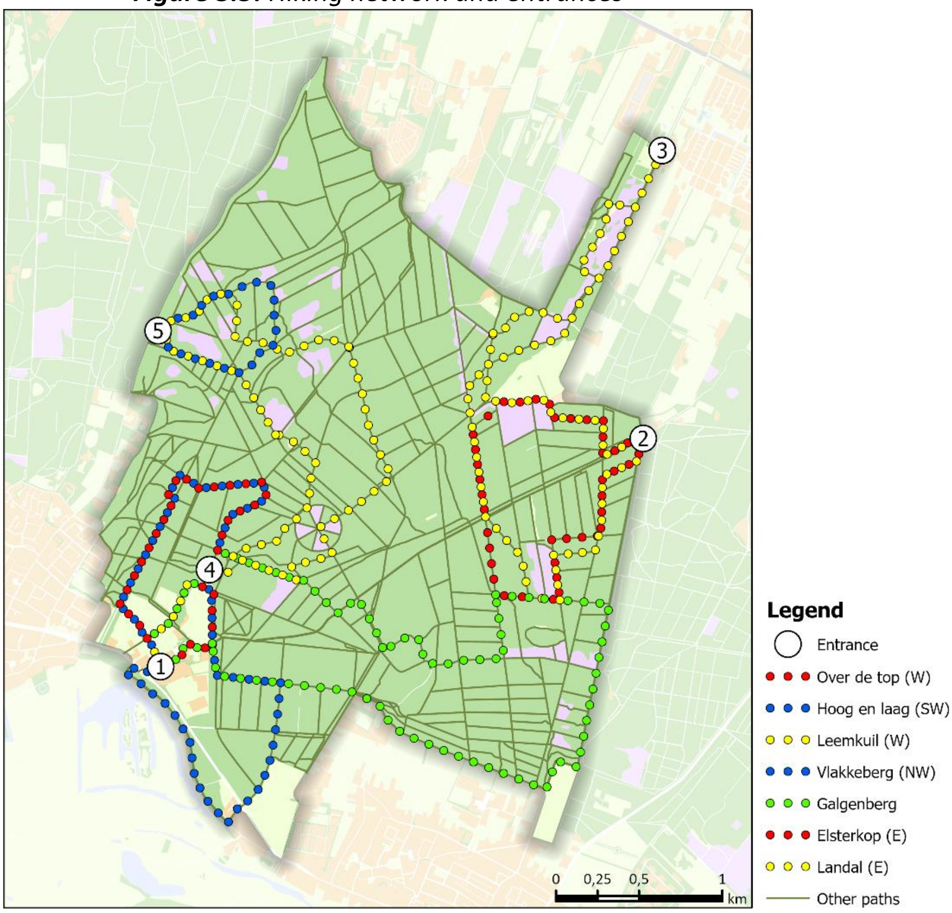
The research area contains one mountain bike track, which can be entered via access tracks. The main track can only be traversed in an anti-clockwise direction. Waypoints are placed along the track to make sure mountain bikers traverse the track in this direction. Most of the route consists of dedicated mountain bike tracks, except for the access tracks from Entrances 1 and 2 and some of the straight lines that can be seen on the map that show locations where the mountain bike track overlaps with the grid of paths that might also be used by hikers. Part of the mountain bike track had to be added to the road network, as the Kadaster (2019) dataset does not contain dedicated mountain bike tracks. Information about the location of mountain bike tracks, including access tracks was gathered from MTBroutesNL (n.d.). Entrances are placed at locations where access tracks enter the research area. Additionally, another entrance was added at the TOP location, as this is also used often by mountain bikers. It is assumed that mountain bikers starting from there will access the main mountain bike track using the cycling path.

Bridleways
Information about bridleways was gathered from Stichting Ruiteren & Mennen in Nederland (2021). Apart from information about bridleways in the area, they provide information about the location of parking locations for trailers and other points of interest for horse riders. Waypoints are placed at locations of intersections within the network. Entrances are located at the points where bridleways enter the area that are connected to a parking place for horse trailers. Additionally, an entrance was placed at the location where bridleways enter the area in the northeast near Veenendaal, to allow horse riders to enter the area from that direction.

Unfamiliar hikers: marked hiking trails
Marked hiking trails are assigned based on the dataset containing marked hiking trails in the Province of Utrecht (Provincie Utrecht, 2021b). Additionally, the Landal route in the northeast was added separately, as it was not part of this dataset (Staatsbosbeheer, n.d.). Trails are only marked in one direction. Therefore, waypoints were placed along the trails to ensure that visitors would traverse them in the right direction. It is assumed that unfamiliar hikers will only follow trails in this direction. Seven trails are included in the model. For simplification purposes, trails are only included in the model if they completely fall within the research area. The resulting hiking network is visualised in Figure 3.5.

Familiar hikers
Familiar hikers will follow any path in the entire study area that is not a dedicated mountain bike trail. It is assumed that, because of the narrowness and steepness of these paths, as well as because of their use by mountain bikers, these paths are too unattractive to be used by hikers. For the purpose of this model, familiar hikers utilise the same entrances as the unfamiliar hikers. Familiar hikers use landmarks as their waypoints.

Figure 3.5: *Hiking network and entrances*

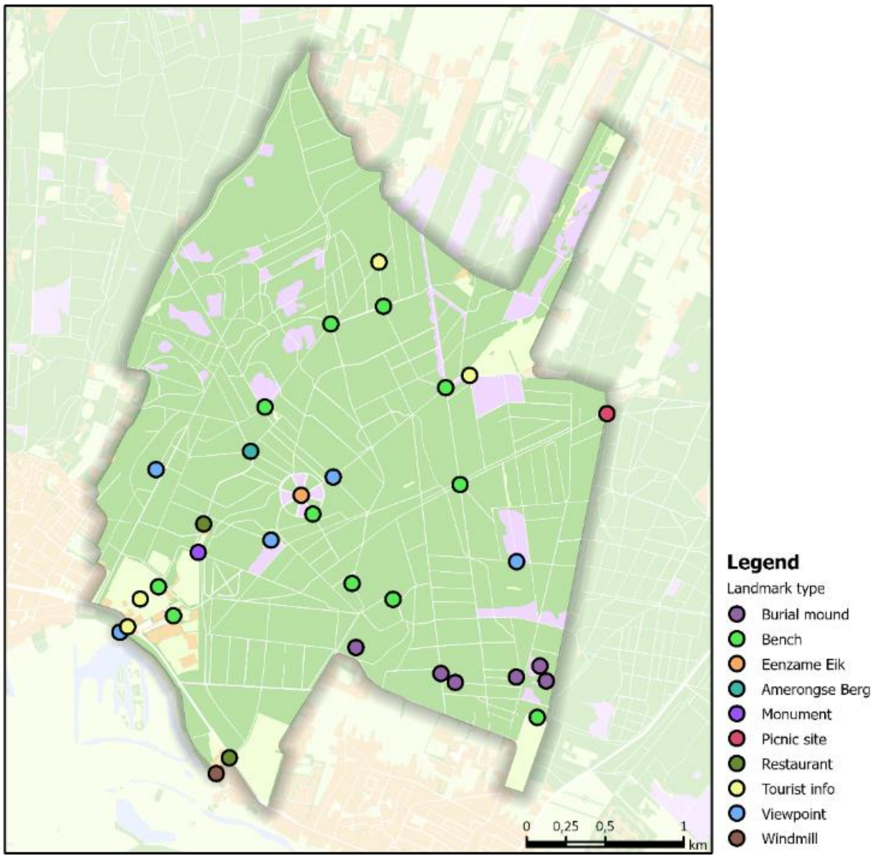


Source: Provincie Utrecht (2021b) and Staatsbosbeheer (n.d.).

Landmarks
An overview of the landmarks included in the model is presented in Figure 3.6. These landmarks function as waypoints for familiar hikers and are places where any hiker may decide to stop for a short while. No information is available about the relative popularity of different landmarks in the research area or about how much time visitors spend at different landmarks. Landmark locations were gathered from OpenStreetMap (OpenStreetMap contributors, n.d.). The study of Orellana et al. (2012), discussed in the theoretical framework, provides some insights into what realistic numbers can be, as it took place in the Dwingelderveld area, another natural area in the Netherlands. Their study shows that visitors on average spend between 1 and 5 minutes at most amenities and attractions, with the exception of car parks and restaurants. Therefore, it has been decided that in the ABM, when a visitor decides to stop at a landmark, they will do so for a random number of cycles between 1 and 5 minutes. Car parks and restaurants form an exception to this. Car parks are incorporated in this study as entrances and not as landmarks and, because the behaviour of visitors in and around restaurants is not represented in this model, it was decided to include restaurants as a potential waypoint for familiar hikers, but to not let hikers stop at restaurants.

Next, it had to be determined how likely it was that a hiker would stop at different landmarks. As there is no data available about this, estimations had to be made, which can be seen in Table 3.5. This results in hikers on average stopping 1.59 per visit. This might be relatively low, compared to the number of MSPs that were observed per GSP in the study of Orellana et al. (2012), however, it was not seen as realistic to further increase the waiting chances. The difference might be explained by the Dwingelderveld being a larger study area, as well as by the study by Orellana et al. (2012) including more waypoints, even considering the differences in area size. The Vlakkeberg route, for example, does not pass any landmarks, so hikers following this trail will not be able to stop at any landmarks during their visit.

Figure 3.6: *Locations of landmarks in the research area*



Source: OpenStreetMap contributors (n.d.).

Table 3.5: *Waiting chances*

Type of landmark	Waiting chance (%)
Burial mounds, Eenzame Eik, Amerongse Berg, Tourist information, viewpoint, windmill	30
Bench, monument, picnic site	10
Restaurant	Not included

3.2.6. Visitors

After having described what the environment looks like in the previous paragraph, attention will now be given to the agents that inhabit the environment: visitor groups, also referred to as visitors. Their general behaviour has already been shortly introduced in Figure 3.3. This figure has shown that visitor enter the area in a certain location, they travel through the area using the road network, during which they encounter other visitors, until they have reached their destination, upon which they leave the area. This behaviour is the same for all visitors, i.e., hikers, cyclists, mountain bikers, and horse riders, however, there are also differences in their behaviour. Table 3.6 gives an overview of the most important attributes of the visitors within the ABM. Some of these attributes have already been introduced, while others will be described in more detail in the next paragraphs.

Table 3.6: *Visitor attributes and their explanation*

Attribute	Explanation
Activity type	Visitor groups represent either a group of hikers, cyclists, mountain bikers, or horse riders.
Familiarity	Hikers can be familiar with the area, in which case they will not follow a marked trail, but they will choose their own path.
Marked route	Unfamiliar hikers will follow a specific marked trail.
Entrance location	The location where the visitor enters the area.
Exit location	The location where the visitor will leave the area. For simplification purposes, this is the same as the entrance location, except for cyclists.
Waypoints to visit	A list of waypoints that the visitor has to visit. In the case of unfamiliar hikers and mountain bikers, this ensures that they will travel their route in the right direction.
Encounters experienced	The number of times a visitor has encountered another visitor during their stay in the research area.
Encounters with visitors of different activity type experienced	The number of times a visitor has encountered another visitor with a different activity type during their stay in the research area.
Crowding satisfaction	The satisfaction that a visitor has with how crowded it is in the area. This is a number between 1 and 10. A visitor starts with a satisfaction of 10, which will go down as they have more encounters. If it drops below 5.5, the visitor will become dissatisfied.
Weight map (cognitive map)	A map containing information about the cost of travelling a route segment. Only contains segments that can be travelled by the visitor, depending on its activity type. Familiar hikers and horse riders update this cost while travelling through the area, by considering the segments they have already passed and the encounter score of the segments if they are dissatisfied with how crowded it is.
Speed	The speed at which the visitor travels through the area.
Encounter distance	The distance within another visitor needs to be for a visitor in order to register their presence as an encounter.
Waiting time	The number of cycles (i.e., seconds) a visitor has decided to wait at a landmark. This is a number between 60 and 300, or between 1 and 5 minutes.
List of landmarks that visitor has stopped at	Hikers keep a list containing the landmarks they have stopped, to make sure that they do not keep stopping at the same landmark.

List of previous encounters	Visitors keep a list of their previous encounters. This allows them to check when they encounter another visitor whether this is a new encounter or not, to make sure they do not keep encountering the same visitor group over and over again when another visitor groups happens to be within their encounter distance for a long period of time, for example in the case of hikers having stopped at the same landmark.

3.2.7. The arrival of visitors in the research area

Little is known about the behaviour of visitors within the area. A study by NBTC-NIPO Research (2019), commissioned by the Province of Utrecht and previously discussed in Paragraph 3.2.1, provides the most detailed information about characteristics of visitors visiting the study area. According to this study, an estimated 403,000 visitors from the Netherlands visited the Amerongen Forest in the year 2019, accounting for a total number of 1 – 1.25 million visits. 65 percent of these visitors are from the Province of Utrecht, around 22 percent are from the local municipality, Gemeente Utrechtse Heuvelrug. Table 3.7 shows for the four activities that are part of the ABM how often visitors partake in them. There is some overlap between activities, as some visitors might have visited the area multiple times during the year, taking part in different activities. Alternatively, they might have taken part in different activities during a single visit, by for example combining hiking and cycling. Table 3.7 also shows the percentages that were used in this study, based on those presented in the report. Cycling and racing cycling were merged into a single category, as they use the same infrastructure and share the same behaviour in the model.

Table 3.7: *Distribution of activity types*

Activity types	% according to NBTC-NIPO Research (2019)	% used in model
Hiking	66	62
Cycling (including e-bikes)	19	25
Racing cycling	6	-
Mountain biking	12	12
Horse riding	1	1

As mentioned in Paragraph 3.2.4, the day that is being modelled is assumed to receive 0.5 percent of the area's yearly visitors. This translates to 5000 visitors, assuming the total number of visitors is 1 million. In this model, visitor groups are modelled, rather than individual visitors. Another study by NBTC-NIPO Research (2018) provides insights into group sizes. These numbers are not available for the Amerongen Forest but are available on a nation-wide scale. Table 3.8 shows how these group sizes are used to calculate the number of groups from each activity types that visits the area during the simulated day. It should be pointed out that the group size for recreational hiking in this study is 2.8 and 3.0 for hiking sport. Because recreational hiking is around 3.5 times as popular, their group size is used. Furthermore, the group size for mountain bikers also includes racing cyclists but these are included in the model in the cycling activity type. Because racing cyclists are only 24 percent of the cyclist activity type, the group size of cycling is used. Finally, the actual number of horse riders would only be 18 but because of rounding in GAMA, this would result in only 13 visitor groups, therefore 22 is used as the input number, resulting in 17 horse riding groups after rounding. Rounding also occurs with the other activity types but because the number of visitor groups for the other activity type is relatively high, this does not impact the outcomes of the model.

Table 3.8: *Visitor groups per activity type*

Activity	% used in model	Group size	Visitor groups in model	After rounding in GAMA
Hiking	62	2.8	1107	1100
Cycling	25	2.6	481	474
Mountain biking	12	2.7	222	215
Horse riding	1	2.8	22	17

All these visitor groups do not arrive at the same time or in the same place, however. Figure 3.7 shows how arrivals are distributed throughout the day. These arrival percentages are based on visits of the TOP near Amerongen as indicated on Google Maps (Google, n.d.).

Figure 3.7: *Arrival percentages per hour (adapted from Google (n.d.))*

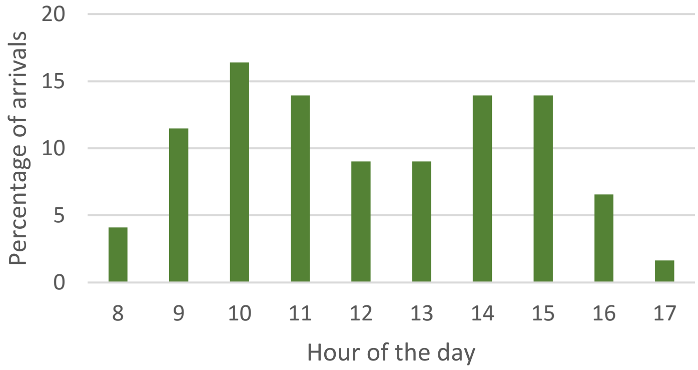


Table 3.9 shows how visitor arrivals have been divided between different entrances, for each activity type. Entrance numbers can be found in Figures 3.4 and 3.5. The NBTC-NIPO Research (2019) report does not provide any information on the relative popularity of different entrances or marked trails. Therefore, assumptions were made about what a possible distribution could look like. These assumptions were discussed during the interviews. The interviewees indicated that they could not make precise estimations about what realistic percentages would be, because of a lack of information on these metrics. They were, however, able to indicate what entrances are popular based on their own experiences. Slight adjustments were made to the percentages based on this, resulting in the percentages shown in Table 3.9.

It should be noted that 20 percent of hikers is assumed to be familiar with the area. This number is based on an estimation of one of the interviewees. Other interviewees were unable to make an estimation of how many hikers follow marked trails compared to how many hikers follow their own path. However, it was pointed out by one of the other interviewees that, generally, hikers that live near the area are less likely to follow a marked trail, due to them being familiar with the area. According to the NBTC-NIPO Research (2019) study, 65 percent of Dutch visitors of the Amerongen Forest are from the Province of Utrecht. 42 percent of those visitors are from the direct neighbourhood, defined as the nearby municipalities of Utrechtse Heuvelrug and Wijk bij Duurstede, or 27.3 percent of all visitors. As mentioned above, for this study the percentage of familiar hikers was assumed to be 20, but because of the uncertainty around this number, this percentage was further explored during the sensitivity analysis, as described in Paragraph 3.3.2.

This interviewee also pointed out that, similar to familiar hikers, horse riders are likely to follow their own path, because they often start at a nearby stable or riding school. It should be pointed out that, while bridleways are marked, there are no specific marked trails comparable to those of hikers for horse riders in the study area. According to the interviewee, this distinction between visitors within an activity type following a marked trail or not only exists with hikers. At the same time, however, among all visitor groups there is the possibility that people will follow trails they are not supposed to. This is not incorporated in this model, as there is no information available about how often this occurs or what the behaviour looks like of visitors not following their own trails, apart from what has been discussed above about familiar hikers.

***Table 3.9:** Arrival of visitors per entrance*

Hikers	% of visitors	Marked trails	% of unfamiliar hikers
Entrance 1	50	Over de top	30
		Hoog en laag	30
		Galgenberg	20
		Leemkuil	20
Entrance 2	10	Elsterkop	100
Entrance 3	10	Landal	100
Entrance 4	20	Over de top	30
		Hoog en laag	30
		Galgenberg	20
		Leemkuil	20
Entrance 5	10	Vlakkeberg	65
		Leemkuil	35

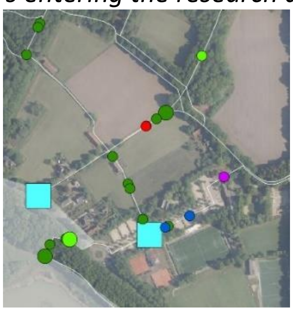
Cyclists	% of visitors	Mountain bikers	% of visitors	Horse riders	% of visitors
Entrance 1	20	Entrance 1	40	Entrance 1	30
Entrance 2	20	Entrance 2	10	Entrance 2	30
Entrance 3	20	Entrance 3	20	Entrance 3	10
Entrance 4	20	Entrance 4	10	Entrance 4	10
Entrance 5	20	Entrance 5	10	Entrance 5	10
		Entrance 6	10	Entrance 6	10

The arrival of visitors is taken care of in the global species. Each hour, for each activity type, it is calculated how many visitors will arrive based on the number of visitor groups indicated in Table 3.8 and arrival time percentages shown in Figure 3.7. Random cycles will then be selected, the amount of which will be equal to the number of visitor groups that will arrive during that hour.

To illustrate this, 1107 hiker visitor groups will visit the area in total. Looking at the arrival percentages, between 10:00 and 11:00, 16.4 percent of these groups will arrive, corresponding to 181.5 visitor groups. Visitor groups are rounded down to an integer, so in this case, 181 hiking groups will enter the area. 181 cycles (i.e., seconds of arrival) will be randomly selected from of a list of a total number of 3600 possible cycles per hour. If the corresponding cycle is reached, the group will be created. An entrance will be selected based on the possibilities presented in Table 3.9. Next, the chance is 80 percent that this group of hikers is unfamiliar with the area, in which case they will follow a marked trail. The trail is once again determined by the possibilities presented in Table 3.9.

In Figure 3.8, a screenshot of the model during a run in GAMA is presented, which shows visitors entering the area. In multiple unfamiliar hikers (dark green) can be seen entering the study area from the TOP Amerongen entrance, the location of the main parking place of the study area (light blue square on the right). Mountain bikers (blue) can also be seen entering the area from there, as well a group of horse riders (purple). On the left, a group of cyclists can be seen (red) that has recently entered the area through the entrance on the left, which is a location where a cycling route enters the area. Two groups of familiar hikers are also visible (light green). In the next paragraph, a description is given of the further behaviour of visitor groups after they have entered the area.

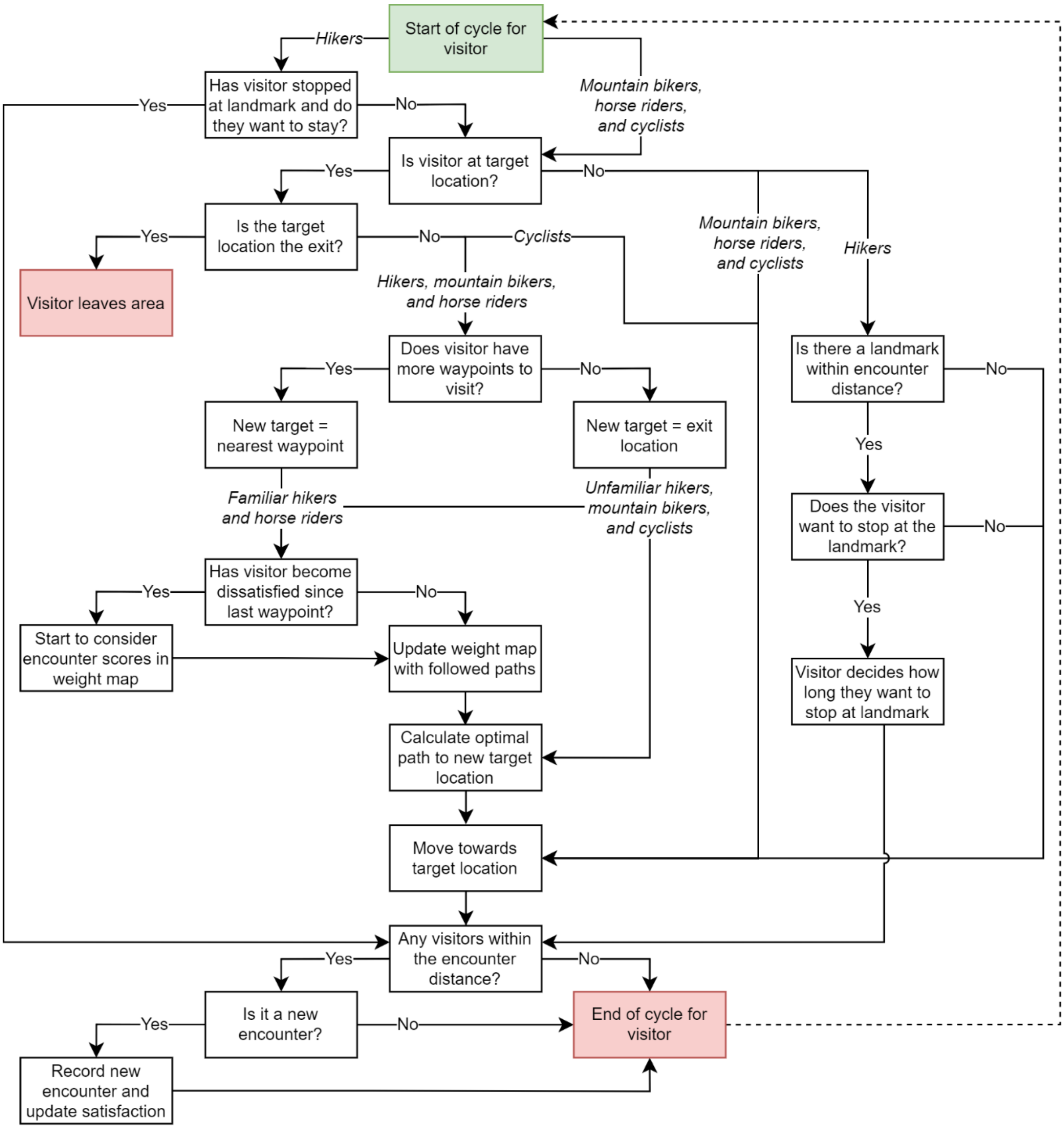
***Figure 3.8:** Visitors entering the research area near the TOP*



3.2.8. Behaviour of different activity types

In Figure 3.9, a flow diagram showing the behaviour of visitors after they have entered the research area is shown. All visitors will follow the steps described in this flow diagram every cycle, starting from the cycle at which they enter the research area, until the cycle at which they leave the area. This paragraph will provide further descriptions of the behaviour of the different activity types during their visit to the area.

Figure 3.9: *Flow diagram of visitor behaviour*



The behaviour of unfamiliar hikers

After groups of unfamiliar hikers enter the research area at their entrance, they will start to follow the marked trial that they are assigned to. Their behaviour thus falls within the imitation strategy, as described in the conceptual model. They will have a list of waypoints that are placed along the trail which they will visit starting from the one that is the nearest to them, calculated taking only into account road segments that are part of their trail. When they reach the next waypoint, it will be removed from this list, and they will recalculate which waypoints is nearest before starting to move towards it. They will repeat this until they have no more waypoints left to visit. At this point, they will start moving to their final target, which is the same location as the entrance, where they will leave the area. As described above, during their hike, hikers might come across landmarks, where they can decide to stop for a duration of between 1 and 5 minutes.

The behaviour of familiar hikers

As opposed to unfamiliar hikers, familiar hikers do not follow a marked trail. Instead, they will select several landmarks to visit. At this point, their behaviour falls within the repetition strategy described in the conceptual model. Landmarks function the same way as waypoints, in that hiking groups will use them to navigate the area by walking towards them, each time walking to the nearest landmark. Familiar hikers will randomly select between 2 and 5 landmarks to visit. This is based on the number of MSPs that are shown to be part of GSPs, according to the study of Orellana et al. (2012) and as discussed in the theoretical framework. Furthermore, while there are no statistics available about how far hikers travel during their visit to the Amerongen Forest, NBTC-NIPO Research (2018) does provide statistics about average distances nationwide. According to this study, for hikers, depending on the intensity of the activity, this is between 7.7 and 6.5 km per activity. On average, hikers in this ABM travel 6.32 km, with unfamiliar hikers travelling 5.9 km and familiar hikers travelling 8.0 km. It is therefore assumed that by selecting between 2 and 5 landmarks, familiar hikers travel a distance that is plausible.

Familiar hikers are equipped with a cognitive map, that is expected to be fully comprehensive according to Xia et al. (2008) and as discussed in the theoretical framework. This, as opposed to the cognitive map of unfamiliar hikers, who need to rely on navigational aids, in this case marked routes, to travel through the area as they are not familiar with it. Familiar hikers will keep track of which paths they have followed and increase the weight paths by multiplying it by 5. This ensures that they are less likely to follow the same path multiple times. Furthermore, if familiar hikers get dissatisfied, they will also incorporate encounter scores in their mental map, as will be explained in more detail in Paragraph 3.2.9. At this point, their behavioural strategy changes from repetition to optimising. Familiar hikers can also decide to stop at landmarks. They can stop at landmarks that they have selected as waypoints and at any other landmark they might come across during their visitor to the research area.

The behaviour of cyclists

The behaviour of cyclists in this model is relatively simple, compared to the behaviour of hikers, especially the familiar ones. This is because there are not a whole lot of options for cyclists within the research area, as there are only a couple of cycling paths, and it is not possible to make a roundtrip within the research area. Rather, the cycling network inside the research area is part of a larger cycling network, it is therefore assumed that most cyclists will simply pass through the area, entering from one entrance and exiting the area at another entrance. When a cycling group enters the research area, they are assigned an exit at random to which they will travel and where they will leave the area. The corresponding behavioural strategy is imitation.

The behaviour of mountain bikers

The behaviour of mountain bikers is similar to that of unfamiliar hikers, in that they are assigned an entrance and they will travel along a marked road, in this case, a mountain bike access trail to the main mountain bike route, which they will follow until they have completed it and they are back at the location where the access road is connected to the main track. Similarly, their behavioural strategy is also imitation. Mountain bikers also follow waypoints, with the first waypoint being situated at the location where the access track is connected to the main mountain bike route. After they have finished the roundtrip, they will follow the access track back to the entrance where they started, where they will leave the area.

The behaviour of horse riders

The behaviour of horse riders is similar to that of familiar hikers, in that they will decide on between 2 and 5 waypoints to visit in the area, to which they will travel starting with the one nearest to them. As a result of this, horse riders on average travel 10.1 km during a visit to the research area, which is a distance not to dissimilar to the average distance of 9.7 km travelled by horse riders as reported by (NBTC-NIPO Research, 2018). The difference between the landmarks of the hikers and the waypoints used by horse riders, is that these waypoints are not visible in the landscape in the form of a recognisable landmark, rather, they are intersections between different bridleways. Furthermore, compared to landmarks, they are purely used by horse riders to navigate through the research area, horse riders will not stop at these locations. Similar to familiar hikers, horse riders also have a cognitive map which they update to make it less likely that they will follow the same road segments twice. They can also become dissatisfied, in which case they will also start to consider encounter scores in their cognitive map. The behavioural strategy of horse riders is therefore also repetition, until they become dissatisfied and change their strategy to optimising.

3.2.9. Encounters and satisfaction

One thing that all visitors have in common, regardless of their activity type, is that they can encounter other visitors. This is of specific interest to this study, as encounters are used to represent the level of crowdedness and conflict that a visitor experiences. The assumption here, is that the satisfaction of visitors decreases as they encounter more and more other visitors, similar to the relationship between the number of encountered groups and acceptability described by Manning et al. (1999) and shown in Figure 2.2. The number of encounters that a visitor group has experienced is thus used in this ABM to measure the level of crowdedness that each individual visitor group experiences during their visit to the research area. Encounters with visitors with different characteristics have a bigger impact on satisfaction, representing that out-group visitor conflicts are more likely to occur than in-group conflicts (Carothers et al., 2001). In the developed ABM, only interpersonal conflicts are represented, as these result from a physical encounter, which can be objectively measured within the modelling environment, while social value conflicts do not require visitors to meet each other (Carothers et al., 2001). As satisfaction is described in the Consumat framework as the extent to which an agent is able to achieve their needs, the need of the visitors in the ABM is to minimise their experience of crowding, by minimising the number of encounters they have. In reality, the satisfaction of a visitor of a natural area will depend on many factors (see e.g., NBTC-NIPO Research (2019)). The term satisfaction as it is used in this model, however, refers only to the satisfaction of visitors with the number of and type of encounters they have had.

Measuring encounters

In order to measure visitor groups encountering each other in the ABM, use is made of an encounter distance. Each cycle, all visitor agents present in the model will check whether there are other visitor groups in their encounter distance or not. The encounter distance is the distance that a visitor can travel within a cycle. With cycles having a duration of one second, this distance is equal to the distance they can travel in one second. Each visitor is assigned a speed when entering the area, which depends on their activity type. It is not known at what speed visitors of different activity types travel during their visit to the research area. Therefore, estimations were made based on statistics available about the time that visitors of different activity types spend during their activity and the distance they travel during this time that are available on a national scale. These statistics can be viewed in Table 3.10.

Table 3.10: *Speed calculations based on distances and activity duration reported by NBTC-NIPO Research (2018)*

Activity	Distance (km)	Time (hours:minutes)	Speed (km/h)
Hiking for leisure	6.5	1:36	4.1
Hiking sport	7.7	1:48	4.3
Cycling for leisure	22.3	2:12	10.1
Racing cycling and mountain biking	41.8	2:18	18.2
Horse riding	9.7	2:12	4.4

Looking at the numbers presented in Table 3.10, it becomes clear that there are not only differences in speed between different activity types, but also among visitors from the same activity type, as they are modelled in this ABM. The top two activities in Table 3.10, for example, both fall under the hiking activity type in the model but travel at different speeds. A study by Meijles, de Bakker, Groote, and Barske (2014) to travel behaviour of hikers in the Drents-Friese Wold National Park in the Netherlands, confirms this notion. They recorded hiking movement using GPS technology and found that, depending on factors such as the motivation, group size, and the presence of children within the group, average recorded movement speeds varied between groups from 2.8 km/h to 4.1 km/h.

Similarly, cyclists with racing bikes are also represented in the cyclist activity type of the ABM, while mountain bikers are represented in the model as a separate activity type. Moreover, differences in speed between cyclists are known to not only be caused by differences in bike type. A study by Schleinitz, Petzoldt, Franke-Bartholdt, Krems, and Gehlert (2017) in Germany, for example, found that the average speed of cyclists with conventional bikes averaged around 15.3 km/h, but cyclists with e-bikes and S-pedelecs were found to travel at speeds of 17.4 km/h and 24.5 km/h, respectively. Apart from this, they also found that speed was influenced by age, the type of road and terrain. Therefore, rather than assigning all visitors of the same activity the same speed, they are assigned a speed within a range, depending on the activity type. This, in order to reflect the diversity within the activity types, as discussed above, and in order to simulate that some visitors will travel faster than others, allowing them to overtake each other. The resulting speeds are presented in Table 3.11. As mentioned above, the encounter distance is defined as the distance a visitor can travel within one cycle. These distances are also presented in this table.

Table 3.11: *Activity types and their corresponding min. and max. speed and encounter distance*

Activity type	Min. speed (km/h)	Max. speed (km/h)	Min. encounter distance (m)	Max. encounter distance (m)
Hiking	3	5	0.83	1.39
Cycling	10	30	2.78	8.33
Mountain biking	10	20	2.78	5.56
Horse riding	4	6	1.11	1.67

As mentioned in Table 3.6, visitors keep track of the encounters they have had. This, not only because they use this to keep track of their satisfaction, but also to make sure that, whenever there is another visitor within their encounter distance, they are experiencing a new encounter. For an encounter to be new, visitors cannot have met each other in the past 1,000 seconds. This is done to avoid the situation where visitors keep encountering each other cycle after cycle while they are slowly overtaking each other, or while they are waiting at landmark together.

Impact of encounters on satisfaction

As mentioned at the beginning of this paragraph, the satisfaction of a visitor decreases as they encounter other visitors. In the theoretical framework, it was discussed that specific encounters can be experienced as a visitor conflict, when this encounter interferes with the goals of a visitor and that out-group conflicts are more likely to occur than in-group conflicts (Carothers et al., 2001). This is represented in this ABM by lowering the satisfaction of a visitor with a greater number when they encounter a visitor with a different activity type.

In their study, Carothers et al. (2001) recorded the occurrence of different causes of visitor conflict among hikers and mountain bikers. On average, across the causes where they found a significant difference between the experience of interpersonal conflicts between hikers and mountain bikers, hikers were 1.83 times more likely to experience conflicts with mountain bikers than with other hikers. Similarly, mountain bikers were 1.48 times more likely to experience conflicts with hikers than with other mountain bikers. The average between these two numbers, 1.65, was used to differentiate between the impact on satisfaction of encounters between visitors with the same activity type and encounters between visitors with different activity types in the ABM that was developed.

There is no information about the satisfaction of visitors of the Amerongen Forest with the level of crowdedness. A study on the national scale, however, shows that the average satisfaction of hikers with the level of crowdedness is 7.4 on a scale of 1 to 10 (Wagenaar, 2016). For the purpose of this model, it was assumed that the average satisfaction of visitors of the research area would also be 7.4. This number was used to calibrate the number that the satisfaction of a visitor is lowered by when they encounter another visitor. Upon entering the research area, a visitor is given a satisfaction of 10. When an encounter takes place, this is reduced by 0.085 if it is with a visitor of the same activity type. This number is multiplied by 1.65, the factor mentioned above, if it is an encounter with a visitor of a different activity type, resulting in a decrease of the satisfaction by 0.14025. Satisfaction cannot drop below 1.

As mentioned in the conceptual model, when satisfaction drops below a certain threshold, or in Consumat terms, the ambition level of a visitors, familiar visitors will change their strategy from repetition to optimising. This threshold is set to 5.5. It is described in the conceptual model that when optimising, familiar visitors will start to use their local knowledge to find paths that will result in a higher satisfaction. In this case, as their satisfaction depends on the number of encounters they have had, they will try to find paths where they can expect to not experience many encounters. It is assumed that, because these visitors are familiar with the area, they will have knowledge about which along which routes encounters are more or less likely to occur, based on their past experiences of visiting the research area. Therefore, instead of calculating the optimal path to their next waypoint purely based on the length of the different road segments, they will also consider the encounter score that each road segment has. The encounter score of a segment is calculated each hour using the following formula:

*Encounter score = Number of encounters on segment in the past hour / Maximum number of encounters on any segment in the past hour * 9 + 1*

This results in an encounter score between 1 and 10, with road segments where no encounters have taken place receiving a score of 1 and the road segment where the highest number of encounters have taken place receiving a score of 10. In their calculation of the optimal path to their next waypoint, the weight of each road segment is therefore:

*Weight of segment = Length * Encounter score * 5 if the road segment has already been passed by the visitor*

As a result of this, dissatisfied familiar visitors are more likely to follow routes where they will not encounter many other visitors. This represents a form of coping behaviour, which is described as the second impact that visitor conflicts can have on the behaviour of a visitor by Marcouiller et al. (2008), along with a decrease in satisfaction, as described in the theoretical framework.

3.2.10. Following a group of familiar hikers

In order to further illustrate the behaviour of visitors as it is modelled in the ABM the behaviour of a visitor group during their visit to the Amerongen Forest, as simulated by the developed ABM, was followed. For this purpose, a group of familiar hikers was followed, because their behaviour is the most complex. This group entered the research area around 11:00, a time at which relatively many visitor groups enter the area, as can be seen in Figure 3.7. The group decides to visit five waypoints. Figure 3.10A shows what the shortest path would be if the group would not consider crowding in their wayfinding, or the roads that they will have already passed. In that case, they would start their walk at the entrance and walk to the southeast of the area, before following their path in a north-eastwards direction to visit a couple of burial mounds. Next, they would walk to the landmark in the centre of the figure. Finally, they would visit the landmark in the northeast of the figure, before walking back to the entrance. Figure 3.10B, however, shows the actual behaviour of this group. The start of their actual walk is the same as what it would be if they would always choose the shortest path, but Figure 3.10B also shows that they encounter other hikers as well as mountain bikers along the way. When they arrive at their final waypoint, in the northeast of the figure, their satisfaction has become smaller than 5.5. This causes them to change their behavioural strategy from repetition to optimising, upon which they will take into account the encounter scores of road segments during their wayfinding process. As a result of this, they decide to walk a different path, compared to what would have been the shortest path, namely the optimal path considering the encounter scores of the road segments and the paths they have already passed. Table 3.12 shows the scores that were calculated during this, indicating that the path they decide to follow does indeed have a lower weight compared to the shortest path when considering these factors. It is visible in Figure 3.10B that, by following this path, they only have three more encounters. Furthermore, the group decides to stop at the landmark in the centre of the figure and also right at the start of their hike, at an additional landmark near the entrance.

***Figure 3.10:** Shortest and optimal path of the followed visitor group*

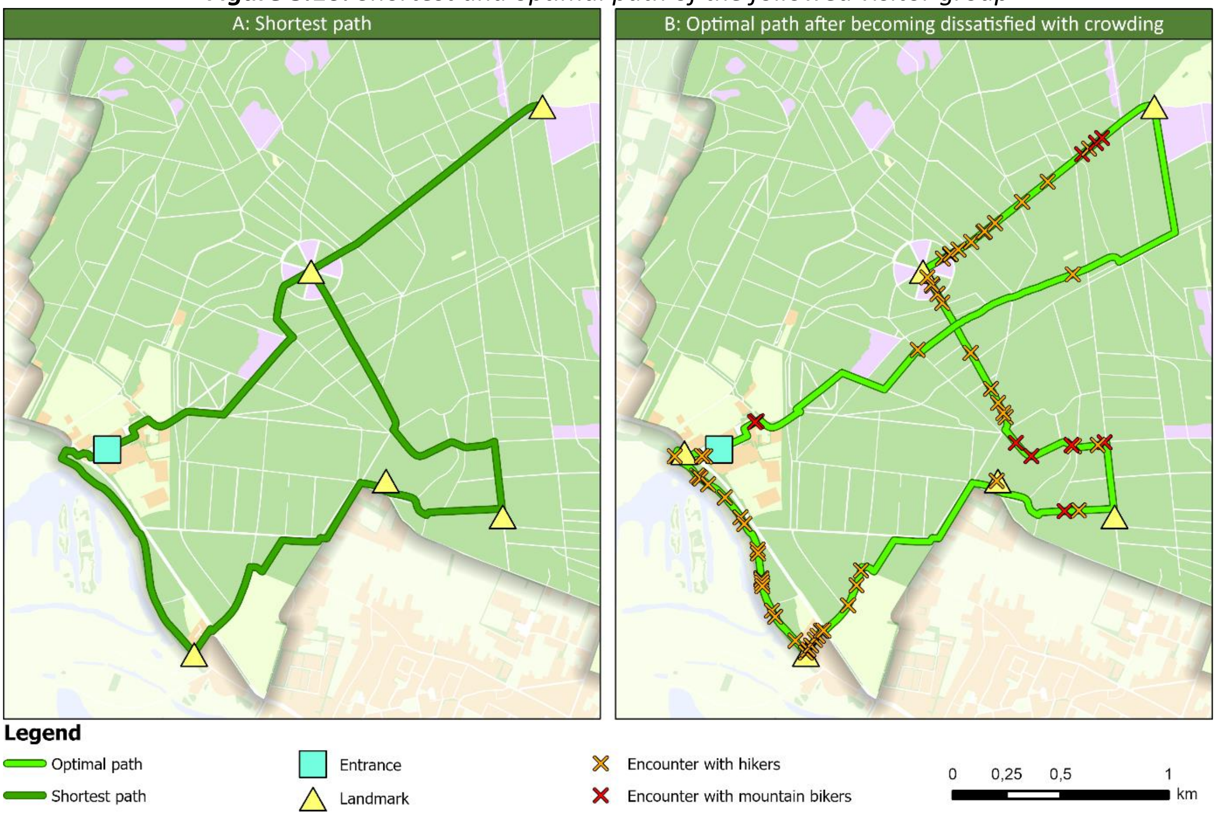


***Table 3.12:** Costs of two route alternatives from the last waypoint to the exit*

Route	Length (m)	Score in cognitive map
Shortest route	2873	12172
Optimal route	3192	4427

3.3. Model analysis and validation

As shown in Figure 3.3 the main output of the model consists of information about the occurrence of encounters and the satisfaction of visitors. Furthermore, information is also gathered about the number of times a landmark is stopped at by hikers throughout the day, and about how often each road segment is passed by visitors of the four different activity types throughout the day. In this section, it will be described how these model outputs have been analysed. As part of the analysis of the model, a sensitivity analysis has taken place during which the two factors were investigated, and two scenarios were developed. Finally, validation has taken place through expert interviews, as will be described in the final paragraph of this section.

First of all, however, it is important to note that the ABM that was developed contains various stochastic elements, as described in detail in Section 3.2. Because there are stochastic elements in the model, this means that the model does not have one possible outcome, but rather a range of possible outcomes. In order to statistically analyse model output by looking at metrics such as the mean and variance of important output parameters, it is therefore necessary to run the model multiple times (Lee et al., 2015). It is, however, not known beforehand how large the sample size, i.e., the number of runs, needs to be in order to reach a point at which these metrics are stable enough to be analysed without too much uncertainty. Therefore, this needs to be determined first, which can be done by looking at the coefficient of variation (c_V) of output parameters, which is equal to the standard deviation divided by the mean (Lorscheid, Heine, & Meyer, 2012). In order to determine the c_v, the model was run multiple times, while iteratively increasing the number of runs, the results of which are presented in Table 3.13. As explained by Lorscheid et al. (2012), this is done until the c_v reaches a point where it becomes relatively stable and remains that way. In this study, this point was defined as the point where the difference in c_v between two consecutive iterations is lower and remains lower than 0.01, after an example of how the c_v can be determined by (Lee et al., 2015). Table 3.13 shows c_v values for three important output parameters for 5, 10, 15, and 20 runs. This table indicates that the point of relative stability is reached after running the model 10 times.

While it is the case with model such as the one presented in this study that the precision of their outcomes increases as they are based on more runs, running the model more times also increases the time required to gather model outputs. Because of this, and because the model is already relatively stable after 10 runs, it was decided that the model would be run 10 times for every different parameter setting that was used during the gathering of output data for the analysis of the base model, as well as for the sensitivity analysis and scenarios. All output data presented in the Results chapter, including data shown in maps, is based on averages over 10 runs. Statistics mentioned previously in this chapter are also based on output averages over 10 runs.

Table 3.13: c_v *values for different numbers of runs*

	Number of runs			
Output parameter	5	10	15	20
Number of encounters	0.011	0.031	0.030	0.029
Encounters between different visitor groups	0.018	0.029	0.033	0.030
Visitor satisfaction	0.004	0.011	0.011	0.010

3.3.1. Model output analysis

At the start of this section, it has been described what model outputs are gathered from the model. In this paragraph, it is described how these outputs are analysed, starting with the number of times each road segment has been passed by visitors of the four different activity types. These numbers are presented proportionally for each road segment in Figure 4.1 in Section 4.1 and provide insights into the frequency at which different road segments are being used by different activity types, reflecting the flows of movement of visitors belonging to each of the four visitor types during their visit to the research area. Presented as well in Section 4.1, is a proportional map showing the number of times a group of hikers has stopped at each landmark.

The next section, Section 4.2, focusses on the location of encounters. As discussed in Paragraph 3.2.9, the crowdedness that visitors experience depends on the number of encounters they have had. Locations where many encounters occur therefore represent locations where visitors will experience high levels of crowding. The location of every encounter that takes place throughout the day that is simulated is recorded. With the resulting data points, a kernel density map has been constructed, which is presented in Section 4.2. By analysing this map, it can be identified at which locations the model suggests that visitors will experience a lot of encounters, and therefore, crowding.

Furthermore, as previously discussed, visitor conflicts are more likely to occur as a result of encounters between visitors with different characteristics, as these encounters are more likely to interfere with a visitor's goals than an encounter with a visitor with similar characteristics. As the main characteristic that differentiates visitors from each other in this model is their activity type, it is therefore interesting to gain insights into where encounters between visitors with different activity types occur, as this could help identify potential locations where visitor conflicts could occur. For this purpose, kernel density maps showing the density of encounters between different activity types were constructed, showing all six possible combinations of encounters between the four activity types. All kernel density maps presented in Chapter 4 are calculated using ArcGIS Pro's Kernel Density function, using a search radius of 100 m, and are displayed using 3 m pixels, classified using the natural breaks classification method.

In the section thereafter, it is analysed what the impact of these encounters is on the satisfaction of the visitors. Differences between activity types, and further differences between familiar hikers and unfamiliar hikers, hiking different marked trails, are analysed. It is also investigated how the satisfaction of visitors develops throughout the simulated day.

3.3.2. Sensitivity analysis

An important part of the analysis of an agent-based model, is performing a sensitivity analysis (Thiele, Kurth, & Grimm, 2014). During a sensitivity analysis, it is explored what the sensitivity of a model's output is to parameter changes, and how robust model output is to uncertainty surrounding input parameter values. This is important, as it allows for a better understanding of the model and of the system that is being modelled. A sensitivity analysis is performed through systemically varying parameter values and investigating the impact of these parameter changes on the output of a model (Klügl, 2008). As is the case with the base model, the model was run 10 times for every parameter setting, as the model contains stochastic elements. Through this process, it can be determined which parameters are important to include in the model. This is important to know, as these parameters will have to be calibrated accurately, in order to accurately represent the system that is being modelled.

Familiarity percentages

As outlined in the conceptual framework and discussed in the previous section, the concept of familiarity is an important determinant for the behaviour of visitors in the developed model. However, there are no statistics available about the percentage of hikers that follow marked trails compared to those choosing their own path. As described in Paragraph 3.2.7, for the base model, it was assumed that 20 percent of hikers would be familiar but, when looking at the percentage of visitors from near municipalities, this number could be higher. Because of this uncertainty, as well as because of the important role of the concept of familiarity, this is an interesting parameter to explore during a sensitivity analysis. This parameter has been explored by running the model with the percentage of familiar hikers set to 10, 15, 20, 25, 30, 35, and 40 percent. It was then analysed what impact these parameter values had on the occurrence and location of encounters and on visitor satisfaction. It is expected that increasing the percentage of familiar hikers leads to an increase in the occurrence of encounters between them and visitors with other activity types. This, because there will be less hikers that will follow marked routes, and as discussed, marked routes are an important zoning instrument used to prevent these types of encounters from happening (Carothers et al., 2001).

Cognitive map

In the theoretical framework, it is described that the two main impacts of the experience of a visitor conflict on visitors are a lowered satisfaction and coping behaviour (Marcouiller et al., 2008). Coping behaviour is represented in this model by familiar hikers and horse riders changing their behavioural strategy from repetition to optimising. This should result in a higher satisfaction compared to when they would not change their behaviour. In order to explore whether this is the case or not, and how much of an impact this has on the number of encounters and the satisfaction of these and other visitors, the model was run with the four settings presented in Table 3.14, which also incorporate the impact of avoiding paths that visitors have already passed before in their wayfinding.

Table 3.14: *Four cognitive map settings*

Included in cognitive map	Description
Roads passed and encounters scores	The base model: familiar hikers and horse riders start to incorporate encounter scores in their wayfinding when they become dissatisfied. They also take into account which path segments they have already passed.
Roads passed	Familiar hikers and horse riders consider previously passed road segments, but do not change their behavioural strategy when they become dissatisfied.
Encounter scores	Encounter scores are considered by dissatisfied familiar hikers and horse riders. Previously passed road segments are not considered.
No cognitive map	Familiar hikers and horse do not change their behavioural strategy and do not take into account previously passed road segments.

3.3.3. Scenarios

One of the uses of ABMs of visitor behaviour in natural areas, is that they can be used to estimate the impact of scenarios (Lawson, 2006). Lawson (2006) explains that, through simulating a scenario in a model, potential impacts of a scenario can be estimated in a way less risky and less costly than what real-world trials would be. To illustrate how the ABM developed for this study can provide insights into potential impacts of scenarios, two scenarios were simulated, both of which will be explained in more detail below.

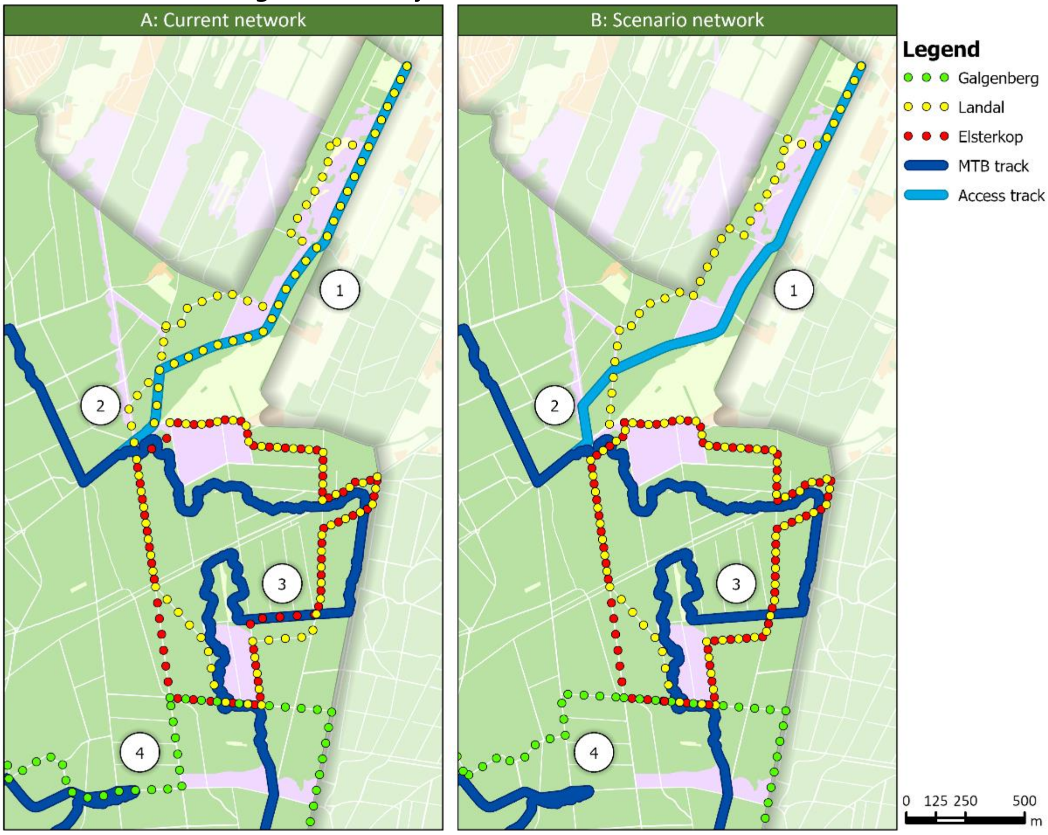
Adjusting route networks scenario

As is described in Paragraph 4.2.1, apart from the area near the TOP, the model output suggests that relatively many encounters between hikers and mountain bikers occur in the northeast of the research area. At several locations within this general area there is an overlap between mountain bike trails and marked hiking routes. In this scenario, adjustments were made to the location of the three marked hiking trails situated here, as well as to the mountain bike access track. The adjustments make use of the already-existing path structure of the area. The scenario is simulated in order to explore what the potential impact could be of these adjustments on the occurrence of encounters between hikers and mountain bikers in this area, and on the satisfaction of mountain bikers and hikers of the three hiking routes that pass through this area. Changes to the relevant route networks are presented in Figure 3.11 and described in Table 3.15.

Table 3.15: *Adjustments made to the route networks*

Location	Adjustments
1	An adjustment has been made to the location of the Landal hiking trail. In the current network, the access trail starting from mountain bike Entrance 2 as shown in Figure 3.4 almost completely overlaps with the location of the Landal hiking trail. This overlap is reduced in the scenario by letting hikers of the Landal route make use of the same paths in both directions.
2	The mountain bike access trail has been shifted slightly westwards, in order to further minimise the overlap between the Landal hiking trail and the access track.
3	The Elsterkop route has been shifted slightly southwards. Because of this, it overlaps with the Landal trail, rather than with the main mountain bike track. This way, the chance of an encounter between hikers of the Elsterkop trail and mountain bikers occurring is minimised.
4	The Galgenberg route is moved slightly northwards, thereby removing an area of overlap between it and the main mountain bike trail.

__Figure 3.11:__ Adjusted route network



2030 scenario

In the second scenario that was simulated, it is explored what the impact on encounters and satisfaction could be if visitor numbers keep increasing as they are expected to. According to one of the interviewees, it is expected that by 2030, the number of visitors to the research area will have doubled. As the base model assumes that the area will receive 1 million visits annually, in this scenario, it was simulated what would happen if 2 million visits were to take place on a yearly basis. In this case, during the simulated day, 2214 groups of hikers would visit the area, as would 961 groups of cyclists, 444 groups of mountain bikers and 40 groups of horse riders.

3.3.4. Validation

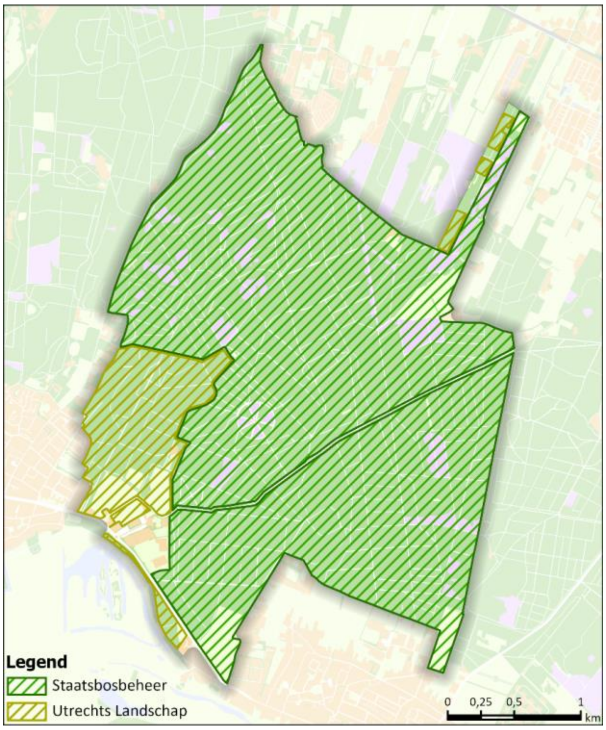
Validation is an important process in the development of any ABM (Klügl, 2008). If a model is valid, this means that the processes that are captured within the model and the results that are produced by the model accurately reflect the system that is being modelled. In that case, the model is able to produce reliable results. However, as pointed out by Klügl (2008), statistical validation is often not possible because of a lack of data. This is also the case in this study. At multiple points throughout this chapter, it has been described that assumptions had to be made about input parameter values, because of a lack of information about their true values. The same is true for output data. As described at the start of this section, the outputs of the ABM developed for this study are the frequency at which visitors with different activity types use different road segments, how often hikers stop at the different landmarks, the locations of encounters between visitors, and the resulting satisfaction of visitors with the level of crowding they have experienced during their visit. No real-world data is available about any of these topics within the research area. Therefore, it is not possible to statistically validate them. However, through face validation, it can be determined how plausible the model outcomes are.

Face validity is described by Klügl (2008) 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" (p. 39). For this purpose, four nature management organisations were involved in the study. Two of these organisations, Staatsbosbeheer and Utrechts Landschap, together own much of the research area. Figure 3.12 shows what parts of the research area are owned by these two organisations. Furthermore, the research area is also part of Nationaal Park Utrechtse Heuvelrug, another organisation that was involved. Finally, Natuurmonumenten was also involved. Although this organisation is not present in this study area, the processes that are represented in the model are the same for many other Dutch natural areas. From each of these four organisations, one expert was interviewed. Together, the interviewees represented different fields of expertise relevant to the process that has been modelled, with some experts working on the ground, while others are working on a policy or strategic level.

The interviews consisted of discussing the development of the model and showing the model as it was running. The results of the interviews are presented in Section 4.6. Recordings of the interviews are available via the author. The following topics were discussed during the interviews:

- **Input parameters and calibration**
  The interviewees were asked about their knowledge and experiences regarding the distribution of visitors throughout the research area. Important insights gained from this have already been discussed in this chapter.
- **Base model outputs**
  Furthermore, the experts were asked to react to the resulting patterns of encounter densities. They were asked about to what extent these patterns matched their experiences and knowledge. This also included asking about patterns that they did not recognise. The temporal aspects of these encounters were also discussed, as was the occurrence of encounters between visitors with different activity types.
- **Scenarios and sensitivity analysis**
  Apart from the output of the base model, the experts were also asked to look at the outcomes of the scenarios and sensitivity analysis.
- **The potential of using ABM in visitor management**
  Finally, the potential of using agent-based modelling in the management of visitors of natural areas was discussed with the experts.

Figure 3.12: *Nature management organisations in the study area*



Source: Provincie Utrecht (2021a).

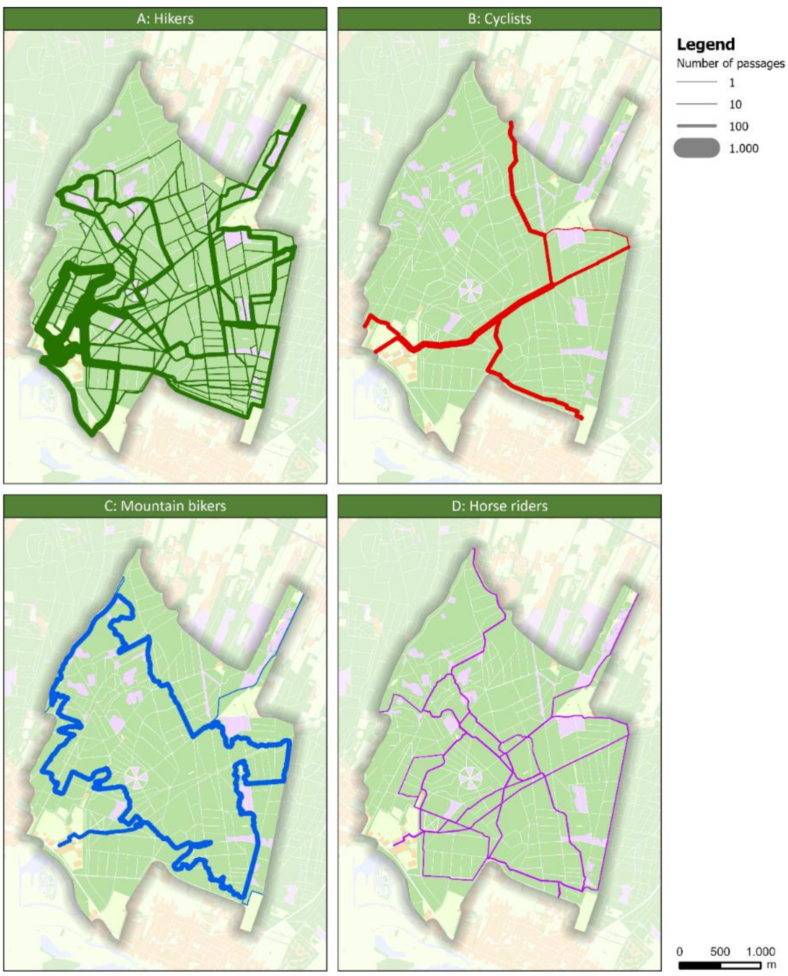
4. Results

In this chapter, the model outputs, as discussed in Section 3.3, are presented and analysed. By doing this, this chapter provides insights into how the model that has been developed suggests that visitors of the Amerongen Forest behave spatially, and what the plausibility is of the simulated behaviour. This will be done by, first of all, looking at the movement of visitors throughout the research area, including the locations where hikers will stop during their hike. Next, it will be discussed how this spatial behaviour results in encounters between visitors in general, and between visitors with different activity types in particular. This, in order to identify both what places the model suggests visitors will experience crowding and what locations the model output suggests that there is the potential for conflicts between visitors based on differences in activity type. The influence that these encounters have on satisfaction, as simulated using the ABM, is presented next, with additional attention being paid to how this develops throughout the day. The results of the sensitivity analysis and scenarios are presented thereafter. Finally, the outcomes of the expert interviews are presented.

4.1. Passages and visits to landmarks

Figure 4.1 shows for every road segment how often it has been passed by visitors from each of the four activity types. The number of passages shown are those that have taken place over a full day of simulation. Figure 4.1A shows that the road segments that are used most often by hikers are those that are part of a marked trail. Relatively many hikers are set to arrive at hiking Entrances 1 and 4, which is also where multiple marked trails start, resulting in hiking paths near these entrances receiving relatively much of the flow of hikers throughout the area. Because familiar hikers can also decide to follow their own paths, hikers can be found throughout much of the research area.

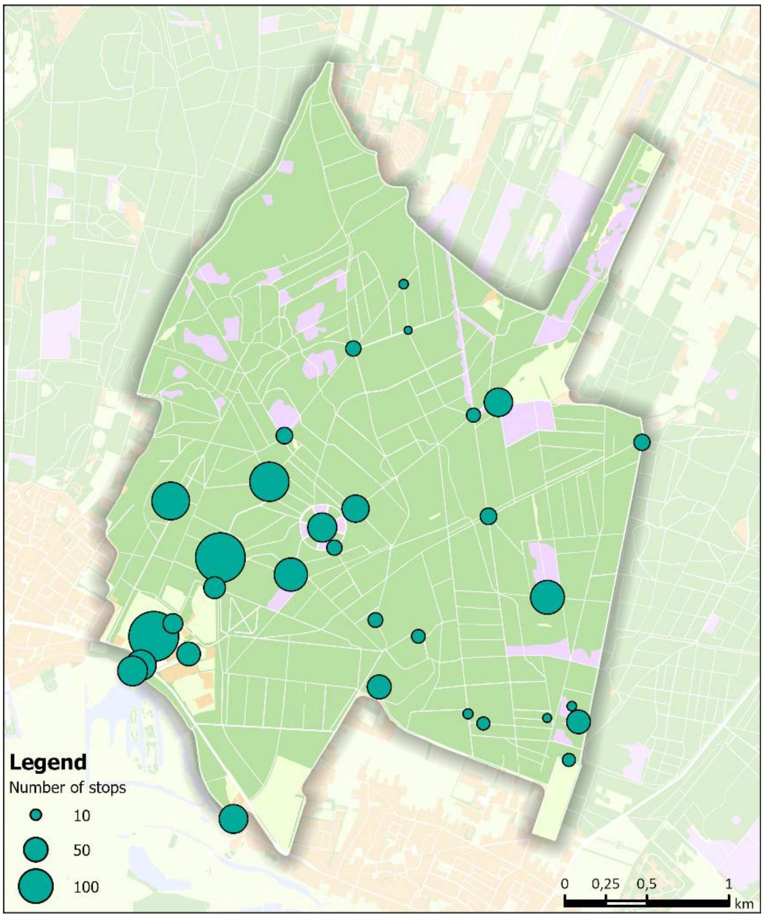
Figure 4.1: *Number of passages per road segment per day*



The area around the TOP is also visited frequently by cyclists. Furthermore, cyclists also frequently make use of the cycling path that cuts through the research area from the TOP in the southwest to the northeast. Along the first stretch of this path, there is an overlap with the paths that are frequently used by mountain bikers, as this also functions as an access trail from the TOP to the main mountain bike trail. Road segments part of the main mountain bike trail are also passed frequently, as all mountain bikers visiting the area are programmed to complete this trail. Lastly, horse riders make use of most of the available bridleways, but at much lower frequencies compared to the other activity types, as in numbers, they are the smallest activity type in the model.

Figure 4.2 gives an overview of the frequency at which hikers decide to stop at the different landmarks within the area. The landmarks that were visited the most are the visitor information point near the TOP and the nearby restaurant. By comparing Figure 4.2 to Figure 4.1A, it can be derived that, generally, landmarks that are located on road segments that are not part of a marked hiking route are visited less, because less hikers pass by them, compared to landmarks that are situated along a marked hiking trail.

Figure 4.2 *Landmark visitor frequency*



4.2. Encounters

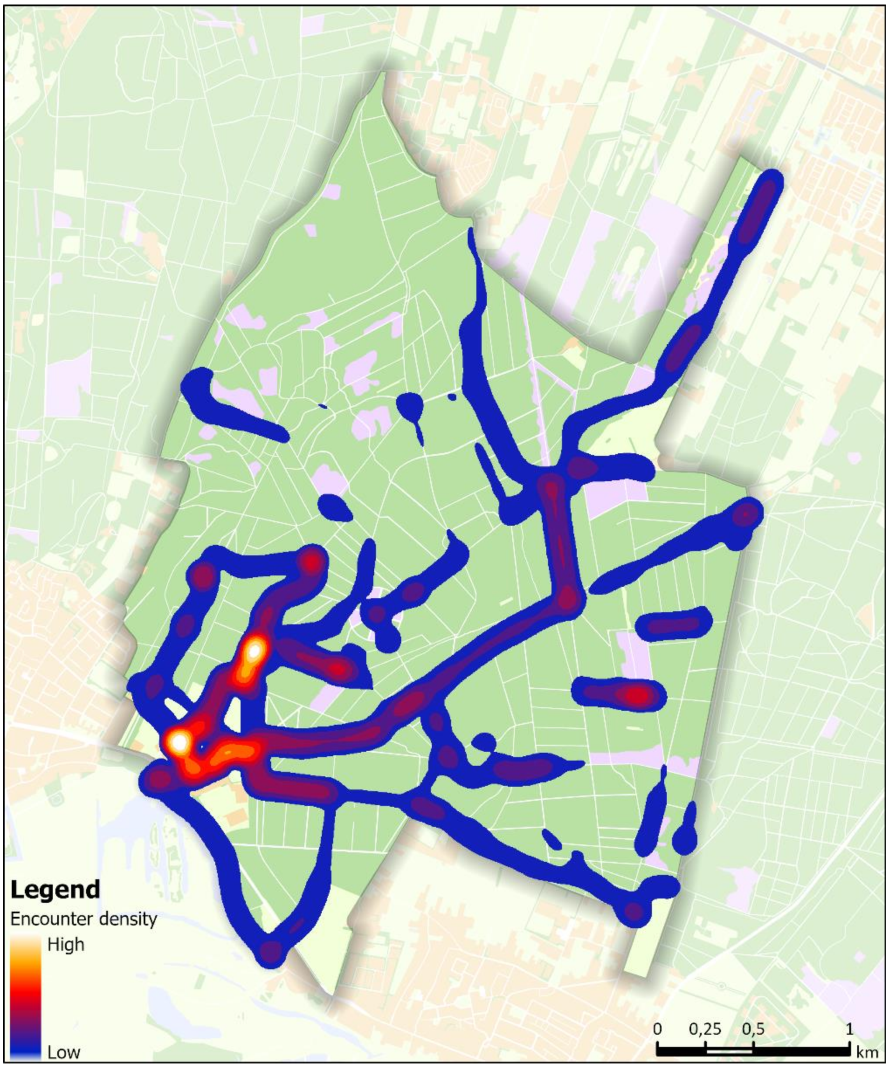
As described in the methodology, encounters between visitors are registered when visitor groups enter each other's encounter distance. The location of these encounters, as well as information about groups invovled in the encounter, are recorded. In Table 4.1, descriptive statistics about the occurance of encounters in general, as well as encounters between visitors with different activity types specifically, are presented. As mentioned in the methodology, statistics are based on 10 runs. Table 4.1 shows that around 24,000 encounters are recorded throughout a simulated day, with around a quarter being encounters between visitors with different activity types.

Table 4.1: *Descriptive statistics encounters*

	Mean	Standard deviation	Minimum	Maximum
Encounters	24182	465	23270	24884
Encounters between different activity types	6394	168	6151	6744

Figure 4.3 shows the density of the occurrence of encounters taking place between any visitor group with any other visitor group during an entire simulated day. These patterns are referred to in this thesis as encounter densities. As discussed in Paragraph 3.2.9, in the model, the number of encounters a visitor has had is reflected in their experience of crowding. Locations in Figure 4.3 where there is a high encouner density therefore represent areas that the model suggests that visitors are more likely to experience an increase in their feeling of crowdedness, as compared to areas with lower encounter densities.

Figure 4.3: *Density map of all encounters during a simulated day*



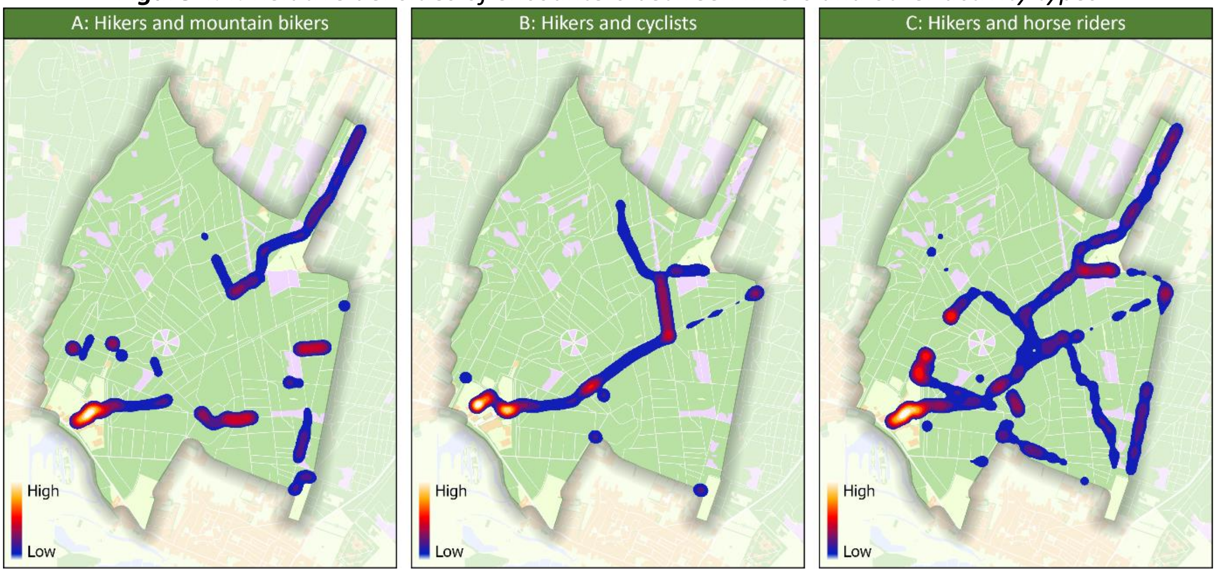
Highlighted on the map as an area where relatively many encounters occur, is the area in the southwest near the TOP. This area contains the starting locations of multiple marked hiking trails, as well as entrances for mountain bikers, cyclists, and horse riders. From Figure 4.1, it was already made clear that this results in relatively many visitors passing through this area. Furthermore, by comparing Figure 4.3 to Figure 4.2, it also becomes clear that especially the areas near frequently visited landmarks show relatively high encounter densities.

Outside of the area near the TOP, relatively high encounter densities can also be observed along some of the more frequently followed marked trails, such as the Hoog en laag and Over de top trails that were introduced in Figure 3.5. The cycling path that runs through the middle of the research area also shows up as a path along which relatively many encounters occur, as does the mountain bike access track starting in the northeast of the area that overlaps largely with the Landal hiking route. The same is also true for some of the other entrances outside of the TOP area in the southwest, such as hiking entrances 5 in the west and 2 in the east. Finally, relatively high encounter densities can also be observed around frequently visited landmarks outside of the TOP area.

4.2.1. Encounters between activity types

Whereas Figure 4.3 can provide insights into at what locations visitors are more or less likely to experience crowding, it is also interesting to look at the locations where encounters between visitors with different activity types take place. This, because this could help identify locations where visitor conflicts will potentially occur. Figure 4.4 shows the relative densities of encounters between hikers and visitors with different activity types, i.e., mountain bikers, cyclists, and horse riders. When comparing these three maps, it is important to consider that they represent different numbers of encounters. For example, if an area has a high density of encounters between hikers and horse riders, this is high compared to other areas, not compared to the density of encounters between hikers and activity types other than horse riders.

Figure 4.4: *Relative densities of encounters between hikers and other activity types*

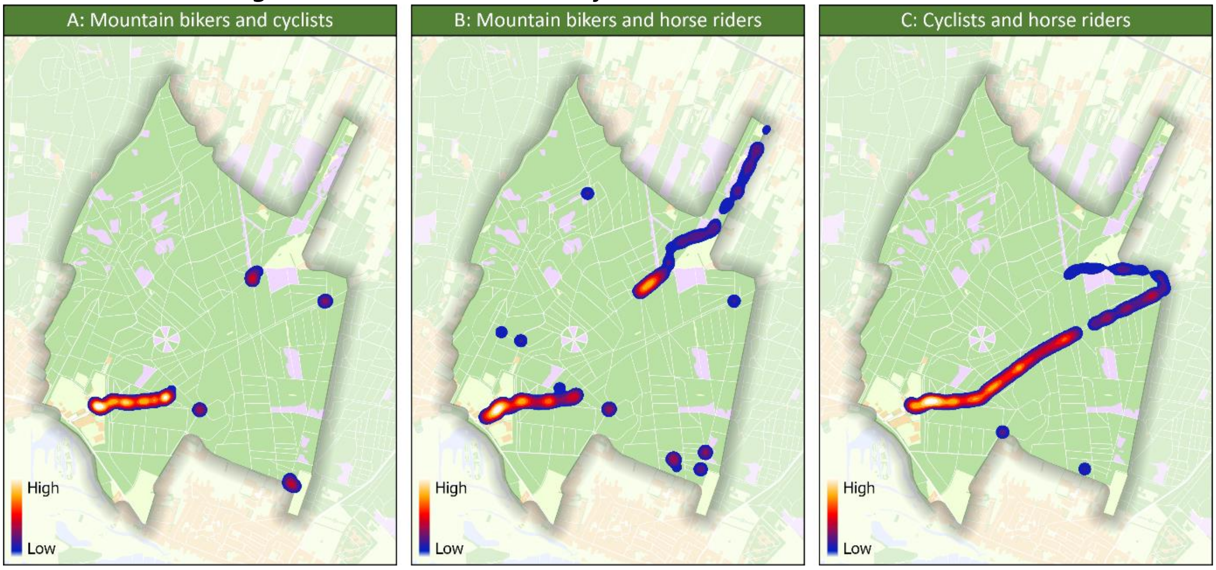


Starting with Figure 4.4A, this density map shows the spatial distribution of the on average 2413 encounters that occur between hikers and mountain bikers throughout a simulated day. The highest encounter densities occur near the entrance in the southwest and along the access track that starts there. Furthermore, the map shows other areas where encounters occur over a relatively long distance. This happens at places where there is an overlap between the mountain bike trail and hiking routes. An example of where this occurs, is along the access track in the northeast, which overlaps with the Landal hiking route. Lastly, the map shows a couple of smaller locations dotted around the map where encounters occur. These are areas where mountain bike trials intersect with marked hiking trails.

Figure 4.4B shows the locations of encounters between hikers and cyclists. On average, over a whole day, 3226 of these encounters. More encounters therefore occur between hikers and cyclists than between hikers and mountain bikers, but there are also more cyclists that visit the area: 474 as opposed to 215 mountain bikers. As the map indicates, the encounters concentrate around the TOP and along the cycling path that runs through the middle of the research area. Along this path, higher encounter densities occur at locations where cycling paths and marked hiking trials are situated right next to each other. At these locations, the distance between these paths will be less than 3 metres, meaning that hikers will be within the encounter distance of cyclists. Furthermore, familiar hikers might decide to use the paved cycling paths, rather than unpaved hiking paths, as these are both part of their route network. Other locations where encounters occur are situated at intersections between cycling paths and marked hiking trails.

Finally, Figure 4.4C gives an indication of where encounters between hikers and horse riders are most likely to occur. It should be pointed out that these encounters occur less than the previously discussed encounters, on average only 223 times, mostly because only 17 horse riding groups will enter the area throughout the day. Most of these encounters occur at the entrance in the southwest as well as at places where bridleways overlap with marked hiking routes.

Figure 4.5: *Relative densities of encounters between non-hikers*



Moving on to encounter between non-hikers, Figure 4.5A shows that encounters between cyclists and mountain bikers, on average 496 per day, occur mostly along the access track between the entrance in the southwest and the mountain bike trail, because this access track follows the cycling path. The other locations where encounters occur are at intersections between the mountain bike trail and the cycling network.

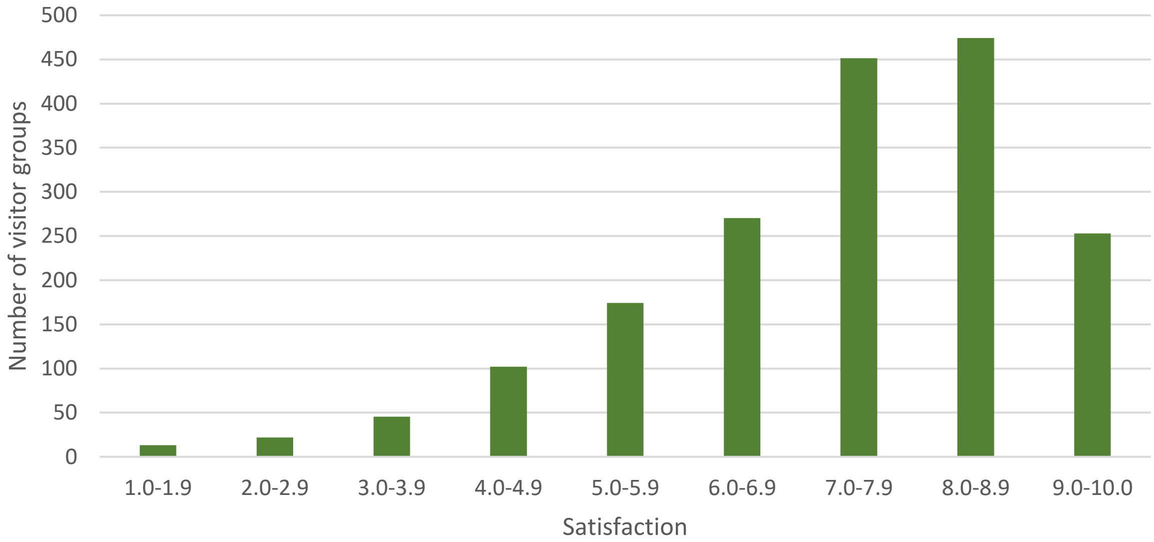
The access track mentioned above is also highlighted in Figure 4.5B, as a bridleway is situated next to it. This is where many of the on average 51 encounters between mountain bikers and horse riders occur. Another access track is highlighted in the northeast. At this location, mountain bikers and horse riders both make use of the same trail. At the end of the access track, there is an area with an even higher encounter density. Here, the main mountain bike track is also part of the bridleway network. Further encounters take place at intersections between the mountain bike track and the bridleway network.

Lastly, Figure 4.5C shows the density of encounters between cyclists and horse riders. On average, 97 such encounters occur. As is the case with encounters between cyclists and hikers, the cycling path that runs through the middle of the research area is situated next to a bridleway, resulting in encounters between cyclists and horse riders along this path. To the north, encounters occur where there is an overlap between the cycling and bridleway networks. Finally, in the southeast, encounters occur at intersections between the two networks.

4.3. Satisfaction

The previous sections have outlined how visitors move through the research area and where they encounter each other. In this section, it will be investigated what the impact of the spatial behaviour of these visitors and the encounters they have had during their simulated visit to the research area is on their satisfaction. To reiterate, the term satisfaction as it is operationalised in this ABM refers to how satisfied the simulated visitors are based on their experience of crowding, i.e., based on their encounters with other visitors, with encounters with visitors with a different activity type having a larger impact on satisfaction, as these are more likely to result in a visitor conflict. The average satisfaction of all simulated visitor groups upon leaving the area is 7.33 (SD = 0.05). Of all visitors, on average 85.5 percent leave the area satisfied, i.e., with a satisfaction of 5.5 or higher (SD = 0.71). More information about how satisfaction marks are distributed among visitors is presented in Figure 4.6. These numbers, however, vary across activity types and further depends on the time of day. The following two paragraphs will elaborate on these two factors.

Figure 4.6: *Distribution of satisfaction values across visitors*



4.3.1. Crowding satisfaction per activity type

Table 4.2 shows the crowding satisfaction of the four different activity types. Further distinction is made between familiar and unfamiliar hikers, and among unfamiliar hikers, between the seven different marked routes. Of the four activity types, cyclists have the highest satisfaction with an average of 8.36. Of the four activity types, cyclists also travel the least distance within the study area, which reduces the time they have to encounter other visitors.

Mountain bikers, on the other hand, travel the longest distance of all activity types, with an average of 20.25 km. This does not result in the lowest satisfaction, however. Apart from when they are travelling along one of the access tracks, mountain bikers will mainly encounter other mountain bikers, because they make use of a dedicated mountain bike track. Horse riders have a similar number of encounters per visitor group compared to mountain bikers, but are less satisfied, because most of their encounters are with visitors with other activity types. This activity type also shows the largest variation between runs when it comes to their satisfaction.

Of the four activity types, hikers have the most encounters per group, with an average of 33.18 encounters per group over 10 runs. Compared to the other activity types, however, relatively many of these are with other hikers, resulting in a satisfaction that is higher than that of horse riders, and not much lower than that of mountain bikers. There are, however, large differences among hikers when it comes to their satisfaction.

First of all, Table 4.2 shows that, on average, familiar hikers are less satisfied than unfamiliar hikers: 5.35 compared to 7.28. Table 4.2 indicates that, on average, familiar hikers travel longer distances than unfamiliar hikers, during which they have more encounters. A larger percentage of these encounters is with visitors engaged in a different activity, which might be caused by the fact that familiar hikers are able to use cycling paths, bridleways, and some of the mountain bike trails, as opposed to unfamiliar hikers, who only make use of marked hiking trails.

Differences in satisfaction also exist between unfamiliar hikers walking the seven different marked trails. Visitors hiking the Galgenberg trail, one of the longest trails, have a satisfaction that is comparable to that of familiar hikers. Hikers that follow the Landal trail travel slightly further, but encounter fewer other visitors, as they travel through an area that is visited less, as shown in Figure 4.1. They do encounter relatively many visitors engaged in another activity however, as they share sections of their trail with mountain bikers, cyclists, and horse riders. The same is true for hikers of the Elsterkop trail, but their satisfaction is higher than that of the hikers of the Landal trail, as the Elsterkop trail is relatively short. The Vlakkeberg trail also deserves a mention, as this is the trail with the highest satisfaction. This is also the shortest walk, and a walk where encounters between hikers and visitors of a different activity type hardly occur. Because this area is also less busy than, for example, the area near the TOP, visitors walking the Vlakkeberg on average only encounter 2 other visitor groups according to the model output.

Table 4.2: *Satisfaction and encounter statistics*

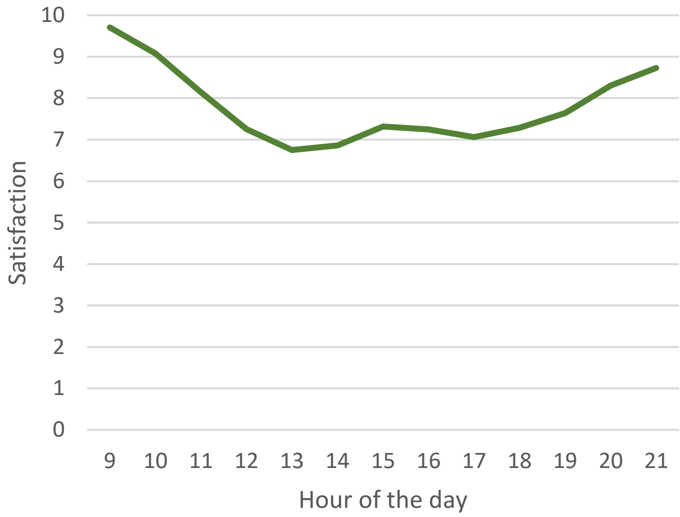
		Satisfaction		Encounters per visitor group		
Visitor group	Number of groups	Mean	Standard deviation	Number of encounters	% with other activity type	Distance (km)
Cyclists	474	8.36	0.07	14.16	55.23	3.86
Mountain bikers	215	7.39	0.07	22.11	59.91	20.25
Horse riders	17	6.80	0.49	23.49	92.89	10.05
Hikers	1100	6.89	0.07	33.18	16.06	6.32
Familiar hikers	220.6	5.35	0.17	47.27	24.88	8.00
Unfamiliar hikers	879.4	7.28	0.06	29.64	12.54	5.90
Over de top	182.7	7.68	0.08	25.02	14.07	3.52
Hoog en laag	185.9	7.20	0.10	32.32	2.99	6.05
Leemkuil	151.1	6.89	0.18	35.63	3.91	7.41
Galgenberg	125.5	5.29	0.08	50.15	15.96	8.34
Vlakkeberg	55.7	9.83	0.03	2.01	0.08	2.03
Elsterkop	88.8	8.29	0.07	16.09	38.14	4.25
Landal	89.7	7.43	0.20	25.29	30.37	8.51

4.3.2. Temporal patterns

As mentioned above, satisfaction numbers also vary by time of day. Figure 4.7 shows how the satisfaction of visitors leaving the area develops throughout the day. At hour 9, the average satisfaction of visitors leaving between 8:00 and 9:00 is shown, while at hour 10, the satisfaction of visitors leaving between 9:00 and 10:00 is shown, etc. Satisfaction gradually declines, before it reaches its lowest point at 13:00. After this, it slightly increases until it dips again at 17:00, after which it gradually rises again, with more and more visitors leaving the area.

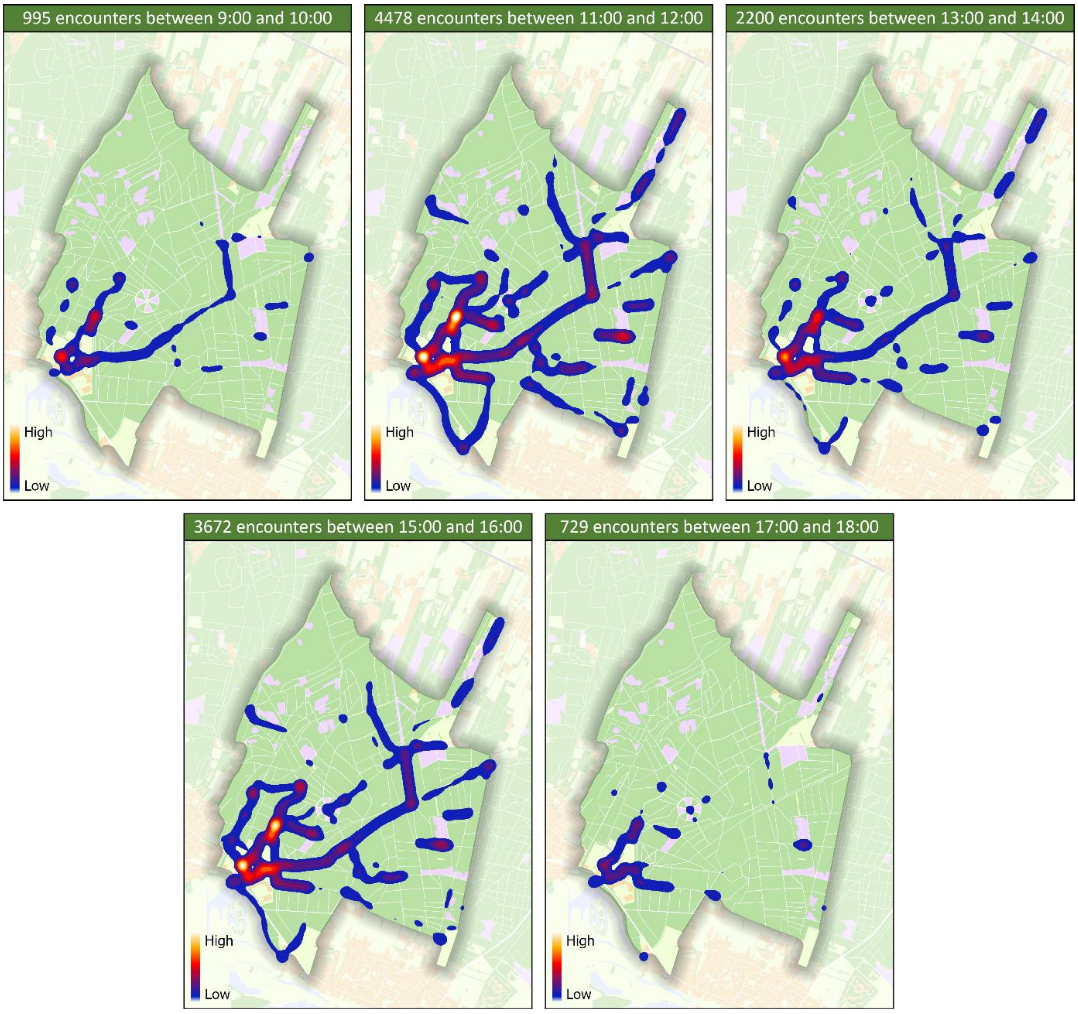
Figure 4.7: *Satisfaction per hour*

Figure 4.8 shows what encounter densities look like throughout the day. The maps use the same scale.



The general pattern that is visible in all of the maps is similar to the one shown in Figure 4.3, with the highest densities being present in the same area, regardless of the time of day. However, this figure also shows that, for many of the areas where encounter densities are relatively high during the middle of the day, they are relatively low early in the morning and from late in the afternoon onwards.

Figure 4.8: *Encounter density throughout the day*



4.4. Sensitivity analysis

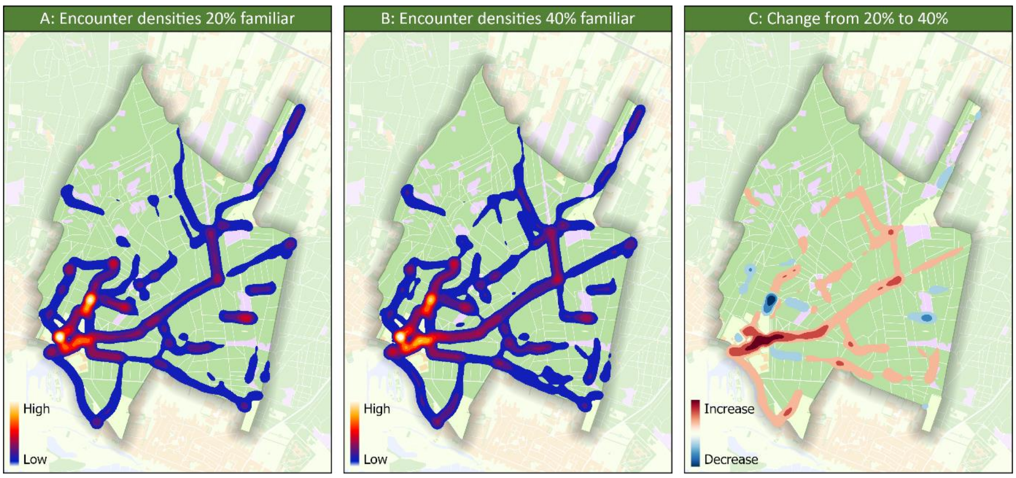
4.4.1. Familiarity percentages

As described in Paragraph 3.3.2, as part of a sensitivity analysis, the impact of the percentage of hikers that is assumed to be familiar with the research area was investigated. The output values of a variety of important parameters for familiarity percentages ranging from 10 percent to 40 percent are presented in Table 4.3. This table shows that, with an increase in the percentage of hikers that is assumed to be familiar with the research area, the number of encounters increases. The proportion of encounters that occurs between visitors with different activity types also increases, while the satisfaction of visitors decreases. In Figure 4.9, it is displayed what the difference is between encounter densities when it is assumed that 20 percent of the hikers is familiar, as is the case in the base model, and when 40 percent is assumed to be familiar. This figure shows that encounter densities have increased along the cycling path that runs through the middle of the research area, especially near the entrances in the southwest. Encounter densities have decreased around landmarks that are visited in the base model by relatively many unfamiliar hikers, i.e., landmarks that are situated along frequently used marked hiking trails. At the same time, encounter densities have increased around landmarks that are visited by relatively few unfamiliar hikers in the base model. These landmarks are more likely to be visited, as more hikers decide for themselves what landmarks they want to visit, as opposed to visiting the landmarks that are situated along the marked trail they are following.

Table 4.3: *Statistics at different familiarity percentages*

	Familiarity percentage						
Output parameter	10	15	20	25	30	35	40
Encounters	22176	22860	24182	25124	26147	27085	28059
Encounters between different activity types	5619	5948	6394	6871	7335	7823	8172
Satisfaction	7.57	7.49	7.33	7.22	7.09	6.98	6.86
Satisfaction familiar hikers	5.49	5.38	5.35	5.23	5.20	5.14	5.08
Satisfaction unfamiliar hikers	7.36	7.35	7.28	7.25	7.22	7.19	7.18
Satisfaction cyclists	8.51	8.46	8.36	8.27	8.17	8.10	8.02
Satisfaction mountain bikers	7.58	7.50	7.39	7.34	7.20	7.11	7.04
Satisfaction horse riders	7.27	7.28	6.80	7.03	6.84	6.60	6.46

Figure 4.9: *Comparison between visitor densities of 20% and 40% familiarity*



4.4.2. Cognitive map

In Table 4.4, the results of the sensitivity analysis of the use of the cognitive map by familiar hikers and horse riders are presented. In the base model, these visitors will change their behavioural strategy from repetition to optimising, meaning that they will start to consider the encounter scores of road segments when deciding on what paths to follow, when their satisfaction is below 5.5. They also consider the paths they have already passed, regardless of their satisfaction. Table 4.4. shows that, compared to considering neither of these two factors, including encounters scores in their cognitive map when having become dissatisfied has a positive impact on the satisfaction of both familiar hikers and horse riders. At the same time, the number of encounters has decreased. Only considering the roads passed in their cognitive map, on the other hand, has a negative impact on satisfaction. Including both, as is the case in the base model, has a negative impact compared to when only incorporating encounter scores. All differences are, however, relatively small.

Table 4.4: *Output statistics different cognitive maps*

	Included in cognitive map			
Output parameter	Roads passed and encounters scores	Roads passed	Encounter scores	No cognitive map
Encounters	24182	24251	23723	24108
Encounters between different activity types	6394	6409	6213	6372
Satisfaction familiar hikers	5.35	5.27	5.52	5.29
Satisfaction horse riders	6.80	7.18	7.44	7.20

4.5. Scenarios

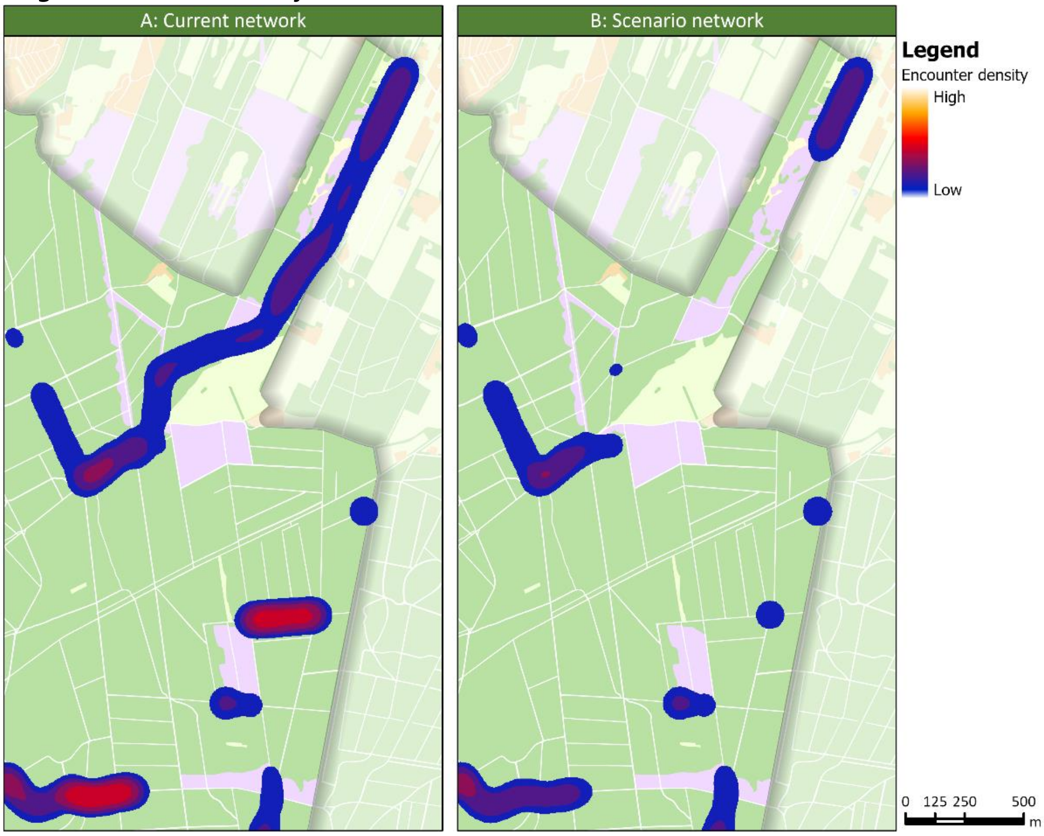
4.5.1. Adjusting route networks

Table 4.5 shows that, as a result of the adjustments to three marked hiking trails and a mountain bike access track as described in Paragraph 3.3.3, the number of encounters between hikers and mountain bikers has decreased by 26 percent. Upon inspection of Figure 4.10, it becomes clear that, in the scenario, in the areas where there is an overlap between marked hiking routes and the mountain bike trail in the base model, the majority of encounters have dissapeared. Two new intersections are visible, but apart from those locations, no more enounters take place in these areas. An exception to this is the area in the southwest of the figure, where encounters are still taking place. These are, however, encounters among familiar hikers and mountain bikers, and it is also visible that encounter densities have decreased in the area where there used to be an overlap between the Galgenberg trail and the mountain bike trail. What Table 4.5 also shows is that these path adjustments are expected to have a postive impact on the satisfaction mountain bikers and hikers of the Galgenberg and Elsterkop trails. On the contrary, hikers of the Landal trail are less satisfied. This is because in the scenario, they have to walk some road segments in both directions, causing them to have more encounters with other hikers.

Table 4.5: *Comparison between base model and scenario*

Output parameter	Base model	Scenario
Encounters	24182	24113
Encounters between different activity types	6394	5708
Encounters between hikers and mountain bikers	2413	1792
Satisfaction mountain bikers	7.39	7.80
Satisfaction Galgenberg	5.29	5.58
Satisfaction Elsterkop	8.29	8.62
Satisfaction Landal	7.43	6.61

Figure 4.10: Densities of encounters between hikers and mountain bikers



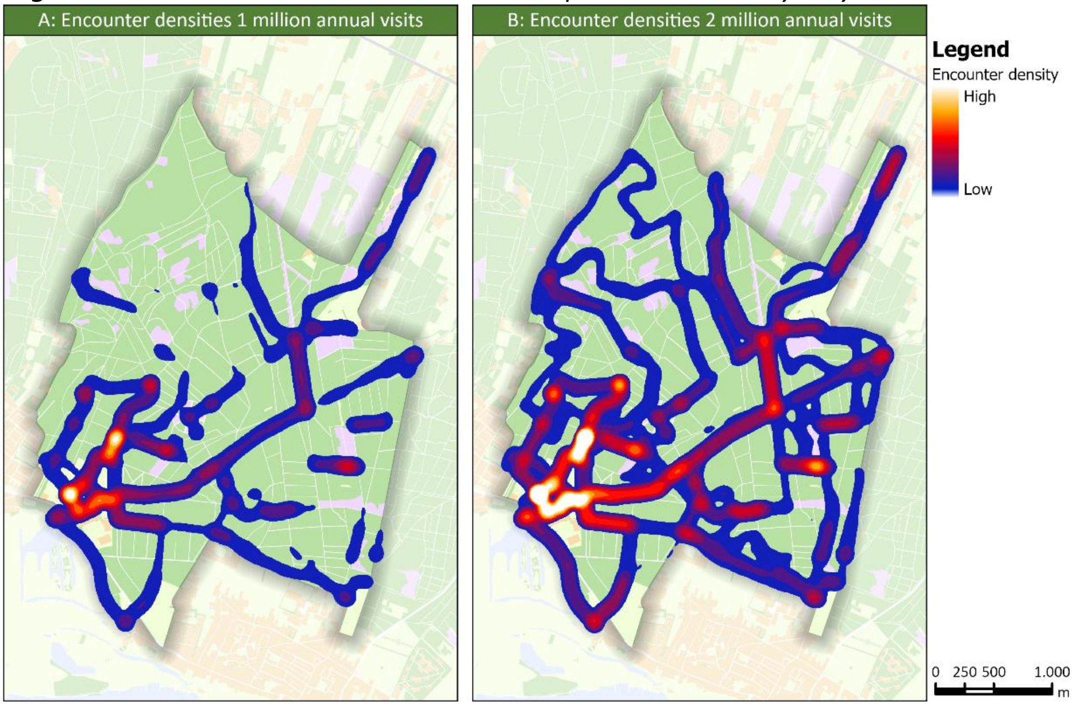
4.5.2. 2030 scenario

In this scenario, the number of annual visits that is assumed to occur in the research area is doubled, from 1 million to 2 million. Table 4.6 shows that this is estimated to result in around three times as many encounters. This has a large impact on satisfaction, with only cyclists leaving the area with a satisfaction higher than 5.5. Figure 4.11 shows that encounter densities have increased across the entire research area. Areas which already had high encounter densities are suggested to have even higher encounter densities, while areas that did not have high encounter densities also show increased encounter densities.

Table 4.6: *Statistics of 1 million visits compared to 2 million visits*

Output parameter	Annual visits	
	1 million	2 million
Encounters	24182	71672
Encounters between different activity types	6394	20035
Satisfaction	7.33	5.72
Satisfaction cyclists	8.36	7.24
Satisfaction mountain bikers	7.39	5.48
Satisfaction horse riders	6.80	5.08
Satisfaction familiar hikers	5.35	3.13
Satisfaction unfamiliar hikers	7.28	5.47

Figure 4.11: *Encounter densities: 1 million compared to 2 million yearly visits*



4.6. Expert interviews

As described in Paragraph 3.3.4, experts from four nature management organisations were interviewed. As described, the interviews consisted of discussing the development of the model, including discussing input parameters and the calibration of the model, discussing model output and discussing the potential that ABMs such as the one developed in this study have for visitor management in natural areas. What has been discussed regarding the calibration of the model will not be discussed in detail in this section, as it has already been discussed in the methodology chapter, when describing the discussed parameters. This section will therefore focus on the last two topics, starting with looking at the plausibility of the model outcomes based on the experiences and knowledge of the interviewed experts.

4.6.1. Plausibility of outcomes

Outcomes of the base model

Starting with the encounter density patterns presented in Figure 4.3, the general patterns visible in this figure were recognisable to the interviewees. Most of the areas that are indicated in this figure as being areas where many encounters take place correspond to the areas where most of the encounters and visitor conflicts take place based on the experience of the interviewees. This is especially the case for the area near the TOP in the southwest. It also fits with the experience of the interviewees that the north-western part of the research area is an area with relatively few encounters.

The maps showing encounters between different activity types also provided recognisable patterns. Because trails are highly separated in the area, it was expected that encounter densities were going to be relatively high around intersections between trails of different activity types. For example, one of the interviewees indicated that the area near the visitor information centre near the TOP is indeed an area where a lot of encounters between hikers and cyclists take place. High encounter densities along the cycling path that runs through the middle of the research area were also recognisable. The same is true for the relatively high encounter densities at the end of the mountain bike access track coming from the north-eastern entrance.

Regarding the frequency of stops at landmarks presented in Figure 4.2, some of the interviewees indicated that they were able to immediately recognise what some of these landmarks were, and that they also understood why some landmarks were visited more frequently than others.

However, other patterns were less recognisable to some of the interviewees. For example, encounters between hikers and mountain bikers along the access track in the northeast came as a surprise to one of the interviewees. In their experience, very few mountain bikers start there, most likely because it is an area where dogs are allowed to be unleashed. On the contrary, the expert expected more encounters to have taken place between hikers and mountain bikers near the hiking entrance in the northwest, because this is a place where many mountain bikers start their visit. They also pointed out that mountain bikers will frequently start at the restaurant near the TOP, which was not considered in the developed model, and that horse riders will also start at locations other than those that are near a parking place for trailers, as horse riders are often from the local area. Finally, they expected some more intersections between hiking trails, the mountain bike trail, and bridleways to show up on the map in the northeast.

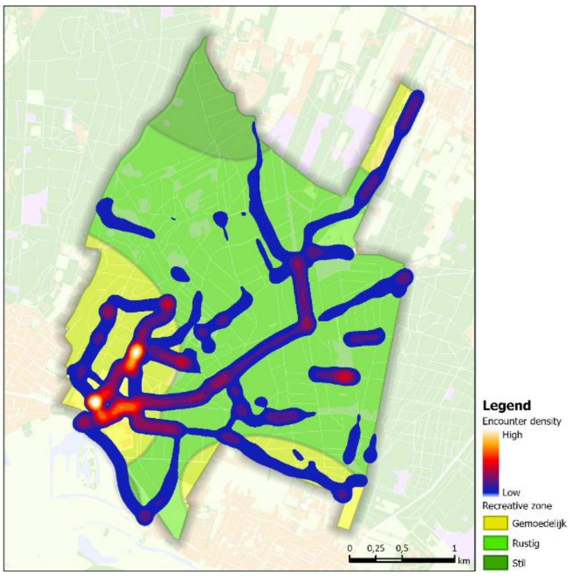
Temporal aspects of the model output, as presented in Paragraph 4.3.2, also provided a recognisable image. One of the experts indicated that the general rule is that as it gets more crowded, visitors become less satisfied. Furthermore, another expert indicated that it is indeed around 13:00 that they experience that people are least satisfied, and that the most visitor conflicts take place.

About the processes incorporated in the model, according to one of the interviewees, it was important that speed differences were incorporated in the model, as this allows visitors to overtake each other. Especially on busy mountain bike tracks, this can lead to visitor conflicts between mountain bikers. Furthermore, allowing hikers to stop at landmarks was also regarded as a good inclusion in the model.

Comparison with recreative zoning map

Regarding the plausibility of model outcomes, one of the interviewees mentioned the recreative zoning map that has been developed by the Province of Utrecht for the Utrechtse Heuvelrug (Provincie Utrecht, 2014). This map is visualised in Figure 4.12, together with the encounter densities as previously shown in Figure 4.3. The research area is divided into three recreative zones that reflect from a policy perspective what the desired distribution of visitor activities is throughout the entire Utrechtse Heuvelrug area. Green areas are areas that are supposed to remain quiet, with dark green areas being the quietest. Yellow areas are areas where more activities can take place. While this map cannot be used to validate the location of crowded areas, through comparing the two maps, it does give an indication of whether encounter densities as suggested by the model correspond to the desired situation according to the zoning map. Table 4.7 shows that on average, higher encounter densities are indeed recorded in areas that are expected to be more crowded based on their recreative zone.

Figure 4.12: *Zoning regulation map and encounter densities*



Source: Provincie Utrecht (2014).

Table 4.7: *Encounters per recreative zone*

Zone	Encounters	Area (ha)	Encounters per ha
Gemoedelijk	14157	225.41	62.80
Rustig	9246	661.44	13.98
Stil	117	65.71	1.78

4.6.2. Scenarios

Both scenarios presented in Section 4.5 were regarded as insightful by different experts. The scenario where path networks are adjusted was seen as an interesting example of how models such as the one developed in this study can be used to gain insights into the potential impacts of scenarios. It was pointed out that such an application is especially interesting from a policy perspective, when dealing with visitor conflicts. However, one of the experts also pointed out that it is quite difficult to adjust the location of marked routes in reality. This is because when deciding on the location of a marked hiking route, not only the location of mountain bike trails needs to be considered, but also the impact that the presence of a marked hiking trail has on nature. The scenario where it was assumed that the number of visitors had increased was also seen as insightful. It was also regarded as a realistic scenario, as the number of visitors has increased since 2019, especially during COVID-19 related lockdowns, and is expected to continue increasing. As indicated by some of the interviewees, getting insights into what an increase in visitor numbers could mean for visitor conflicts was regarded as a useful application.

4.6.3. Reflection on the potential of using ABM in visitor conflict management

Generally, the experts indicated that they regarded the model presented to them as interesting, and they see a lot of future potential. However, in order to fulfil this potential, they also indicate that the model would have to be further developed, in a variety of ways.

Regarding the activity types that were included in the model, one of the interviewees indicated that they would like to see the inclusion of more detail within the hiking activity type to account for differences that exist within this group. Hikers visit nature areas with different goals, and these might also conflict with each other. Conflicts might, for example, occur between runners and hikers that visit the area to go birdwatching. More detail could also be included among the other activity types, as there are, for example, also different types of cyclists.

Another thing that some of the interviewees would like to see incorporated in the model is that not only physical encounters would be recorded, but also encounters that take place at a distance. To illustrate this, hikers could also experience a conflict when hearing mountain bikers talk loudly at a distance, without physically encountering them. It would also be interesting to incorporate the behaviour of visitors other than familiar hikers who do not keep to the trails dedicated to their activity type. It is indicated by the interviewees that visitors that do not keep to their own paths are an important source of conflict between visitors.

It would also be interesting to add some of the decision-making processes that take place before a visitor enters an area and to look into the possibility of upscaling the model to a more regional scale. This would make it possible to investigate the possible impact of adjustments in the Amerongen Forest, for example, on the distribution of visitors throughout the entirety of the Utrechtse Heuvelrug. Other areas of interest for nature management organisation, such as nature conservation could also be included in the model, in order to estimate the impact of visitor behaviour on such areas as well.

Furthermore, it was also indicated that there is the potential of connecting such a model as the one presented in this study to other visitor monitoring efforts or studies that could provide input that could be used to better calibrate and validate the model. This would increase the reliability and usefulness of the model.

While the interviewees see a lot of potential for expanding on the current model, it is also indicated by them that this might prove to be challenging, as there is little information available about visitor behaviour in areas such as the Amerongen Forest. It also remains the case that phenomena such as encounters and satisfaction are hard to measure. Incorporating other decision-making processes that could influence visitor behaviour, such as the relationship between the way a visitor travels to the area and the activity that they will do in the area, would be interesting but would also make the model increasingly more complex. The same is the case for incorporating the behaviour of visitors that do not follow paths that are dedicated to their activities. This is an important source of visitor conflict, but one that will be difficult, if not impossible, to realistically represent in a model. Finally, they indicate that in order to implement such a model as the one presented in this study and to further develop it, technical and financial possibilities and challenges also need to be considered.

5. Discussion

In this chapter, the methodology and results of this thesis are discussed. Outcomes are compared to previous studies, and potential future developments of the model are discussed. The methodology is discussed first, focussing on how the Consumat framework has been translated to the context of visitor behaviour, the assumptions that were made during the implementation of the model, and the way that concepts such as satisfaction were operationalised. Regarding the results of the thesis, the base model output is discussed, together with the results of the sensitivity analysis and scenarios. Finally, the involvement of the experts in this study is discussed.

5.1. Discussion of the developed ABM

5.1.1. Applying Consumat to visitor behaviour in an ABM

One of the starting points of this thesis was that the model that would be designed was going to be based on an existing model of human decision-making, rather than on the assumption that human decision-making is purely rational. The Consumat framework has been used as a basis for the conceptual model. This framework has not previously been applied to the topic of visitor behaviour. However, as pointed out by Pacilly et al. (2019), implementing the framework in a new context should only require slight adaptations.

This proved to be the case for the context of this study as well. The most important conceptual adjustment that was made, was the inclusion of the concept of familiarity, which replaces the concept of uncertainty. However, because of the context of the ABM the familiarity of a visitor could not change during the simulation, which reduces the behavioural strategies that visitors can follow from 4 to 2, in the case of familiar visitors, and from 4 to 1 in the case of unfamiliar visitors. However, this still means that other behaviour is represented in the model than only behaviour according to the rational actor principle, as argued for by Richetin et al. (2010).

When translating the conceptual model based on the Consumat framework to an ABM, further simplifications were made, however. Modes of experience were not included in the ABM, for example, while the attractiveness of path alternatives was limited to only an encounter score, rather than other characteristics described in the Theoretical Framework. These factors were excluded, because there is very little or no information available about these factors for this research area. This is reflective of a weakness of previous models based on Consumat, namely that they are hard to parameterise because of a lack of empirical data about human behaviour and decision-making (Jager & Janssen, 2012).

Combining simulation research, such as the research presented in this thesis, with empirical research, as argued for by Jager and Janssen (2002) would provide a way of dealing with this weakness. For example, the combination of GPS tracking studies and visitor surveys might provide the information to allow for the incorporation of factors such as mode of experience and the attractiveness of paths or landmarks in the developed ABM in a meaningful way.

5.1.2. Assumptions regarding the behaviour of visitors

A lack of empirical data also played a role regarding the parameterisation of visitor behaviour other than what has been mentioned above. Assumptions had to be made about the number of visitors that visits the area during the simulated day, the distribution of visitors among the entrances as well as the location of entrances for different activity types, the exact distribution of visitors among the different activity types, the percentage of familiar hikers, and other factors such as the popularity of landmarks and the waiting time at these landmarks.

The selection of the activity types themselves is also something to discuss. As indicated by one of the experts, other activity types could also be included that might have an important impact on visitor conflicts, such as dog walking services. More detail could also be included among existing activity types, as conflicts might also occur between, for example, hikers and runners, or different types of cyclists, such as conventional cyclists and cyclists with e-bikes. It was already mentioned that dogs, especially unleashed dogs, can be the cause of visitor conflicts (Wolf et al., 2018). Furthermore, it has already been discussed that different types of cyclists travel at different speeds (Schleinitz et al., 2017). Because they make use of the same infrastructure, this could also lead to conflicts.

Currently, however, there is little data available that can be used to incorporate such nuances in the model. Furthermore, including other activity types, especially when they represent a relatively small number of visitors, can provide a challenge to the modeller. As is already the case to some extent with horse riders, including relatively small activity types makes it more difficult to get stable model outcomes, as this will result in more differences between runs. This could potentially make it necessary to run the model many more times before stable results can be obtained.

Acquiring more information about the behaviour of familiar hikers, especially, would increase the reliability of the model outcomes. Their behaviour is more difficult to reliably simulate than that of unfamiliar hikers or any other activity type, as they are less likely to follow a marked trail. For simplification purposes, it was assumed in this model that they would make use of the entrances of the unfamiliar hikers. However, in reality it is likely that they will make use of other entrances than the ones included in the model, because they might be able to reach the area on foot from their homes, reducing their need to start their hike at a carpark. Furthermore, in the model that has been presented, these hikers travel relatively long distances, while in reality, they might also visit the area for a relatively short duration, perhaps to walk a dog, and perhaps even without visiting any specific landmarks. This type of behaviour is currently not represented in the model but could influence encounter patterns, especially near villages. Furthermore, the sensitivity analysis has shown that the behaviour of familiar hikers has a relatively large impact on the occurrence of encounters, suggesting that this is an important factor to more realistically represent in the model.

Furthermore, the difference between familiar and unfamiliar hikers might in reality be less discrete than as presented in the ABM. Familiar hikers might also walk marked routes in reality, while unfamiliar hikers might also decide to walk their own route or make use of navigational aids other than trail markers, such as physical or digital maps or route descriptions found online.

It was also assumed for the purpose of this model that visitors follow the infrastructure that is specific to their activity type, with the exception of familiar hikers that is, while in reality, as pointed out by the interviewed experts, visitors will sometimes follow paths that belong to another activity type. Especially in the context of visitor conflicts, this is important to consider, as this can be an important cause of conflict. It is therefore important to note that the behaviour of visitors as presented in the ABM is a simplification of the much more complex behaviour of visitors in reality. However, as mentioned by Jager et al. (1999), even though simulation models present a simplified version of reality, they are able to capture real behavioural process, allowing them to be studied and experimented with.

5.1.3. Representing visitor conflicts and satisfaction in an ABM

In the Consumat framework, satisfaction has been described as the extent to which agents achieve their needs (Jager & Janssen, 2012). Needs can be varied and complex, as people will visit nature for a wide variety of purposes (Elands & Lengkeek, 2000). In the developed ABM, the concept of satisfaction has been made measurable through the assumption that the satisfaction of a visitor is based on encounters they have had. This assumption is based on the social norm curve described by Manning et al. (1999). However, it has also been discussed in the theoretical framework that the relationship between crowding and satisfaction is complex, with factors such as expectations, tolerance, and the characteristics of the visitor groups involved in an encounter playing a role in how encounters are experienced.

Furthermore, the satisfaction of visitors with their visit to a natural area will in reality also depend on factors other than the encounters they will have had during their visit. Related to this is, for example, the attractiveness of road segments and landmarks, as discussed in the paragraph. It would be interesting to explore what the influence of incorporating other dimensions of visitor satisfaction in the decision-making of the agents would have on the resulting spatial behaviour. Perhaps the satisfaction that a visitor loses by following a certain road segment is offset by the satisfaction they gain because of the attractive view that the visitor has while following the segment, or because it allows them to reach a landmark that they wanted to visit. While such an addition to the model might make the behaviour of visitors more realistic, it would also make it more difficult to calibrate, as satisfaction would become a much more complex concept. By finding out more about the preferences of visitors through empirical studies, as discussed in previous paragraphs, it might, however become possible to more realistically implement such a more complex version of the concept of satisfaction, in which satisfaction is not only impacted by encounters with other visitors but also by visitors achieving the needs that caused them to visit a natural area in the first place.

Furthermore, it should also be noted that the impact that a visitor conflict might have on the satisfaction of a visitor is represented in the model by encounters between visitors with different activity types having a larger impact on the satisfaction of visitors than encounters between visitors with the same activity type. The proportion between the impact of these two types of encounters on satisfaction has been based on the outcomes of a study by Carothers et al. (2001) on the occurrence of conflicts between hikers and mountain bikers. Whether their findings also apply to the context of the Amerongen Forest, and whether the relative impact of an encounter between hikers and mountain bikers is comparable to that of an encounter between, for example, hikers and horse riders, is uncertain and would require further research.

Regarding the way encounters are measured in the developed ABM, it is also important to note that only physical encounters are recorded. However, as pointed out by the interviewees, encounters can also take place at a distance, and encounters at a distance can also be experienced as a conflict by visitors. Hikers could, for example, also experience a conflict when hearing mountain bikers talk loudly at a distance, without them ever entering their encounter distance. Allowing visitors to meet each other at a distance could therefore be an interesting addition to the current model but would require more information about how these encounters occur and about what factors related to visitors and their environment might influence the distance at which visitors can, for example, see or hear each other.

The occurrence of visitor conflicts is another topic that needs to be discussed. In the conceptual model, many factors that influence whether a visitor experiences an encounter as a conflict or not have been identified, that have not been included in the model. Examples of such factors are speed differences between visitors, their relative group sizes, modes of experience, and their tolerance and expectations. Adding these factors to the model would not be that challenging technically. However, without any information that can be used to calibrate these factors, adding such factors would involve having to make more assumptions about, for example, the relative importance of these factors compared to each other, or the distribution of modes of experience across different visitor groups.

As a result of these limitations, the developed ABM cannot be used to determine whether a specific encounter is experienced as a conflict by the visitors involved in it. However, it can be used to identify locations where conflicts may potentially occur, based on the occurrence of encounters between visitors with different activity types. The scenario in which the route networks were adjusted provides an example of how such information can be used to gain insights into the possible impact of visitor management measures on the occurrence of visitor conflicts.

5.2. Discussion of the results

5.2.1. Model outcomes

Despite the limitations and assumptions discussed in the previous paragraphs, the model was able to produce outcomes that were, in general, recognisable to the interviewed experts. Encounter densities were found to be relatively high near entrances and landmarks, with visitors engaged in different activities encountering each other in areas where there is an overlap or intersection between their networks. The temporal pattern, with satisfaction being at its lowest during the middle of the day, was also recognisable. There were, however, also patterns that were less recognisable.

One of the interviewees pointed out that they expected to see more encounters between mountain bikers and hikers at the entrance in the west of the research area. This notion relates to the way the environment was designed, as entrances are represented as point locations in the model. The mountain bike entrance was placed at the location where the mountain bike trail is connected to the outside of the study area via a cycling path, while the entrance of the hikers is placed on a marked hiking trail. As there is no overlap between the mountain bike trail and hiking trail in this area, it is not possible for mountain bikers and hikers to encounter each other. In reality, however, both mountain bikers and hikers might enter the area by car, and they might consequently encounter each other at or around the parking place that is located at this entrance. To better simulate the behaviour that takes place at or near parking places, including encounters, would require to model entrances in a different way than with point locations. Perhaps changing entrances at parking places into lines along which visitors can enter the area would already be a more realistic representation of reality.

It is more difficult to compare the model outcomes to findings of previous studies. The influence of factors described in the theoretical framework as influencing visitor flows, such as mode of experience, landscape type, or path type, cannot be compared to previous studies, as they were not included in the ABM developed in this study. Similarly, the influence of factors such as tolerance and expectations on satisfaction cannot be investigated and compared to previous research. Model output that does correspond to what would be expected based on previous studies, such as that visitor densities are high near parking places that serve as entrances (e.g., Pouwels et al., 2020), will to an important extent be the result of how the model was calibrated. Paths near the TOP area being used frequently, for example, is the result of the entrances in this area being assigned relatively many visitors, combined with the presence of multiple marked hiking trails and the assumption that 80 percent of hikers follow a marked trail.

5.2.2. Characteristics of the research area

Furthermore, it should also be pointed out that some of the model output might be explained by the characteristics of the research area. There is relatively little cycling infrastructure present in the area. As a result of this, cyclists on average only travel less than 4 km per trip, as compared to an expected 22.3 or 41.8 km per trip depending on the type of cyclists (NBTC-NIPO Research, 2018). In reality, cyclists are likely to pass through the research area as part of a larger trip. Their satisfaction, which is the highest among the four activity types, is therefore inflated, as they will in reality meet more visitors during their trip outside of the research area, resulting in a lower satisfaction. The same might also be true for mountain bikers, who travel around 20 km per trip, instead of an expected 41.8 km (NBTC-NIPO Research, 2018). Hikers and horse riders, on the other hand, do travel a distance similar to what would be expected. Simulating entire cycling trips, thereby getting a more realistic picture of their satisfaction, would require the research area to be expanded from the Amerongen Forest to a bigger area, such as the entirety of the Utrechtse Heuvelrug. This would also require modelling of behaviour of other activity types in this wider area.

Regarding the applicability of the model output to other natural areas, it can be expected that the general patterns produced by the developed ABM, i.e., high encounter densities near entrances and landmarks, areas with high potential for visitor conflicts being areas where the networks of different activity types overlap or intersect, and satisfaction being lowest around the middle of the day, will also apply to other areas. This, because of the recognisability of these patterns to the interviewed experts. At the same time, however, specific patterns will differ for each natural area, as each natural area will have a unique environment, consisting of area-specific entrances, trail networks, and landmarks. The trail network of the Amerongen Forest is, for example, already highly separated, reducing the chance of visitors encountering visitors engaged in a different activity. By applying the developed ABM to a research area where this is not the case, it would be possible to study the impact that this has on, for example, the differences in satisfaction between the different activity types.

5.2.3. Sensitivity analysis and scenarios

When investigating the impact of the percentage of hikers assumed to be familiar to the research area, it was found that an increase in the percentage of familiar hikers leads to an increase in the occurrence of encounters. As the proportion of hikers that do not follow a marked hiking trail increases, it is to be expected that there will be more encounters between hikers and non-hikers, resulting in non-hikers having a lower satisfaction. This is also the goal of zoning, which is one of the possible management strategies that are known to be effective, to some extent, in reducing visitor conflicts (Carothers et al., 2001). At the same time, unfamiliar hikers also having a lower satisfaction could be caused by familiar hikers on average spending more time in the research area, leading to more encounters among hikers as well.

Experimenting with the use of the cognitive map has shown that when familiar visitors incorporate encounter scores in their cognitive map, this leads to an increase in satisfaction and a decrease in the number of encounters. This is what would be expected based on them changing their behavioural strategy from repetition to optimising. The fact that the differences might seem relatively small, might be because these visitors only change their strategy after they have become dissatisfied. This is more likely to happen when a visitor is already at the end of their visit, as by that time, they will have had more time to encounter other visitors. It would be interesting to investigate what the influence would be of a more gradual inclusion of encounter scores in the cognitive map of a visitor on their satisfaction.

Another factor that could be interesting to further explore during a sensitivity analysis is the speed of the various activity types. Differences in speed allow visitors of the same activity type to overtake each other, and speed also influences the amount of time a visitor spends in the research area, both influencing the number of encounters a visitor is likely to have. It could be worthwhile to investigate the impact of this factor on encounters and satisfaction. Similarly, as landmarks turned out to be locations where relatively high encounter densities occur, it could be interesting to further explore what the influence is of factors such as waiting chance and duration on encounter numbers and satisfaction.

In the adjusted route network scenario, it was shown how a model such as the one developed in this study can be used to gain insights into the potential effects of infrastructural changes. The difference between the number of encounters in the base model and the scenario is, however, very much dependent on how many hikers and how many mountain bikers follow the involved trails in the first place. Calibrating the model with real-world data and statistically validating the model would therefore be a requirement for such insights to have any reliability and accuracy. This is also the case for the 2030 scenario. The results of the adjusted route network scenario do, however, suggest that zoning can indeed be a strategy that can effectively reduce visitor conflicts.

5.2.4. Expert interviews

Calibration and statistical validation were challenging because of the limited availability of empirical data regarding the behaviour of visitors in the Amerongen Forest. Expert interviews provided an alternative to statistical validation. By involving experts from different organisations, with different expertise, ranging from on-the-ground to the policy and strategic level, it was possible to incorporate multiple viewpoints in the discussion of the developed model. Through these interviews, it came forward that, generally, the patterns generated by the developed ABM can be considered plausible, as they were recognisable to the experts. The experts were also able to point out inconsistencies between the model output and their expectations or experiences, examples of which have been discussed in the previous paragraph. Some of their remarks came too late in the process of developing the model to still be properly included in the model. Therefore, it would be advisable to also involve the experts in an earlier stage of the development of the model. Apart from contributing to the validation of the model output and contributing to some of the calibration done during the development of the model, they could also be involved when designing the environment. Their knowledge and experiences can, for example, contribute to the selection of relevant landmarks, entrances, trails, and activity types. However, their knowledge is also limited to their experiences and the experiences of their colleagues. In order to further validate the model, empirical data would still be required.

6. Conclusion

At the start of this thesis, it has been described that visitor management is becoming increasingly important to natural areas in the Netherlands and around the world, as visitor numbers have increased in recent years, and especially since the outbreak of the COVID-19 pandemic. Increasing visitor numbers put pressure on natural areas, where a balance needs to be found between recreation and nature, in order to ensure sustainable nature-based tourism and recreation, which can provide many benefits to humans, nature, and local businesses. Furthermore, agent-based modelling has been identified as a modelling approach that can provide some of the information that is required for effective visitor management. The Consumat framework has been identified as a framework that allows for the appropriate incorporation of human decision-making in social simulation models. As described in the Introduction, the aim of this study has been to develop an agent-based model that allows for the simulation and exploration of the spatiotemporal behaviour of different visitor groups in a natural area to gain insights into the occurrence of visitor conflicts. Furthermore, this study has aimed at reflecting on the plausibility of the outcomes produced by the model and on the use of agent-based modelling in visitor conflict management. For this purpose, an agent-based model of visitor behaviour in the Amerongen Forest in the Netherlands has been developed in GAMA, based on the Consumat framework of human decision-making. Furthermore, expert interviews have been conducted in order to determine the plausibility of the outcomes of the developed model. In this chapter, the conclusions of this study are presented. Sub-questions will be answered first, before answering the main research question of this thesis. This chapter will finish with recommendation based on the research presented in this thesis regarding the further use and development of ABM in visitor management.

6.1. Sub-questions

The research conducted for this thesis has been carried out based on the sub-questions and main research question formulated in the Introduction. These questions will be answered in this chapter, starting with the first sub-question, which is:

"What factors influence the spatiotemporal behaviour of visitors in natural areas?"

This question has been answered through a literature review. Wayfinding, described by Xia et al. (2008) as the process of finding a pathway from an origin to a destination, came forward from the literature review as an important concept in explaining the behaviour of visitors in natural areas. Visitors make use of a cognitive map when deciding on what path to follow. This cognitive map reflects their knowledge of the environment they are moving through. Landmarks make up an important part of this cognitive map for people that are familiar with an area, as they will use them to navigate an area. Visitors that are unfamiliar with an area need to rely on other sources of information about their environment, such as signposts. This makes familiarity an important concept in the wayfinding process. Visitor behaviour is further influenced by the personal characteristics of a visitor and by destination characteristics (Lew & McKercher, 2006). Important visitor characteristics that have been described in the theoretical framework are activity type and mode of experience, while important destination characteristics are the aforementioned landmarks, as well as landscape and trail characteristics.

Furthermore, visitor behaviour can be influenced by the occurrence of visitor conflicts. This concept has been the focus of the second sub-question:

"When do interactions between visitors of natural areas lead to visitor conflicts?"

This question has also been answered by means of the literature review. Through this literature review, it was determined that, while there is no clear agreed-upon definition of what visitor conflicts are, a commonly used definition is centred around the concept of goal interference, also described as interpersonal conflict by Carothers et al. (2001). This type of visitor conflict is caused by any situation in which the behaviour of visitors interferes with the goals of other visitors. Crowding is regarded as an important source of conflict, as it can reduce the quality of the visitor experience. Specific visitor behaviour during an encounter between visitors can also be the cause of visitors experiencing a conflict. Examples of such behaviour can be rudeness, or visitors passing others too closely or too fast. These types of conflicts occur more often between visitors with different activity types than between visitors taking part in the same activity. The impact of a visitor conflict on the satisfaction of a visitor is also dependent on personal characteristics, such as tolerance towards crowding and expectations.

Through the literature review, agent-based modelling has been identified as a technique suitable for simulating visitor behaviour. Furthermore, the Consumat framework has been identified as a framework that allows for the appropriate incorporation of human decision-making in social simulation models. Together with the answer to the first two sub-questions, this has made it possible to answer the third sub-question:

> *"How can an ABM, based on the Consumat framework, be used to simulate the spatiotemporal behaviour of, and measure the occurrence of conflicts between, visitors in a natural area?"*

An ABM has been developed in GAMA, based on a conceptual framework that has been developed based on the findings from the literature review. Using this model, the behaviour of hikers, cyclists, mountain bikers, and horse riders visiting the Amerongen Forest can be simulated. The model that has been developed consists of two main entities: visitor agents and their environment. The environment consists of entrances, road networks specific to each of the different activity types, and waypoints, which include landmarks. Available visitor statistics have provided information about the behaviour of visitors in the research area. Little is known, however, about the specifics of the behaviour of visitors, therefore, certain aspects of their behaviour therefore had to be based on assumptions. The implications of the assumptions that have been made are discussed in the previous chapter.

Furthermore, the model that has been developed provides an example of how the Consumat approach can be implemented in the context of visitor behaviour and the occurrence of visitor conflicts, something which had not been done before. Importantly, by replacing the concept of uncertainty with familiarity, the framework has been made to better fit this new context. Together with satisfaction, familiarity has become one of the two main driving factors behind visitor decision-making, as it is modelled in this study. In the model, the satisfaction of a visitor depends on physical encounters they have had, whereby encounters with visitors with a different activity type will lower satisfaction more than encounters with visitors with the same activity type. Cognition has also been included in the model through a cognitive map. Furthermore, familiar visitors can change their behavioural strategy when they become dissatisfied. Unfamiliar visitors are, however, not able to do this, and are also unable to increase their familiarity during their visit.

Using the model that has been presented in this thesis, it is not possible to determine whether a specific encounter is experienced by a visitor as a visitor conflict. However, through the analysis of encounter density patterns, the model does provide insights into where people might experience conflict as result of crowdedness, or as a result of encounters with visitors with different activity types. Information about the satisfaction of different visitor groups can provide further insights into how these encounters might affect the satisfaction of these visitors.

Having developed the model, it was possible to answer the next sub-question:

> *"What information about the occurrence of crowding and visitor conflicts may be derived from the visitor behaviour simulated by the developed model?"*

As mentioned above, information about crowding and visitor conflicts can be derived through analysing encounter density patterns produced by the model. These suggest that relatively many encounters occur near frequently visited entrances where multiple hiking trails start. In the Amerongen Forest, this is the area around the TOP. Landmarks, especially those situated along a marked hiking trail, can also be characterised by relatively high encounter densities. Furthermore, the model suggests that encounters between visitors with different activity types primarily occur at locations where there is an overlap or an intersection between paths belonging to the route networks of multiple activity types. Encounter densities are relatively high during the middle of the day, with satisfaction following an inverse pattern. Among visitors, satisfaction has been found to depend on factors such as activity type, familiarity, the time a visitor stays in the area, the time of day at which the visitor is present in the area, whether a visitor only follows routes dedicated to their activity type and whether they start in an area where a lot of other visitors start. The sensitivity analysis that has been performed suggests that when less hikers follow marked trails, this leads to an increase in encounters between hikers and visitors with other activity types, and a decrease in satisfaction. Including the possibility for familiar hikers to change their behavioural strategy seems to have a positive, albeit relatively small, impact on their satisfaction. Furthermore, the developed ABM can provide insights into the potential impacts of visitor management strategies, such as zoning changes.

The final sub-question deals with the validity of these outcomes:

> *"What is the plausibility of the outcomes of the developed model?"*

This question has been answered by conducting interviews with experts from four nature management organisations. From these interviews, it came forward that the general patterns that show where crowding occurs according to the model output match the experience of the interviewees. Furthermore, the figures that suggest areas where conflicts might potentially occur as a result of encounters between visitors with different activity types also provided a picture that was, for the most part, recognisable. The model output can therefore be regarded as plausible. Furthermore, the outcomes of the sensitivity analysis correspond to what was expected based on the theoretical framework. Additionally, while it should not be regarded as proof of the validity of the model, the simulation outcomes also match with what would be expected based on the recreative zoning map of the study area.

6.2. Main research question

After having answered the five sub-questions, the main research question will now be answered. The main research question of this thesis has been:

> *"How can agent-based behavioural modelling, based on the Consumat framework, provide insights into visitor conflicts in Dutch natural areas?"*

This thesis has provided insights into how an ABM can be used to simulate the spatiotemporal behaviour of visitors belonging to four activity types in natural areas, as well as to record physical encounters between visitors. Through this, insights can be gained into the occurrence of visitor conflicts, as it allows for the identification of crowded areas and areas where there is potential for visitor conflicts based on the occurrence of encounters between visitors taking part in different activities. By incorporating aspects of the Consumat framework into the behaviour of the visitor agent in the developed model, it has been grounded in an existing model of human decision-making, as argued for by Richetin et al. (2010). Most importantly, following this approach has allowed for the incorporation of the concepts of satisfaction and cognition. Furthermore, the framework has been translated into a new context, by replacing the concept of uncertainty with that of familiarity. This thesis has also shown how an ABM of visitor behaviour, such as the one presented in this study, can be used to gain further insights into the occurrence of visitor conflicts by performing a sensitivity analysis. Additionally, this thesis has shown how such a model can be used to develop and estimate the possible impacts of scenarios. Through expert interviews, it was determined that the results presented in this thesis can be regarded as plausible. With that, the goal of this thesis, which has been to develop an ABM that allows for the simulation and exploration of the behaviour of different visitor groups in natural areas, in order to gain insights into visitor conflicts, has been reached. It has also been identified, however, that in order to fulfil the potential that ABM has for visitor conflict management, the model that has been presented in this thesis would have to be developed further.

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6.3. Recommendations regarding the future of modelling visitor conflicts

Efforts to simulate the behaviour of visitors in natural areas have been undertaken since the 1970s in order to aid visitor management (Cole & Daniel, 2003; Lawson, 2006). Since then, the urgency of gaining a better understanding of visitor behaviour has only ever increased, as a result of an increasing recreative pressure in many natural areas, such as the Amerongen Forest in the Netherlands, the research area of this thesis. While zoning efforts can help prevent visitor conflicts to a certain extent, even in an area such as the Amerongen Forest, where dedicated infrastructure exists for the four activity types discussed in this thesis, visitor conflicts are still known to occur. With visitor numbers in this area being expected to double by 2030, visitor conflict management is becoming increasingly important, and with that, gaining insights into visitor behaviour and the occurrence of visitor conflicts. This thesis has shown how ABM, based on an existing model of human decision-making, i.e., Consumat, can provide plausible patterns which can provide insights into the occurrence of crowding and visitor conflicts in natural areas. Further developments of models such as the one presented in this thesis can help fulfil the potential that agent-based modelling has for visitor conflict management. Based on the study outlined in this thesis, and the discussion and conclusion specifically, the following recommendations regarding the modelling of visitor behaviour and conflicts using ABM, can be made:

- **Combine ABM with empirical research**

  One of the main limitations of the ABM that has been developed for this study, is that many assumptions had to be made about the behaviour of visitors in the research area, because of a lack of empirical data on this subject. Combining the development of an ABM with empirical research, could provide a way of dealing with this limitation. Information about visitor characteristics, visitor behaviour and a visitors' experiences with visitor conflicts can be gathered through surveys. GPS tracking or people-counting technology could provide further information about visitor behaviour. Information gathered from such studies could be used to better calibrate the model. Furthermore, it could also make it possible to statistically validate the model outcomes, providing insights into the reliability and accuracy of the model output. In turn, this would allow the model to be more reliably used for visitor management purposes, such as the exploration of the potential impacts of new zoning scenarios. When such information is monitored over a longer period of time, it would also become possible to compare scenario outcomes as suggested by the model with actual developments.

- **Explore the possibilities of including more detail in visitor characteristics**

  Future developments of the model presented in this thesis should focus on exploring what the possibilities are regarding including more depth in the way that the visitors are represented in the model. In the discussion, it has already been mentioned that the current division into four activity types is a simplification of reality, as there are also other activity types involved in visitor conflicts apart from the four that were included, and there also exist differences among the included activity types. Examples of such differences are the difference between conventional cyclists and cyclists with e-bikes, and between hikers, runners, and hikers with dogs. Another relevant visitor characteristics to include would be a visitors' mode of experience. Gathering additional empirical data, as argued for in the previous point, might provide the information that is required to increase the level of detail of visitor characteristics.

- **Explore the possibilities regarding a more complex implementation of satisfaction**

  Another area where the model presented in this thesis could be improved in, is the way that satisfaction is represented. Related to the two previous points, gathering additional data and gaining insights into how encounters with different visitor types are experienced by visitors could be valuable in this regard. By not only taking into account activity type, but also other visitor group characteristics such as mode of experience, group size, and speed, it would be possible to represent more factors that influence whether an encounter is experienced as a conflict or not in the model. Tolerance and expectations could also play a part in this. Furthermore, it has been discussed that visitors will visit areas with more needs than only to not want to encounter other visitors. Exploring the possibilities regarding modelling the attractiveness of paths and landmarks for different visitor types and including these factors in the cognitive maps of visitors, could allow for the implementation of a more multidimensional form of the concept of satisfaction.

- **Explore possibilities of modelling visitor behaviour on a regional scale**

Another potential direction for future developments would be to explore the possibilities of modelling visitor behaviour on a more regional scale. By modelling visitor behaviour on the scale of a region, e.g., the Utrechtse Heuvelrug, rather than a specific natural area such as the Amerongen Forest, it will become possible to more realistically represent visitor behaviour that takes place over a larger area. This would be especially relevant for simulating cycling behaviour. Furthermore, this might make it possible to also incorporate pre-trip decision-making, and to explore what the influence of changes in one natural area could be on recreational behaviour on a regional scale.

- **Include other impacts of visitor behaviour**

As mentioned in the Introduction, besides having an impact on visitor experiences, an increase in recreative pressure in natural areas can also have an impact on the quality of nature itself. The model developed for this thesis allows for the simulation of flows of visitor movement throughout natural areas, which could also provide insights into the potential effects of visitor behaviour on nature. As mentioned before, trail damage and pollution, for example, are identified by Wolf et al. (2018) as potential causes of visitor conflict, but could also have an impact on nature. Insights might be derived about potential impacts of visitor behaviour on these topics, using the flows of visitor movement already simulated in the current model.

- **Involve nature management organisations**

This thesis has provided an example of what the added value of involving experts from nature management organisation for the development of ABMs of visitor behaviour can be. They can provide insights that are valuable during different stages of the modelling process, such as calibration and validation. Involving experts from different organisations and with different expertise, allows for the inclusion of different professional viewpoints, which has proven to be valuable in this study. Especially in the Netherlands, where it is often the case that different organisations have an interest in the same area, due to ownership of natural areas being shared among different organisations, it is valuable to involve different organisations. It would be advisable to involve these organisations in an earlier stage than what has been done in this thesis, as they can provide additional information regarding the design of the environment and selection of relevant visitor characteristics. Especially if the goal is to develop an ABM that is to be used by these organisations, it is important to involve them throughout the process of developing the ABM, as this would allow for the incorporation of their needs, whether they be technical or financial, or related to the level of detailed they require in order to explore scenarios, in the process of developing the model.

- **Investigate zoning possibilities and exploring other means of dealing with visitor conflicts**

The results of the developed model suggest that encounters between visitors engaged in different activities occur near intersections and in areas where there is overlap between different activity-specific trails. Together with the results of the sensitivity analysis and the adjusted route network scenario, this indicates that zoning can be effective in dealing with visitor conflicts. Based on these findings, it would therefore be advisable to organisations involved in visitor management to investigate the possibilities regarding zoning in their areas. However, even in an area with highly separated infrastructures such as the Amerongen Forest, visitor conflicts are still known to occur. Therefore, it is important that other ways of dealing with visitor conflicts are also considered in visitor management. Educating visitors about the presence of other visitors is one such way suggested in literature (Carothers et al., 2001; Wolf et al., 2018). Crowding monitors, as discussed in the Introduction, provide an example of how geographical information can also play a role in that regard.

7. References

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