Geographical Information Management and Applications

An agent-based approach to the assessment of carrying capacity in Amsterdam

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Preface

This document, my thesis, is part of the Master's program Geographical Information Management and Applications (GIMA). It is titled 'An agent-based approach to the assessment of carrying capacity in Amsterdam'.

An important topic of this thesis is the concept that individuals carry around a protective zone in which others are not allowed: personal space. Personal space is a critical topic in the current situation regarding COVID-19 and the way we as a society are trying to overcome the seclusion that goes alongside it. A substantial part of this thesis was written during the COVID-19 outbreak in The Netherlands. I hope that everyone reading this is in good health.

Completing this study would not have been possible without the supervision of Arend Ligtenberg. I would like to thank you for your feedback and support. I would also like to thank my fellow students, which I have spent many hours with discussing each other's work. Thank you for the valuable coffee and lunch breaks.

I hope you enjoy reading this thesis.

Vince Doelman

Summary

Overcrowding in urban areas is increasingly becoming a problem. One of the causes is tourism and the adverse impact it has on destinations. In Amsterdam, tourism is reaching a state in which negativity towards it starts to occur. In this study, the concept of carrying capacity is under investigation. Carrying capacity in an urban context indicates a maximum level of visitors an area can sustain, before deterioration starts to occur. It is reached, when the demand for physical space has overgrown the supply of it. A term related to carrying capacity, is crowding. Crowding is a negative evaluation of visitor density and occurs when a high number of people gather together. As crowding is experienced on an individual level, but is the result of a congregation of people, agent-based simulation was used as method for assessing carrying capacity. It was assessed on street level, where people and their mutual interactions best resemble crowded situations. An agent-based model was developed for a segment of the Kalverstaat in Amsterdam, simulating pedestrians dynamics. A critical variable was used to assess whether the area was too crowded or not: personal space. Any situation where an individual's encounter with another one resulted in a higher demand of space, one's personal space was intruded. Indicators were assigned to the pedestrians to simulate pedestrian dynamics, such as the size of personal space, the number of others allowed in one's personal space, the time that one allows others inside one's personal space, the adjustment of people their walking speed as to empty out one's personal space, and the severity in which one circumnavigates around other pedestrians as to empty out one's personal space. Persisting intrusions of personal space by other pedestrians resulted in pedestrians deciding to leave the model area. This decision was based on a crowding norm. This crowding norm consisted of a general norm, multiplied by the moderating effect that age and ethnicity have on the perception of crowding. Pedestrians leaving the model area due to experienced crowding was used to assess the carrying capacity. The size of one's personal space and the number of others that are allowed in one's space have the most effect on the number of pedestrians that decide to exit the street due to crowding. A scenario was implemented to investigate whether the spatiotemporal characteristics of an area influence the carrying capacity. The busiest day of the year, the Saturday before Christmas, was simulated. Higher visitor numbers lead to a higher numbers of pedestrians deciding to exit the street. Another scenario was implemented to investigate the effect of the moderating variables age and ethnicity on the crowding norm and its subsequent effect on the carrying capacity. The use of moderating variables appears to have somewhat of an influence in the assessment of carrying capacity, but additional research is required.

Contents

1. Introduction

1.1 Background and context

For years now, cities have been attracting people. A global trend of moving towards cities has been occurring in the past century, and it does not seem to stagnate any time soon (Rees & Wackernagel, 1996; Buhaug & Urdal, 2013). This growth of cities' populations puts a serious pressure on society's ability to provide services to its inhabitants such as housing, health care and electricity. But cities are not only growing in terms of inhabitants. Visitor numbers are increasing as well, and urban tourism as a result of increasing leisure-expendable income has made its way into the cities (Spirou, 2003). Especially since the economic crisis of 2008, economic revival, cheap ways of travel and unique city branding fueled the phenomenon of urban tourism. Urban tourism has for some years been growing twice as fast as national tourism, due to strategic city marketing plans (Gerritsma & Vork, 2017). Amsterdam is estimating to host 17.4 million overnight stays in 2019, a number as high as the population of the entire Netherlands (Gemeente Amsterdam, 2019; NOS, 2019).

Tourism is considered an economic driver for cities, and local policy has been inviting towards tourism. Direct benefits come from tourists sleeping in hotels and making use of for tourist-designed services. Indirect benefits come from goods and services typically not designed for tourist use and also not exclusively used by them. It is these indirect benefits that add value to an urban economy making cities competitive (Bellini & Pasquinelli, 2017). There are, however, downsides related to tourism. First, the actual financial contribution of tourism is criticized because of a supposed inequality of the distribution of benefits (Lankford & Howard, 1994; Bellini & Pasquinelli, 2017). More directly visible negative impacts are related to nuisance caused by tourism. Mass tourism can result in an undesirable spatial concentration of tourists in popular destinations or areas. Congestion, as a result of this spatial concentration, can result in a reduction of visitors' enjoyment. Moreover, congestion has negative impacts on the area itself as well, in the sense of environmental or social deterioration (Riganti & Nijkamp, 2008).

Many of the cities that accommodate tourists are large places with a diverse and multifunctional character. Tourists can easily be absorbed in places like these. Additionally, (international) tourists are not the only users of the city. Inhabitants and domestic (day) visitors participate in the urban space use as well (Neuts & Vanneste, 2018). The various types of urban space users and growing numbers of urban visitors make some researchers think that there is *"a lack of agreeable evidence that current urban tourism development trends in fact contribute to creating more livable cities"* (Bellini & Pasquinelli, 2017, p. 55).

1.2 Problem statement

Neuts and Vanneste (2018) define 'crowding' as *"a negative assessment of visitor density, leading to stress."* (Neuts & Vanneste, 2018, p. 403). Overcrowding in cities is increasingly becoming a problem, and tourism is one of the causes (Gerritsma & Vork, 2017). Crowding, as a result of tourism, has led to 'overtourism' becoming a popular term. Both in scientific articles as well as mainstream media, overtourism has made its entrance (Koens, Postma & Papp, 2018; Trouw, 2019). It is a relatively new term, and it is built around a concept which has, for quite some years now, been a major part of the discussion on tourism and the adverse impact it has on destinations: carrying capacity (O'Reilly, 1986; Koens, Postma & Papp, 2018). Even though carrying capacity is an often used term, it also subject to scrutiny. First and foremost, due to the terms ambiguity. Different researchers have a different focal point when defining carrying capacity (McCool & Lime, 2001). A second critical note relates to it not being just a singular numerical constrain. While this is in some cases suggested, it is considered to be a dynamic concept that changes over time (Saveriades, 2000). Currently, the theory surrounding carrying capacity is vast, but there is no single approach on defining or assessing it. Moreover, what is considered adverse impact varies between different authors and approaches (Simon, Narangajavana & Margues, 2004).

Narrowing down to an urban scale, the city of Amsterdam is experiencing annual increases in visitor numbers (Gemeente Amsterdam, 2019). In Amsterdam, tourism is reaching a state in which negativity towards it starts to occur. Not only locals, but visitors too, feel that the city is too crowded (BOMA, 2016; Gerritsma & Vork, 2017). A proper assessment of where and when densities of visitors occur seems fitting for the current extent of the problem. A preliminary look at the available data reveals that visitor numbers are available for specific destinations or areas, but these numbers concern all types of visitors (foreign and national, overnight and day-trip) and are aggregated, sometimes covering the extent of a year (Gemeente Amsterdam, 2018). This seems unfit when assessing carrying capacity.

The dynamic and complex character of the concept makes it highly suitable for assessment by means of simulation. Additionally, as full data coverage of the issue is missing, determining tourist densities by computer simulation offers the possibility to model real world situations on a small scale in order to capture bigger emergent phenomenon that are otherwise not easily predictable (Macal, 2016). Defining carrying capacity into a tourism context and using it as a foundation for a simulation model will contribute to the assessment of tourism-induced crowding in two ways. First, densities of visitors can be deduced to determine possible situations of reached carrying capacity. Second, to create such a simulation, a formalization on the assessment of carrying capacity has to be established. Visitor densities can be captured best through microscopic modelling. Microscopic models are used to capture collective phenomena emerging from complex interactions between individuals. Especially when assessing the carrying capacity of a destination, emergent behaviour from individuals and their interaction with space is crucial.

1.3 Research objective and questions

The aim of this thesis is to develop a framework and a simulation model that provides insight into the effect visitors have on the carrying capacity in Amsterdam. In a tourism context, carrying capacity is related to crowding, and it is expected that different moments in time have a different effect on that crowding. This thesis has the following main objective:

To determine the carrying capacity at street level in Amsterdam by firstly defining carrying capacity and its indicators and secondly simulating the interactions of visitors in relation to the spatiotemporal characteristics of the research area.

To achieve the research objective, the following research questions are formulated:

RQ1: What is carrying capacity and what are its indicators?

RQ2: How can these indicators be formalized into a scheme applicable to agent-based modelling?

RQ3: What are the spatiotemporal characteristics of the case study area in relation to the carrying capacity indicators?

RQ4: How do the agents influence the carrying capacity of the case study area?

RQ5: To what extent is the model representative to simulate the carrying capacity of a destination according to pedestrian presence?

1.4 Scientific and societal relevance

This research will contribute to the scientific debate on how to define and assess the carrying capacity of a destination. Different definitions with different focal points, key assumptions and assessment methods have been developed over the years (McCool & Lime, 2001). This body of literature focuses too narrowly on static capacities of areas, while carrying capacity has a much broader, dynamic character (Shi, Wang & Yin, 2013). This study aims to add to this discussion by defining and conceptualizing the concept of carrying capacity for the Amsterdam urban area. Additionally, crowding and pedestrian movement has yet often been studied by means of simulation, and it has proven to be suitable method for determining group behaviour by having single agents interact with each other. This study adds to this research field by combining agent-based simulation on with tourism and crowding. Furthermore, this research will contribute to the societal debate whether there are actually too many visitors or not and if their presence exceeds a certain threshold after which negative impacts occur (De Volkskrant, 2018). The street level area which will be modelled in this research is the Kalverstraat in Amsterdam, which has been closed temporarily in 2013 due to extreme visitor numbers in the days before Christmas (AT5, 2017). Popular areas with a specific purpose (e.g. shopping) but with a limited confined space can be put under severe visitor stress, ultimately leading to loss in customer satisfaction and visitor enjoyment. People tend to leave a crowded area, or if crowding occurs over a longer period of time, areas get closed down with possible loss in revenue as a result. This study has societal relevance in creating insights for policy makers regarding (over)crowding of pedestrians with shopping and passage purposes in a shopping street.

1.5 Reading guide

This first chapter contained the introduction with the problem statement, research questions and relevance of the study. The second chapter will give a theoretical overview of carrying capacity and its related concepts, how to define indicators of assessing carrying capacity, the Social Force Model will be discussed, and the chapter will be concluded with a literature review on agent-based modelling. The third chapter contains this study’s methodology. Here, a formalization of the in the second chapter discussed indicators of assessing carrying capacity will take place. Moreover, the conceptual model and the implementation of the agent-based model will be explained. The fourth chapter contains the validation and verification stage of this study, where the model is investigated on its functioning. The fifth chapter contains the results of this study, which are derived by means of a sensitivity analysis. In the sixth chapter, 2 scenarios are explained, implemented and analyzed, in which the different spatiotemporal characteristics of the model area are under investigation as well as the moderating effect of the personal characteristics age and ethnicity. The seventh chapter concludes this study, and the eighth and final chapter discusses this study’s further research opportunities and impediments.

2. Literature study

This chapter will provide a review of the literature on the concepts of carrying capacity, crowding and agent-based modelling. Carrying capacity and crowding are no novel subject. Carrying capacity is used in various fields of study, ranging from ecology to spatial planning. Crowding has been under investigation quite extensively in outdoor settings, and pedestrian crowding appears to be very suitable to be investigated by means of simulation. Among the topics of this chapter are definitions of carrying capacity, how to assess it, crowding and an introduction to agent-based modelling. Section 2.1 starts with a general introduction of how modern urban tourism, followed by a review of the concept of carrying capacity and tourism carrying capacity (section 2.2). Hereafter, crowding and the assessment of crowding are under review (section 2.3 and 2.4). In section 2.5, the Social Force Model is explained, which is a critical model in understanding pedestrian movement. Section 2.6 touches upon the topic of agent-based modelling. Pedestrian dynamics in agent-based simulations, section 2.7, is the final topic of this literature study.

2.1 Urbanization and urban tourism

In the period after the second world war, the amount of people living in cities increased from 740 million to nearly 3 billion (Altvater, 2005). In the same time, cities deployed new economic development strategies, by investing in the urban infrastructure and the marketing of cities as places of entertainment. These strategies were fueled by the fact that citizens, for instance on holiday or visiting for business, had ever increasing amounts of leisure-expendable income than ever before. Local governments increased the investments on cultural services, to serve the needs of a more culturally diverse public demand (Spirou, 2003). These investments resulted in an economy of urban tourism, which in most recent years has been gaining immense popularity over national tourism (Spirou, 2003; Gerritsma & Vork, 2017). Local governments focused on highlighting the heritage of their city and cultural identity, hoping to gain revenue from the social and economic transformation. Globalization further fueled this focus, by enabling competitiveness between cities to attract both business and recreational visitors, forcing cities to adopt new strategies to appeal to these groups. Tourism, both national and urban, became a means of economic growth, resulting in a reorganization of the physical landscape of cities (Spirou, 2003).

Unlike its scientific embedding now, with over 1300 references on Scopus, the topic of urban tourism used to be considered fragmented, or not be seen as a distinctive field of study at all (Ashworth & Page, 2011). This is somewhat paradoxical, according to Ashworth and Page (2011). First, urban tourism is of global importance, but receives relatively little attention in scientific literature from both tourism scholars and city geography scholars. Despite its significance (it being a more popular form of tourism than national tourism), it remains an abstract concept lacking a clear definition (Ashworth & Page, 2011; Gerritsma & Vork, 2017). Second, while there are multiple reasons for a tourist to visit a city, tourists are to a large extent invisible. The cities that accommodate most tourist are large multifunctional entities into which tourists can effortlessly absorb, thus becoming economically and physically indistinguishable from local communities. Third, to build on the second paradox, tourists make extensive use of cities' facilities while these facilities have generally not been designed for tourist use. Fourth, tourism can generate serious economic welfare, but the cities whose economies rely most upon tourism generally benefit the least and vice versa. Fifth, the relationship between tourist and city is not mutual, which has many implications for policy-makers. The tourism industry needs the multifunctional character of the city, whereas the city not necessarily needs tourism (Ashworth & Page, 2011, pp. 1-2). As cities are increasingly under pressure, the question of what cities can absorb before negative impacts take over arises. This is called carrying capacity.

2.2 Carrying capacity

Carrying capacity originates from the field of ecology, and it is influenced by Malthus' theory of population growth and the limiting factors of the environment on the human progression (Seidl & Tisdell, 1999). The environment's resource base, upon which all (economic) activity is based, includes ecological systems that take care of a variety of services. This resource base is not unlimited, and careless use of this resource system can have an irreversible effect on the capacity of the system (Goss-Custard et al., 2002). This is frequently denoted by the term carrying capacity (Arrow et al., 1995; Goss-Custard et al., 2001). The term indicates the amount of demand, for instance hungry birds, that can be supported by a certain supply, for instance food. From its use in ecology, the concept made its way to other fields of study (Saveriades, 2000; Simon, Narangajavana & Margues, 2004; Oh et al., 2005). In urban planning, carrying capacity is usually defined as the ability of a (natural or artificial) system to absorb population growth or physical development without structural damage (Oh et al., 2005). Likewise, there is an interpretation of carrying capacity for tourism. Carrying capacity relating to tourism (i.e. tourism carrying capacity) generally focusses on the largest number of tourists a destination can fit, based on the maximum use of the available land (Marsiglio, 2017). A numerical maximum is derived in relation to what the investigated space or land can offer. Critical notes to this definition is that it lacks factors influencing visitor flows, such as environmental and cultural factors of a destination. Additionally, the concept of tourism carrying capacity is generally interpreted in relation to the quality of the experience. Here, the carrying capacity concept is supplemented with the idea that a destination can fit a maximum amount of visitors before the quality of the experience starts to decline (Hovinen, 2002; Marsiglio, 2017). Saveriades (2000) further elaborates on the definition of tourism carrying capacity by summarizing multiple definitions. All definitions relating to carrying capacity treat two major components. First, there is the issue of the bio-physical component, relating to the integrity of the resource-base which implies a tipping point after which the ecosystem in use will experience deterioration because of over-exploitation. Second, there is a behavioural component, relating to the quality of the recreational experience (Saveriades, 2000).

Despite multiple endeavors of defining carrying capacity within a tourism context and expressing it in numbers of visitors, certainty about the coverage of the definitions and assessment methods remains difficult. When taking into account that at some point tourist experiences start to deteriorate, what are than the experiences provided at the scale for which the carrying capacity is assessed? What value system is used when measuring carrying capacity? According to McCool and Lime (2001), these questions are of crucial importance when investigating carrying capacity, but these questions are generally ignored in literature studies (McCool & Lime, 2001). Within these questions, McCool and Lime (2001) imply that carrying capacity is inherently bound to the function of the location that is under investigation, and they criticize most studies on carrying capacity by arguing that too many attempts focus on just a numerical limitation. McIntyre (1993) defines carrying capacity as the maximum use of a destination without causing negative effects on resources, resulting in lost visitor satisfaction. Inskeep (1991) defines carrying capacity as maintaining a level of development that will not lead to environmental or cultural deterioration. Pigram and Wahab (2005) put their focus for carrying capacity on the maximum use of any place without causing negative effects to this place. However, tourist destinations are no static environments with even amounts of visitors at all times. Destinations are subject to selective visitor behaviour, as seasonal influences play a major role in tourism (Chung 2009; Koens, Postma & Papp, 2018). Moreover, as tourists move between sights, monuments, museums and other attractions related to their trip (Kádár, 2014), they inevitably have to deal with clusters of other visitors. Emphasis should be placed on the social and spatial conditions at a destination, allowing for a more dynamic definition of carrying capacity. This is of importance when assessing it, but it is hardly ever addressed (McCool & Lime, 2001; Wei et al., 2015).

Regarding tourism carrying capacity, Cocccossis and Mexa (2017) argue that the carrying capacity of touristic areas has been under investigation as long as there are concerns on the impacts of tourism. There should be limits on touristic development, but carrying capacity can be interpreted and utilized in many ways. For larger geographical areas, such as island, settlements, towns or regions, the concept is interpreted in a more economic sense, relating to touristic development such as (the number of) hotels versus (the number of) leisure activities. For smaller geographical areas, the concept is interpreted in terms of crowding (Coccossis & Mexa, 2017). As is becoming clear, the various ways carrying capacity is defined, relate to the sector and size of the area for which it is measured. When measuring it, an environmental aspect indicating the infrastructure needs to be taken into account as well as a social aspect, indicating visitor enjoyment and host tolerance (McCool & Lime, 2001; Zehrer & Raich, 2016; Coccossis & Mexa, 2017).

2.3 Crowding

Generally, tourist cities tend to have similar tourist-related problems. However, tourist destinations that have been on the radar for a longer time, also called mature destinations, more frequently witness negative impacts caused by tourism. These issues are usually characterized by overcrowding or congestion (Riganti & Nijkamp, 2008). Crowding becomes a serious problem when negative externalities related to the urban quality occur (Neuts & Vanneste, 2017). Crowding is defined as *"a negative assessment of visitor density, leading to stress"* (Neuts & Vanneste, 2018, p. 403). With this definition, a distinction is made between density, as a physical limitation of space, and stress, as a perception of this density. Crowding is a complex concept, because crowding phenomena are related to other societal issues, making it often difficult to separate perception elements from physical spatial limitations. Variables relating to the spatial limitation of space as well as the effect crowding has on human behaviour vary at each spatial level (Stokols, 1972). Crowding is generally associated with situations where an individual perceives that the carrying capacity of an area is exceeded, resulting in some form of displeasure (Neuts, Nijkamp & Van Leeuwen, 2012). Density deals with a numerical constraint, where a physical situation is expressed in terms of persons per available land area (Steffen & Seyfried, 2010).

As travel intensity will continue to increase, and more people will be able to travel, trip sizes are expected to become shorter and more frequent. More pressure will consequently be put on destinations. This pressure won't be new, especially not in mature tourist destinations, but concentration and congestion of visitors is likely to increase (Coccossis & Mexa, 2017). With increased spatial crowding, people are likely to feel limited in their freedom of movement, which can be considered an inability to people's personal space (Song & Noone, 2017). This limitation in the freedom of movement is likely to provoke feelings of discomfort and stress. People feeling stress are likely to respond to that stress by applying coping mechanism appropriate to their behaviour. It is generally thought that there are two coping mechanisms. In the first strategy, an individual decides to remain within its crowded surroundings, trying to reduce stress by basically ignoring what is going on and trying to stay calm and positive. In the second strategy, the opposite occurs and an individual feels the urge to leave the environment as soon as possible, by doing so eliminating the feeling of stress (Song & Noone, 2017). Peoples' behavioural responses to the presence of others can be theoretically underpinned by the Social Force Model. This model, which will be explained more in depth in paragraph 2.5, assumes that pedestrians are, while in motion, subject to certain forces. These forces drive individuals to move in a certain direction, constantly evaluating the situation in which they are involved. The perception of crowding is thus an evaluation based on the presence of others (Schmidt & Keating, 1979; Helbing & Molnar, 1995; Neuts & Vanneste, 2018).

2.4 Crowding assessment

Crowding issues arise when large groups of people gather together (Zehrer & Raich, 2016). When these groups of people encounter each other, different expectations are involved. Usually, these expectations do not align, as individuals have different motives for visiting an area (Vaske & Shelby, 2008; Coccossis & Mexa, 2017). Moreover, people do not feel the same when encountering others. There are tolerances involved, which vary between different groups of people (Neuts & Nijkamp, 2012). According to Neuts & Nijkamp (2012), these variations in tolerances and norms among groups of people should be taken into account when investigating visitor density. A critical variable which has been used to link the amount of people in an area to an assessment of people perceiving an area as (too) busy or not, is personal space.

personal space

The section on carrying capacity elaborates on the principle that when carrying capacity is exceeded, the demand for space has overgrown the supply of it. Within crowding phenomena, this translates to any situation where an individual's encounter with another one results in a higher demand of space. The situation can then be marked as crowded (Stokols et al., 1973). An individual's demand for more space can be expressed in terms of personal space. Personal space is defined as a small, protective zone around an individual, that acts as a barrier between them and others. When someone else intrudes this space, a person may react negatively towards the situation. Feelings of fear and anxiety may occur. Bigger groups of people (i.e. crowds) can trigger feelings of anxiety, lost sense of control of a situation, reduced pleasure and other responses aimed at avoiding the situation (Jacobsen et al., 2019).

Von Sivers and Köster (2015) further investigated the concept of personal space. They argue that personal space is the distance one keeps from the other, to feel comfortable. This distance is, as originally investigated by Hall (1966), measured in centimeters in a circle around an individual. What is considered comfortable, usually varies between 45 and 120 cm and is highly dependent however on demographic factors (Stokols et al., 1973; Chattaraj, Seyfried & Chakroborty, 2009). According to the research done by Hall (1966), people crave certain spaces. There are four zones carried around by individuals: the intimate zone, personal zone, social zone and public space (Von Sivers & Köster, 2015). The intimate zone defines the first 45 centimeters, and it is the space in which it is nearly unavoidable to fence off bodily contact. In this area, human odor and heat are distinguishable, and it is considered an area reserved for sexual partners and children that need care or protection. The second zone is the personal space, which ranges from 45 to 120 centimeter. In this space, family and friends are accepted, and it is the minimal individual distance that is kept between a person and a stranger. It literally enables a person to keep someone *at arm's length* (Von Sivers & Köster, 2015). The social zone and the public space, respectively ranging from 120 to 360 centimeters and more than 360 centimeters, don't directly influence pedestrian dynamics, and are thus of lesser importance when assessing crowded situations (Von Sivers & Köster, 2015). Figure 2.1 (left panel) shows the distances someone carries around. One's intrusion of someone other's personal space may dispose someone with feeling crowded (Stokols et al., 1973). The right panel of figure 2.1 differentiates between close and far phases in a person's zone, indicating that even within 'one zone', people can experience different feelings. As mentioned, keeping one at arm's length is a desirable range for someone to experience freedom of movement (i.e. no intrusion of personal space), but this is considered the far phase of one's personal space. Considering the close phase, people have 'elbow room', indicating a different feeling towards others while it's part of the same personal space zone (Von Sivers & Köster, 2015).

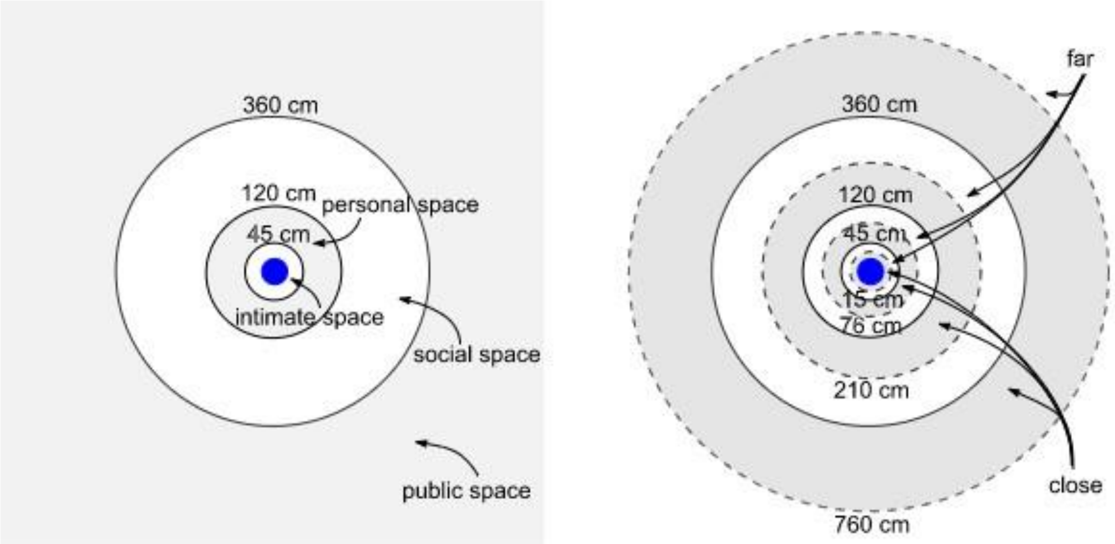


Figure 2.1: Zones of personal space (Von Sivers & Köster, 2015)

Walking space
As most cities that accommodate tourism offer their experience to tourism on foot, a walkability characteristic is a suitable indicator for measuring tourism carrying capacity (Ujang & Muslim, 2014). A place is considered walkable when the built environment supports and encourages walking, walking comfort and safety is provided, destinations are connected, and destinations can be reached within a reasonable amount of time (Southworth, 2005; Ujang & Muslim, 2014). In high density urban conditions, the idea of maintaining one's personal space can prove to be difficult, such as walking in high-density streets. Intrusions of personal space by strangers can lead to feelings of discomfort, but keeping one's social distance (i.e. the preferred distance between individuals) is dependent on the total amount of space that is available (Engelniederhammer, Papastefanou & Xiang, 2019).

Individual factors on perceived crowding
Yet briefly touched upon in the beginning of this section, individuals evaluate high-density situations or crowds differently. When assessing carrying capacity, these differences should be taken into account. Generally, the differences are expressed in terms of moderating effects of an individual's perception of crowding. Perceived crowding is an expression of an individual's judgement, and individual differences have a moderating effect on this (Kuentzel & Heberlein, 2003). Different moderating effects have been linked to the perception of crowding and appear to be context specific. Crowding in retail settings is often assessed with moderators like hedonic or utilitarian shopping, base level of emotion of customers and store layout (Eroglu, Machleit & Barr, 2005). There are more general moderators for the assessment of outdoor tourist pedestrian crowding too. These moderators are, perhaps obviously, age, gender and cultural background, although the relationship between gender and perceived crowding has been questioned (Jacobsen et al., 2019). Age, however, has been found to influence visitor perceptions of crowding. Older people tend to be less negatively impacted by crowded spaces than younger visitors. (Zehrer & Raich, 2016). Younger people's perception of personal space is thus different than that of older people. Cultural background is found to be of influence on perceived crowding too. Different studies show that people with a Western background (i.e. Northern America and Europe) have a different level of tolerance towards crowding than people with a non-Western background (i.e. the Middle East and Asia). People with a non-Western background appear to have a higher level of tolerance, due to all kinds of cultural traits (Pons, Laroche & Mourali, 2006; Chattaraj, Seyfried & Chakroborty, 2009). Another factor that influences the tolerance levels of visitors

on crowding, is whether they are a first-time visitor or not. Repeat visitors perceive crowding differently in contrast to fist-time visitors since they know what to expect (Zehrer & Raich, 2016).

Crowding norms
All individuals have standards regarding acceptable behaviour in a specific context. These standards are defined as norms (Vaske & Donnelly, 2002). Individuals have standards which they use for evaluating environments and activities, and they allow them to assess a certain situation as good or bad, better or worse. A standard can be expressed in terms of norms, and these norms are used by people to define how to behave and what to think of certain situations. Norms have often been used to understand encounters between people, and it was assumed that perceived crowding was an expression of an individual's judgement on shared norms about keeping an 'appropriate' distance at a given time and place (Vaske & Donnelly, 2002; Kuentzel & Heberlein, 2003). In addition, this norm is influenced by individuals' preferences, such as the previously described individual factors on perceived crowding (Kuentzel & Heberlein, 2003).

2.5 Social Force Model

Next to individual's norms and perception of a crowded situation, there's the actual behaviour of reacting to it. Human behaviour in normal situations is not considered regular or predictable, but rather chaotic or irregular (Helbing & Molnar, 1995). Often, behavioural changes are influenced by social forces and interactions between individuals. The Social Force model describes crowd behaviour as a state of crowd interactions (Helbing & Molnar, 1995; Mehran, Oyama & Shah, 2009). According to the social force model, a sensory stimulus causes a behavioural reaction that depends on the personal aim of the pedestrian in question. Normally, this aim is to reach a specific destination as comfortable as possible. In terms of pedestrian crowding, this would relate to a situation where no intrusions of personal space occur (Hall, 1966; Helbing & Molnar, 1995). This route would normally be the shortest route possible. But in walking towards one's destination, there is the possibility of encountering others. The way pedestrians interact with each other can be translated into an equation of motion. According to this equation of motion, the changes a single pedestrian makes in his or her behaviour is described by quantity of the behaviours of others, which can be interpreted as social force (Helbing & Molnar, 1995). The social force represents the effect of the environment on the specific pedestrian. The environment can usually be described as other pedestrians or borders; such as walls or other physical restrictions. The social force that is felt by the pedestrian expresses itself in a motivation to accelerate or decelerate when encountering these external forces (Helbing & Molnar, 1995).

Through the Social Force Model, a pedestrian is pulled towards a destination while simultaneously being pushed away from the things that are exercising force on the pedestrian. Figure 2.2 depicts the trajectory of 2 pedestrians and show a predicted collision according to their trajectories. In, what is called by Sakuma, Mukai and Kuriyama (2005) the critical zone, pedestrians take direct action to avoid collision. This avoidance by pedestrians is an expression of the Social Force Model (Helbing & Molnar, 1995; Sakuma, Mukai & Kuriyama, 2005).

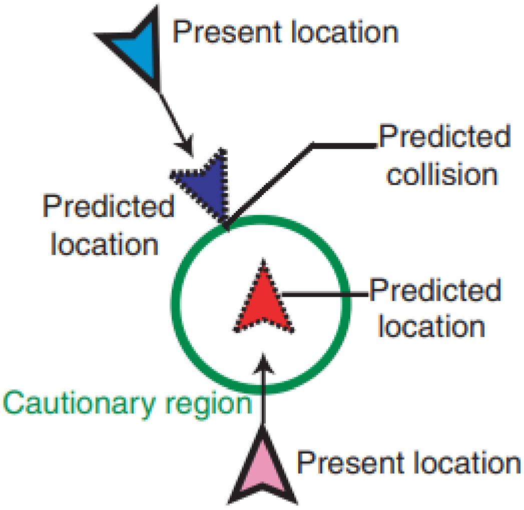


Figure 2.2: Pedestrians' trajectory and predicted collision zone (Sakuma, Mukai & Kuriyama, 2005)

When a future collision is detected by the individual, an optimum avoidance response is determined out of a few possible options. Smooth avoidance is implemented by an individual by gradually steering to the side, when there is enough time to react. The direction in which to gradually move away is determined by the positional relation among the agents, meaning they will steer to the way which they were already heading. This is illustrated in the left pane of figure 2.3 (Sakuma, Mukai & Kuriyama, 2005). In the right pane of figure 2.3, urgent avoidance is illustrated. When another individual is entering one's critical region (e.g. personal space), the individual has to pick a strategy that will rapidly lead to an increase in his or hers personal space. This is decelerating when following a preceding pedestrian, or stepping aside when encountering another pedestrian (Sakuma, Mukai & Kuriyama, 2005). The objective of any of the strategies is to ensure no intrusions of someone's personal space.

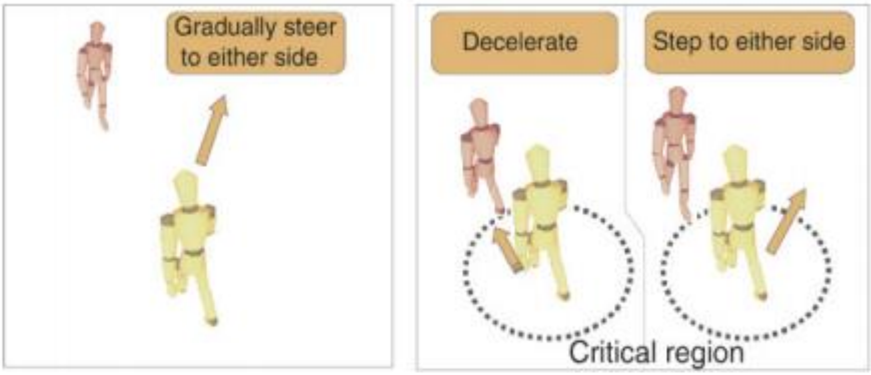


Figure 2.3: Smooth and urgent avoidance strategies (Sakuma, Mukai & Kuriyama, 2005)

2.6 Agent-based modelling

Simulation has often been used as a method of efficiently controlling groups of simple, individual creatures (Sakuma, Mukai & Kuriyama, 2005). Agent-based modelling (ABM) or agent-based simulation is a support tool to capture movement patterns and emergence. Through agent-based modelling, a system is modelled as a collection of autonomous decision-making entities called agents. Each agent individually assesses its situation and makes decisions on the basis of a set of rules. Agents may execute various behaviours appropriate for the system they represent (Bonabeau, 2002, p. 7280; Antonini, Bierlaire & Weber, 2004; Lau & McKercher, 2006). A feature of agent-based modelling is repetitive interactions between agents possibly leading to behavioural dynamics which cannot be captured with traditional methods. An agent-based model can even in its simplest form provide valuable information about real world dynamics by allowing agent interactions and the possible resulting unanticipated behaviour. There are three general benefits as to why an ABM should be used. It firstly, captures emergent phenomena from interaction between individuals (Bonabeau, 2002). The idea here is that the whole is more than the sum of its parts. Emergent phenomena can have properties that cannot be traced back to the properties of an individual entity. The power of the agent-based model, is that in a model, one simulates the behaviour of the system's individual units and interactions, looking for emergent phenomena from the bottom up when the individual units (i.e. the agents) are interacting with each other (Bonabeau, 2002). Secondly, an agent-based model provides a natural description of a system. When looking into a system that's made up out of behavioural entities, an agent-based model is a suitable system to ensure the model stays close to reality. When investigating how people move through a specific area, an agent-based model will be a better method than analyzing statistical data on aggregated walking data (Bonabeau, 2002). Thirdly, is it flexible. More agents can for instance easily be added to the model, possibly leading to different emerging phenomena. Also within the agents, different levels of complexity can easily be added or removed, and often when implementing an agent-based model, these options appear to be a necessary feature (Bonabeau, 2002).

In the field of geography, systems are characterized by continuous change through time and space. Individuals interact with each other and with the environment, and these interactions can have an impact on multiple spatial and temporal scales (Crooks & Heppenstall, 2012). To understand geographical problems such as sprawl and congestion, simulating individual decision making processes became a viable approach for capturing the answers to these problems (Bonabeau, 2002; Crooks & Heppenstall, 2012). As crowding can be defined as something that is experienced by individuals, it is highly suitable to investigate by means of simulation. An individual agent carries zones of intimate and personal space around, and the interaction between pedestrians and between pedestrian and environment can determine the overall perceived crowding on a higher scale, indicating whether tourism carrying capacity is reached or not (Kerridge, Hine & Wigan, 2001; Von Sivers & Köster, 2015).

2.7 Pedestrian dynamics in agent-based modelling

The previously mentioned Social Force Model and concepts such as crowding norms and individual moderators can all easily be implemented into an agent-based model. Such models shows full potential in contexts of pedestrian environment, because of the collective behaviour that can emerge from local movements. These movements do not only apply to closed spaces such as stores or railway stations, but agent-based models can be implemented in any spatial context (Pluchino et al., 2013). There is a broader mechanism responsible for applying the Social Force Model by individual agents. These are the cognitive abilities of agents (Turner & Penn, 2002). Abilities to detect obstacles and react accordingly, apply some sort of field of vision, is among the things mentioned by authors in the segments 'conclusion and future work' (Turner & Penn, 2002; Koh & Zhou, 2011). Additionally, not only obstacles should be in the cognitive spectrum of agents. Also elements such as knowing and noticing that there is an entrance or exit to go to when this is desired, and plan a new route towards that entrance or exit, should not be left out when modelling pedestrian dynamics through agent-based modelling (Turner & Penn, 2002).

3. Methods

3.1 General approach

This chapter described the developing phase of the simulation model. The literature review performed in the previous chapter, focusing on crowding, the assessment of crowding and pedestrian dynamics in an agent-based simulation were taken as input for this model, in order to determine the effect of pedestrian visitors on the street level carrying capacity in an Amsterdam shopping street. First, the general outline of the methodology chapter is described in figure 3.1. Section 3.2 gives a brief summary of the key findings from the literature chapter. In section 3.3, the conceptual model of this study is described, elaborating on model assumptions and the formalization of indicators derived from literature. Section 3.4 discusses the model implementation.

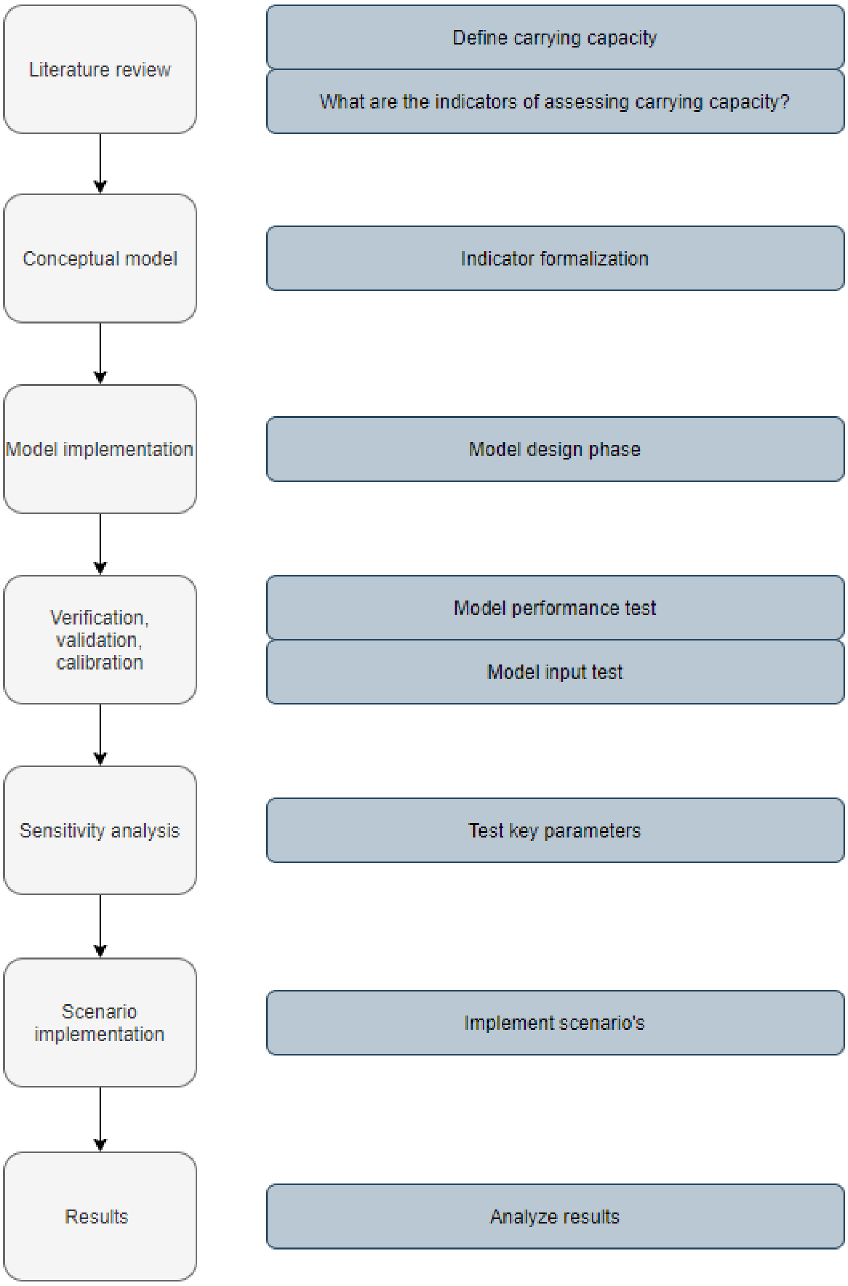


Figure 3.1: General outline of the research

3.2 Conclusion from literature study

Many contributions have been made to add to the definition of carrying capacity, in different fields of study. A common focus of the various definitions, was the focus on a supply and demand of a natural resource. Carrying capacity is reached when the demand for something has overtaken the supply it. A crucial part of carrying capacity in tourism context, is that it firstly relates to the maximum number of tourists a destination can have before irreversible damage occurs. Secondly, it relates to the amount of visitors an area can sustain before tourist experiences start to deteriorate. An important distinction here is made between **visitor numbers** and **deterioration of experience**.

Determinants on which to assess carrying capacity are both vaguely defined as well as highly dependent on the area for which they are assessed. It was therefore crucial to limit the determinants of carrying capacity in this study. In this research, emphasis was put on crowding and crowding-related behaviour. Crowding is a way of assessing carrying capacity when investigating smaller regions, and crowding is something that is perceived by individuals. The collective behaviour of different individuals perceiving crowding can result in emerging phenomena, making agent-based modelling a suitable method of assessing carrying capacity. Additionally, situations are labelled as crowded if one is limited in fulfilling their objective due to physical constraints imposed by other people present and obstacles. For this study, both the **physical obstacles**, i.e. the street and other pedestrians, and carrying capacity in terms of fulfilling one's objective and **achieving one's objective**, are determinants on which carrying capacity was assessed. Other determinants as mentioned in literature will be not taken into account, such as environmental and resource degradation.

Throughout the literature review, it became apparent that in the concept of crowding, there is a distinction between capacity as a number and capacity as a perception. Crowding is measured in terms of **physical density**, as a derivative from the maximum number, and **social density**, as a derivative of the perception of experience. The physical density is expressed in terms of the size of one's personal space and the freedom of movement that related to the size of this space. This social density is measured in terms of intrusions of this space, and the negative feelings that go alongside these intrusions. Additionally, when investigating carrying capacity, the scale on which the investigation is performed is critical when determining variables to assess it. As mentioned in the literature, for large scale research, it is usually measured in terms of hotel stays relative to the leisure experiences offered. For smaller geographic areas, it is assessed in terms of crowding. In this research, physical density and social density are the variables which are assessed in the agent-based model.

Intrusions of personal space is by some met with feelings of fear and anger, while others tend to ignore it and focus on the positive. People who considered crowded situations as bothersome will were offered the choice to **leave the area** while others **decided to stay**. This choice was influenced by a base level of tolerance of every pedestrian, also known as a crowding norm. This norm was then influenced by the moderating effects of age and ethnicity, expressed in terms of a multiplier. Age and ethnicity allowed variation in individual's personal norms.

Pedestrian dynamics that are modelled in microscopic environments can be simulated by means of the **social force.** This behavioural method lets pedestrians react to outside forces such as other pedestrians or physical obstacles by adjusting walking speed and direction, which are known as **avoidance strategies**. Social forces act as **push and pull factors**. Pedestrians are pulled to their destination (e.g. a store or the other side of the street), while being pushed away from obstacles (e.g. physical obstacles and other pedestrians).

3.3 Conceptual model

The purpose of the simulation model was to assess street level carrying capacity, by investigating if a street can be marked as crowded. The crowding of the area depends on whether the personal spaces of the visitors of the area were intruded or not, and if the visitors could have achieved their objective.

3.3.1 Model assumptions

For the modelling phase of this study, model assumptions were derived from the theoretical framework. With the conclusions from the literature study in mind (section 3.2), the following assumptions were made:

- Obstacles will lead crowding. Obstacles are of physical nature, such as small corridors, stores or other people
- Pedestrians do not enter each other's personal space unless necessary, and agents apply social force when walking
- Pedestrians have a walking speed within a general range and walking speed-related influences such as age or general individual mobility are not taken into account.
- Pedestrians either perform shopping activities or use the street for passage and agents perform one objective at a time. If an objective is achieved, a new objective can be given to the agent.
- Crowding is the result of objectives being unable to be achieved, due to others walking in the way.
- Pedestrians generally use the right side of the street for walking, meaning that there is a natural dynamic in network situations where people stick to 'their side of the road' without causing extreme chaos. Unless their current objective is elsewhere located in the model area, agents stick to the right side of the street.

3.3.2 Study area

The model area is designed after a part of the Kalverstraat in Amsterdam. Figure 3.2 shows the Kalverstraat in its topographic context. This street allows pedestrian dynamics to be modelled realistically, as no other road users are allowed in this area. Additionally, the Kalverstraat offers 'walking through the city' and 'shopping', which are among the most undertaken tourist activities. The Kalverstraat is also mentioned most often for leisure shopping while simultaneously being among the lowest ranked for leisure shopping (BOMA, 2016; Gemeente Amsterdam, 2019). Spatial characteristics of the network will be explained later in this chapter. Figure 3.3 shows the model network and the area in the Kalverstraat after which it is modelled.

Figure 3.2: The Kalverstraat in its topographic context

Figure 3.3: The model network (left) and a segment of the Kalverstraat (right)

3.3.3 Agents, behaviour and environment

Agents

In this model, the agents represent individual pedestrians. Just like the model area, the model population is designed after the Amsterdam tourist population. The research published by the Amsterdam Marketing Bureau acts as input source for the model population, as this research contains tourist information of the Amsterdam urban region (BOMA, 2016). Age and ethnicity were moderating variables for the perception of crowding, so the distribution of age and ethnicity among the Amsterdam urban tourists were derived from this document. Neuts & Nijkamp (2012) state that crowding is experienced by many people, but not everyone considers it to be a negative feeling. Their study found that in that front country (i.e. urban areas) crowding was experienced negatively by 18.3% of the respondents (Neuts & Nijkamp, 2012). Other participants of this study claimed to be neutral about the experienced crowding of the area, or value it positively. As crowding is experienced by everyone, but valued differently among people, every agent starts with the same individual norm for evaluating a crowded situation as negative. This general norm is subject to the moderating effects of age and ethnicity which acted as multipliers on the general norm. The resulting norm, containing individual preferences, was then plotted into normal distribution. This ensured variance among agents in evaluating crowded situations as negative, reflecting the subjective nature of perceived crowding. This general norm is 0.183, as derived from Neuts and Nijkamp (2012). Table 3.1 gives an overview of all agents' variables, a description of these variables, what value is assigned to these variables in order to formalize the variable, and the source from which this variable is derived.

Table 3.1: Agent variables, description, value and source

Variable	Description	Value	Source
Crowding norm	Probability of evaluating a crowded situation as negative	Mean 0.183	Neuts & Nijkamp, 2012
Personal space	An area surrounding a person of 1.20 meter denoting someone's personal space	1.20 meter	Hall (1966)
Walking speed	Velocity assigned to the agent	Random between 0.85 and 1.35 m/s	Gehl and Svarre, 2013
Adjusted walking speed	Velocity when an instance of a personal space intrusion is encountered	0.5 m/s deducted from the walking speed	
Pedestrian travel time	Total time the agent was active in the model	Calculated in the model	
Agents nearby	Number of other agents that are within the 1.20-meter range of the agent	0 (changes when interaction between agents occurs)	
Personal space saturation	The number of people that are allowed in one's personal space	1	
Intrusion time	Total time the personal space of the agent is intruded, in seconds	0 (changes when interaction between agents occurs)	
Is intruded	Boolean variable determining whether an agent considers its personal space to be intruded – requested after the continuous intrusion time passed a threshold value	Yes / no (determined by agent interaction)	
Wants to leave	Boolean variable determining whether an agent wants to leave the street – requested when the Is Intruded variable returns 'yes'	Yes / no (determined by agent interaction)	
Window-shopping	Boolean variable determining whether the objective of the agent	Yes / no	

	is to visit a store or to walk towards the end of the street	

Another attribute is walking speed and adjusted walking speed. Different studies have been performed in order to determine walking speed. Not surprisingly, different results were found, and differences in these walking speeds are due to walking preferences or other (limiting) mobility factors. In this study, a walking speed is assigned randomly to every agent, ranging from 0.85 to 1.35 meters per second. As agents do not want their personal space to be intruded, an adjusted walking speed is assigned as well. This adjusted speed is a deduction of 0.5 meters per second from their original walking speed. The resulting decrease in pace offered the agents the option to let the agent in front of him/her walk out. The total duration of the agent on the network is expressed in the pedestrian travel time.

Agents' adjusting their walking speed is the first avoidance strategy when another agent is too close by. This is noticed by agents in the variable 'agents nearby' (table 3.1), which is by default zero when there are no intrusions of personal space. For every agent that is too close, this number will increase with 1. From the personal space zones surrounding a person as described by Hall (1966), the personal zone, indicating the 1.20-meter buffer zone, will be used for determining the size of personal space. In this zone, relatives and friends are allowed, but strangers are kept at this distance. On the verge of the 1.20-meter buffer zone, strangers can be kept 'at arm's length'. Inside this personal space zone, a person still has 'elbow room' to move around (von Sivers & Köster, 2015). The described distances are, however, depicted as concentric zones surrounding individuals. As an indicative measure for personal space, this seems sufficient. However, in order to actively evaluate a crowded situation, an individual, with its cognitive senses, must notice the intruder (Duives et al., 2015). For that reason, the concept of viewing distance is added to the personal space zones. Agents that are in close proximity but not inside an individual's field of view are not taken into account when evaluating a crowded situation. An agents' field of view comprises of an angle (field of view) intersected by the circle of the personal space zone. The angle for an agents' field of view is set at plus and minus 45 degrees from the front of the agent, given every agent a total viewing angle of 90 degrees (Duives et al., 2015). An overview of these setting can be found in table 3.2. An addition to investigating intrusions of personal space is by checking how many people are allowed in one's space, and what the effect is on the carrying capacity. This variable is called PS Saturation, indicating the saturation point of one's personal space, and is by default 1. In reality, however, crowded situations can occur with more than 1 other person inside one's space. By increasing the threshold number of other people inside one's personal space, thus increasing the tolerance for crowding, different experiments can be performed.

The amount of time that an agents' space is intruded is counted in seconds. This is stored in the variable intrusion time. By default, intrusion time is zero, and this variable counts up for every second of personal space intrusions. After 10 seconds, the agent feels intruded, but this does not yet have any implications. The crowding norm determines how the agent evaluates the situation. The norm is interpreted as a probability of staying in the street or leaving by taking the nearest exit. The threshold value for intrusion time has not yet been properly studied in scientific literature. This value is taken as an estimate, in relation to the total length of the network, which is 100 meters in length. 10 seconds resembles approximately 10% of walking time through the model area (considering extra meters to avoid other pedestrians), which is assumed a sufficient amount of time to experience a crowded situation and to evaluate this situation.

As pedestrian behaviour in a shopping street is investigated, some of the agents are given the objective to window-shop. The Boolean variable window-shopping is assigned to each agent. For 75% of the agents, this value is true, meaning that these agents are partaking in window-shopping. For the other

25%, this value is false, meaning that these agents are not partaking in window-shopping and they use the street solely for passage.

Table 3.2: Variables and settings for determining agents' vision

Variable	Description	Value	Source
Personal space	Zone around an individual describing personal space, indicating who is allowed inside the zone (partner, children, close friends) and who not (strangers, distant friends)	1.20 meters	Hall (1966) Popp (2012)
Viewing angle	Angle in degrees indicating the field of vision that is captured by the human eye.	-45 degrees, +45 degrees	Duives et al., 2015, GAMA, 2020.

Age and ethnicity have a significant effect on the perception of crowding and personal space (Chattaraj, Seyfried & Chakroborty, 2009; Jacobsen et al., 2019). These two parameters are therefore considered main moderators in their effect on the individual crowding norm of agents. According to (Zehrer & Raich, 2016), older people are generally less influenced by negative crowding experiences than younger people. Younger people tend to have a higher need for physical space. As described by the Amsterdam Marketing Bureau, the average age of visitors is 38 (BOMA, 2016). Different age categories were investigated, but the age groups closest to the average age borders at 40. In this study, age is categorized in two groups, above 40 and below 40. As this study models after the Amsterdam urban area, 61% of the agents are placed in the below 40 category and 39% of the agents are placed in the above 40 category (BOMA, 2016). Since older people are less negatively influence by crowding than younger people, moderating values to the general crowding norm are introduced. For the age variable, these moderating values are derived from Jacobsen et al. (2019). The agents in the age category above 40 are given a multiplying factor 0.8. Lowering the value for agents that care about crowding less than other agents lowers the probability of eventually perceiving a crowded situation as negative. Agents in the age category below 40, thus more sensitive to crowding, are given a multiplying factor of 1.2 (Jacobsen et al., 2019). The difficulty here resides in the fact that crowding and the subjective nature of the phenomenon have not been thoroughly investigated in this type of research. The vast majority of articles on evaluating crowding are based on Likert-scale type quantitative research.

Ethnicity has a moderating influence on perceived crowding too. The size and evaluation of personal space vary throughout different parts of the world. People with an Asian background tend to be less susceptible to crowding, due to cultural differences in social use level. Also, people with an Asian background have smaller personal space boundaries than people with non-Asian background (Chattaraj, Seyfried & Chakroborty, 2009; Neuts & Nijkamp, 2012). In the Amsterdam urban region, visitors can be categorized into Asian and non-Asian groups of agents, and distribution of agents in these two groups are respectively 11.3% and 88.7% (Gemeente Amsterdam, 2018). Due to the aggregation of some groups, the 'Asian' category also comprises of the BRIC countries, meaning that next to the obvious inclusion of China and India, Brazil and Russia are included in this group too. The size of personal space is for modelling purposes kept the same for all agents, but since the evaluation of personal space varies throughout different countries, its moderating effect is expressed in a multiplier value. For the ethnicity variable, these moderating value are derived from Chattaraj, Seyfried and Chakroborty (2009). The Asian group, with a lower probability of evaluating crowded situations or intrusions of personal space as negative, receives a multiplying factor of 0.7. The Non-Asian category is assigned a multiplying factor of 1.3, simulating the opposite effect (Chattaraj, Seyfried & Chakroborty, 2009). An overview of the moderators can be found in table 3.3.

Table 3.3: The variables age and ethnicity and their moderating effect on the crowding norm

Variable	Description	Value	Source
Above 40	Multiplying factor to crowding norm	0.8	Jacobsen et al., 2019
Below 40	Multiplying factor to crowding norm	1.2	Jacobsen et al., 2019
Non-Asian	Multiplying factor to crowding norm	1.3	Chattaraj, Seyfried & Chakroborty, 2009
Asian	Multiplying factor to crowding norm	0.7	Chattaraj, Seyfried & Chakroborty, 2009

Behaviour

Every agent is equipped with a set of behavioural preferences and actions when encountering others. These behavioural preferences and actions are designed specifically to avoid intrusions of personal space. This model includes the concept of motion. Agents mode of transportation in the model is walking, and the speed of walking is not expressed in a uniform value. When encountering a pedestrian that has a lower walking speed, the agent reduces its walking speed by subtracting 0.5 meter per seconds of its own walking speed. Adjusted walking speed is a method of avoiding a collision with other people or obstacles, by allowing preceding pedestrians to gain advantage (Maeda et al., 2009). This method is only deployed by an agent if another agent is within its field of vision, inside the 1.20-meter personal space zone. When there is no longer an instance of personal space intrusion, the agent picks up its original pace.

Another method of avoiding a collision, is by adjusting walking direction (Maeda et al., 2009). Adjusting one's walking direction is a way of implementing social force. As explained in the literature review, social force assumes that pedestrians are subject to certain forces. Every pedestrian attempts to move towards a certain target, but wields a repulsive distance when encountering these forces like other pedestrians (Dias et al., 2018). A distance in which obstacles such as pedestrians are severely avoided is added to the model and implemented at 0.8 meters (Von Sivers & Köster, 2015). This means that if an obstacle is encountered at a distance of 80 centimeters, the pedestrian updates his target by moving away from the obstacle, while simultaneously being pulled towards the original target. When no obstacle is encountered in the specified distance, the agents picks up the shortest route towards the original target.

Within the most frequently undertaken activities by tourists in Amsterdam, are walking through the city center and shopping, respectively done by 88% and 50% of the visitors (BOMA, 2016). Agents in the model walking towards a target that is in line with either of those two activities. The objectives of the agents are thus visiting a shop to do some window-shopping, or walk through the street to reach the end of the street. The agent's target is defined by the objective, and agents have 1 objective at a time. If the objective is achieved, the agents either exits the model or a new objective is assigned. The model area is, next to some alleys intersecting the street, enclosed by stores at the two sides of the street. In figure 3.3, this is displayed by the blue lines (stores) and the black points (exits). When the agent has the objective to window-shop, a store to visit is assigned randomly to the agent. When the agent has reached the store, its objective is updated to either visiting another store with a one-third probability of happening, or to reach the end of the street. The agents walking direction is determined according to the shortest path towards their target, only diverting from using the shortest path when an obstacle is encountered.

Environment

In this study, the network is modelled after a shopping street. The street is entered by the agents through the north and south entrance of the network. The network is 100 meter in length and 16 meter in width. The east and west side of the street are covered by stores, for the agents to perform window-shopping on. Included in the model are five alleys, located on different points on the east and west side. These alleys offer agents the way of exiting the network, if their evaluating of crowding makes them want to. Figure 3.3 show the network and the part of the Kalverstraat after which it's modelled. The network in this study is for modelling purposes undone from bends, and the street width is leveled out.

Figure 3.4 illustrates the relation between the basic model entities. This model consist of agents (i.e. the tourist pedestrians) and a network (i.e. the street through which they move). The street is a confined space, meaning it only has limited space to offer to the pedestrians. The relation between the model entities are simple, and the complexity of this study resides in the agents mutual interaction.

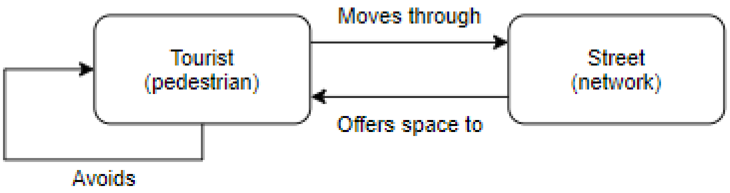


Figure 3.4: Relation between basic model entities

3.4 Model implementation

3.4.1 Software selection

For the development of an agent-based model, the GAMA modelling platform is used. In comparison to other platforms, such as NetLogo and Repast, GAMA aims to overcome the requirements of a high proficiency in for instance Java programming by offering its users tools for developing complex models through a properly thought out integration of programming, visualization and geographic data management (Grignard et al., 2013). GAMA provides an integrated developing environment through the GAma Modelling Language (GAML), which allows its users to build models fast and easily. Version 1.8 continuous built with the 'Pedestrian' plugin is used specifically for creating the simulation model for assessing carrying capacity. The pedestrian plugin allows a smooth integration of the Social Force Model, which is a critical concept when studying pedestrian dynamic. This plugin is designed for the continuous built version of GAMA.

3.4.2 Process overview

In Figure 3.5 the main simulation process is illustrated. The agent enters the model area through the main street entrance (north or south entrance). The probability of entering through either side of the street is 50%, in order to simulate a realistic use of the street. The assumption is made that visitors of the model area are distributed equally over the north and south entrance of the street considering both the purpose of the street (shopping) and its location in the bigger city region, which is between multiple tourist sites. Time steps of 1 second are used to express in time, simulate pedestrian movement and calculate intrusion time of agents' personal space. Agents walk the street towards the target that is in line with their objective (window-shopping or passage). If the agent's encounters a situation where its personal space is intruded, its walking speed is reduced. This method of avoiding obstacles is deployed when another agent is within 1.20 meters' reach. When an agent is within 0.80 meters' reach, an agent is considered to be too close, and updating the walking direction is deployed as a method of avoiding others. After keeping its original track but with a reduced speed, or after returning to the original walking trajectory after avoiding an obstacle, walking the street towards the target is continued. If the agent has reached the shop that was set as objective, the target is updated to the opposite entrance of the street where the agent was spawned. The agent continues walking the street towards the exit. Another target update occurs when a situation is marked as too crowded by an agent. The time that an agents' personal space is intruded is counted, and when an agent has reached more than 10 seconds of personal space intrusions. 10 seconds of intrusion time marks the agents' tolerance being reached, and the probability of leaving street early (the crowding norm) is requested. If the probability of leaving the street is found to be true, the agents' target is updated by looking for the nearest street exit and leaving the street through that exit. If the probability of leaving is found to be false, the target is not updated and the agent walks towards the main street exit. Figure 3.5 is colour coded. The red blocks describe the beginning and end of an agent's time inside the model. The green block describes the agent's movement, and the blue blocks describe agent's decision process regarding personal space intrusions.

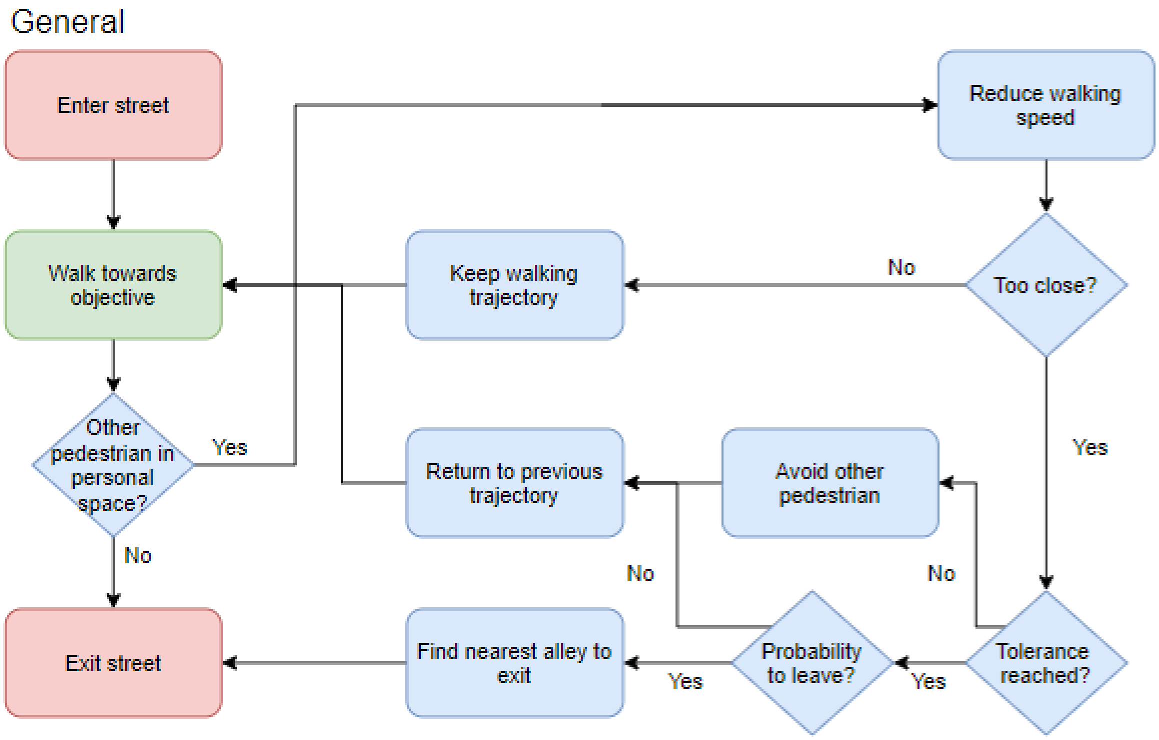


Figure 3.5: Main simulation process

3.4.3 Spawning, number of agents and duration

Agents are spawned evenly over the north and south entrance of the street, and are spawned at either the top left moving south or bottom right moving north segment of the street. This is to ensure that pedestrians stick to the right side of the road, as is common in the Netherlands (Lewis et al., 2020). If the objective is to use the street for walking and reaching the other side, the target is set on the same segment of the road that the agent is spawned on, again to ensure sticking to the right side of the road.

Visiting a store on the other side of the street, or using an exit on the other side of the street due to it being the nearest exit, overwrites to tendency to stick to the right side of the road.

The Kalverstraat is known to attract many visitors. Estimates and counts of passerby's done by commercial companies mention numbers as high as between 50.000 and 70.000 on an average Saturday, and up to passing 100.000 in the days before Christmas (AT5, 2017). Opening hours of the shops in the Kalverstraat range between 10:00 and 19:00. To determine the amount of pedestrians in the model, a consideration has to made between the number of agents that are spawned in the model and the amount of time that is represented in the model. For both runtime and computations purposes, it is unfavorable to perform high density model runs for a full day. Both visitors and hours are scaled down. An estimate is made regarding the spread of visitors over the day. This can be seen in table 3.4. These numbers are based on information from the municipality of Amsterdam (2016), but attenuated, because the model area does not comprise the whole Kalverstraat. As mentioned, modelling a full day would require too much computational power and time, so the model runtime is adjusted to two hours. It is assumed that visitor numbers increase as the day continues, so the majority of the visitors enter in the afternoon.

Figure 3.6 shows counts of passerby's in one week. The Kalverstraat has the highest number of people walking through, counting 5 milion in one week (Gemeente Amsterdam, 2016). Adding the numbers of the left graph of figure 3.6, the Kalverstraat has a 36% share in the total of passerby's. In this study, an average busy day is calculated regarding the number of visitors in the Kalverstraat. This is done by taking the 36% share of the Kalverstraat of visitor numbers, devided by the 9 hours of store opening hours. This means, that on the average day, around 3520 visitors per hour visit the Kalverstraat. This number is rounded to 3600 visitors, meaning that every second, 1 agent is spawned in the model.

Figure 3.6: Number of passerby's in Amsterdam shopping streets (Gemeente Amsterdam, 2016)

This model represents 2 hours, meaning 2 * 3600 = 7200 seconds (cycles). To have the possibility of adding variation in the spawning rate, every 900 cycles (or 15 minutes) a new spawning rate will be established. Table 3.4 shows the spawning rate per 15 minutes. From here on, the spawning rate in table 3.4 will also be known as the default setting or default scenario. For now, it is assumed that pedestrians enter the street in an even manner, but this spawning scheme allows for scenarios to be implemented at a later stage. The previous section discussed that in an average day, approximately 3600 agents walk through the street each hour. As this study aims to expose pedestrian dynamics in crowded situations, this number of agents being spawned is doubled. This will lead to a more crowded situation in which agents have to find a way to keep an empty personal space, while still being in line with realistic visitor numbers.

Table 3.4: Model duration and number of agents spawned per quarter

	time							
Minutes	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**
Nr of agents per quarter	1800	1800	1800	1800	1800	1800	1800	1800

3.4.5 Moderated crowding norm

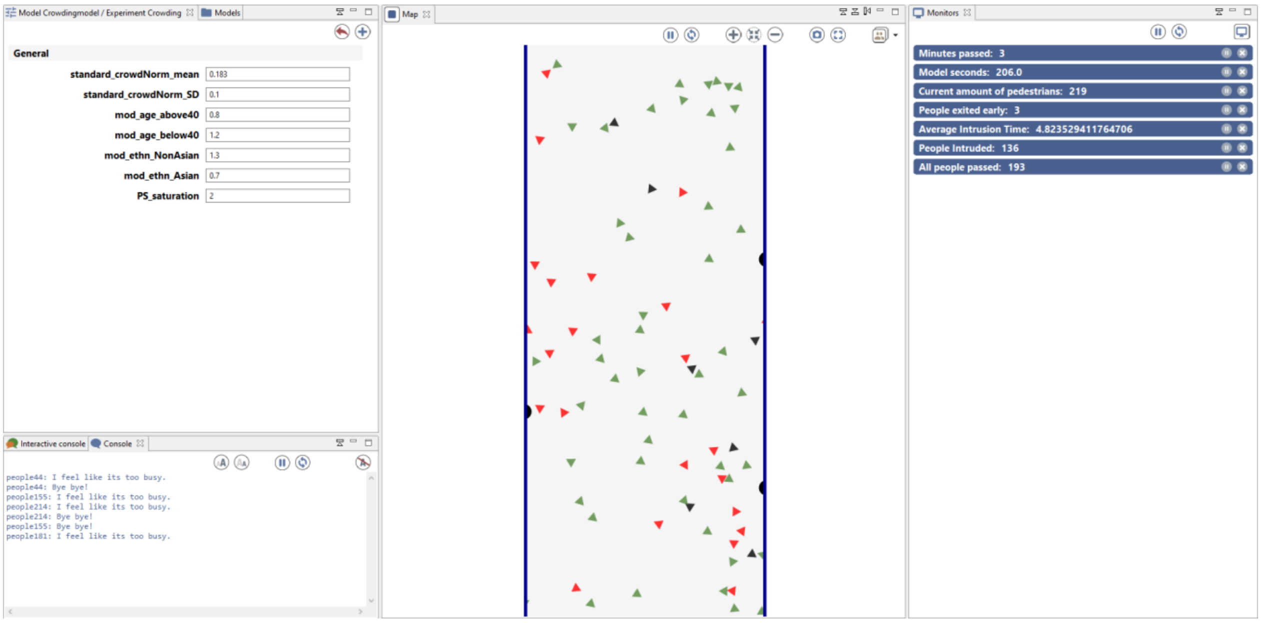
The crowding norm and its moderating variables have been covered in previous section of this study. In this paragraph, the calculation of the complete crowding norm as the probability to leave the model area prematurely is described. Upon entering the model, every agent starts with the same probability value of evaluating crowding negatively. This value is 0.183 (Neuts & Nijkamp, 2012). The moderating variable age and ethnicity, which are distributed among the agents in accordance to the visitor profiles of the Amsterdam urban tourists, are used as a multiplying effect to this standard crowding norm. The final crowding norm, from here on called the moderated crowding norm, is expressed as the following formula:

$$\begin{aligned} &Moderated\ crowding\ norm \\ &\qquad = Guassian\ distribution\ (Crowding\ norm, Standard\ deviation) * \\ &\qquad Moderating\ age\ variable\ * Moderating\ ethnicity\ variable \end{aligned}$$

A Gaussian distribution is a statistical distribution where instances are spread normally, according to a mean value (0.183), and a standard deviation (0.1). The Gaussian distribution is often used in probability theory. Considering the insufficient theoretical and empirical foundation of tourist crowding simulations in front country (urban) regions, it is a suitable method of establishing a statistical distribution among the agents in the model.

3.4.6 Walking to target

Agents have the ability to walk, meaning that they can move in a space while finding their way on a virtual network. This is done, as briefly mentioned before, by following the shortest path to the given target. Agents apply their walking speed to get to this target, and when no more target update is possible, they exit the model. The target is determined by the objective that is assigned to the agent and the objective switches once the agent reached the target's vicinity. The objective are either using the street for passage, with no window-shopping involved, or to first perform window-shopping and then use the street for passage. Figure 3.7 shows a snapshot of the model. Agents in green have the objective to use the network for passage. Agents in red have the objective to use the street for window-shopping. Once the target store has been reached, the objective is updated to using the street just for passage, the agent turns green, and the objective is reaching the other side of the network. The store an agents wants to visit is determined as a point, placed randomly on either two sides of stores surrounding the east and west side of the street. Agents walk the shortest path towards this store, and when they are within a 1-meter reach, the agents' objective is updated.



standard_crowdNorm_mean: 0.183
standard_crowdNorm_SD: 0.1
mod_age_above40: 0.8
mod_age_below40: 1.2
mod_ethn_NonAsian: 1.3
mod_ethn_Asian: 0.7
PS_saturation: 2

```
people44: I feel like its too busy.
people44: Bye bye!
people155: I feel like its too busy.
people214: I feel like its too busy.
people214: Bye bye!
people155: Bye bye!
people181: I feel like its too busy.
```

Minutes passed: 3
Model seconds: 206.0
Current amount of pedestrians: 219
People exited early: 3
Average Intrusion Time: 4.823529411764706
People Intruded: 136
All people passed: 193

Figure 3.7: Overview of the GAMA dashboard, zoomed in on the network. Green agents walk towards the end of the street, agents in red are walking towards a store for window-shopping. Agents in black use their adjusted walking speed

3.4.7 Pedestrian encounters

Simultaneously, agents encounter each other. Throughout achieving their objective, and with every new model cycle, the possibility can occur that an agent feels that its personal space is intruded by another agent. While on global level, the social force model is implemented to ensure that agents desirably respect each other's personal space, one agents' diversion of its walking path to avoid a personal space intrusion can mean that this agent diverts into another agent's personal space. It is also merely a coefficient to take each other into account, it is not a hard physical rule that agents are rebounded by obstacles, such as other agents. Intrusions of personal space therefor inevitably occur when encountering others in a busy shopping street. While walking towards the declared target is their primary goal, personal space intrusions are noted and seconds of intrusion time are counted, up until an agents' individual intrusion time passed the 10 seconds boundary. As mentioned, this resembles approximately 10% of walking time through the model area, which is assumed a sufficient amount of time to experience a situation as too crowded and move on to determining what an agent's evaluation of this crowding is. Additionally, 10 seconds appears to be a proper duration to actually experience crowding. Once crowding is experienced, the feeling does not go away anymore (Popp, 2012). Seconds intrusion time is subject to the sensitivity analysis in paragraph 5.1, where also 5 and 15 seconds of intrusion time are examined for their effect on the carrying capacity.

The crowding norm that is given to each agent, multiplied by the different moderating variables, leads to the moderated crowding norm (paragraph 3.4.5). This norm is the probability of evaluating a situation as negative, and is only called upon when the number of intrusion seconds is exceeded. If the moderated crowding norm is found to be true in the next situation where an agents' personal space is intruded, the agent will want to leave and starts looking for the nearest street exit and updates its target to this exit. Figure 3.8 shows the walking scheme of an agent, how an agent behaves when encountering others and which target to walk to according to either their objective or to their decision to leave the street.

3.4.8 GAMA social force Plugin

Social force is said to be implemented through a change in walking speed or a change in walking direction. Change in walking speed is mentioned in section 3.3.3. A change in walking direction, is covered by the plugin. The obstacle consideration distance is set at 0.8 meters instead of the 1.20 meters as determined as personal space by Hall (1966), in order to give the agent the possibility to first deploy the reduction of walking speed as an avoidance strategy instead of detouring right away. The obstacles to be considered are other pedestrians, and the probability to either detour or halt for a brief moment is 50%. The overlapping coefficient, which determines the desire not to overlap, is kept at the default setting of 0.5 as determined by the modelling program. Table 3.5 gives an overview of the key social force parameters and their settings, as offered by the plugin.

Table 3.5: Key parameters of the Social Force Model

Variable	Description	Value	Source
Obstacle consideration distance	Intensity of reaction to obstacles	0.8 meters	Von Sivers & Köster, 2015
Obstacle species	The list of species that are considered as obstacles	People	GAMA, 2020
Probability to detour	The probability to accept to do a detour	50%	GAMA, 2020
Overlapping coefficient	Coefficient for the tendency to avoid overlapping	0.5	GAMA, 2020

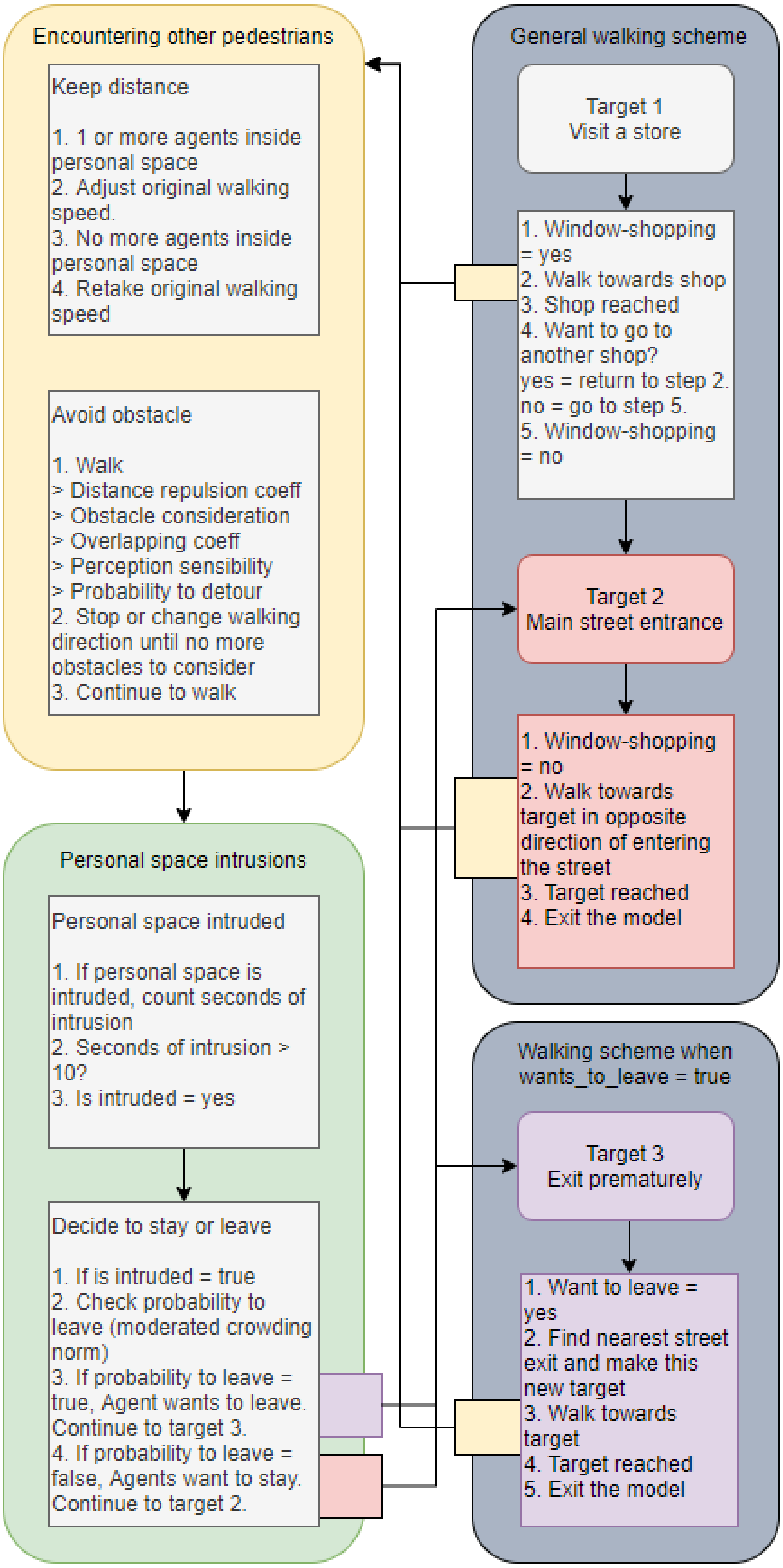


Figure 3.8: General walking and decision scheme of each pedestrian

4. Model verification and validation

4.1 Verification

Verification of the model ensures that the model works in the way that it is designed (Pizzitutti et al., 2014). Model verification is an iterative process that starts the at the same time as the model development phase, ensuring that every new line or segment is tested and works as is intended. Through the development phase of this model, model verification has taken place through visual verification and by following specific agents and checking whether the rules and behavioural characteristics are implemented correctly. Visual verification is performed by looking at the interactions between agents, do agents visit a shop and do agents move to one of the exits it they want to. Checking whether rules and behaviour are implemented correctly is performed by checking agent's attributes and global environment attributes. Regarding the environment attributes for instance, are the specified numbers of agents added to the model area with every new cycle, is the concept of time implemented correctly? Agents' attributes are checked as well. When encountering another agent, is the walking speed adjusted? Additionally, if another agent comes too close, is their presence noted by the agent? If an agents' personal space is intruded, are the seconds of intrusion time counted correctly, and do the variables such as 'is intruded' and 'want to leave' switch from no to yes at the right time?

4.1.1 Agents spawning

According to table 3.4, 2 agents spawn with every new tick for the first 900 model seconds. As can be visually verified in figure 4.1, as well as checked by monitoring global model attributes, 2 new agents spawn every tick. Furthermore, the distribution of agents among the top left and bottom right entrance of the model area can be considered relatively even.

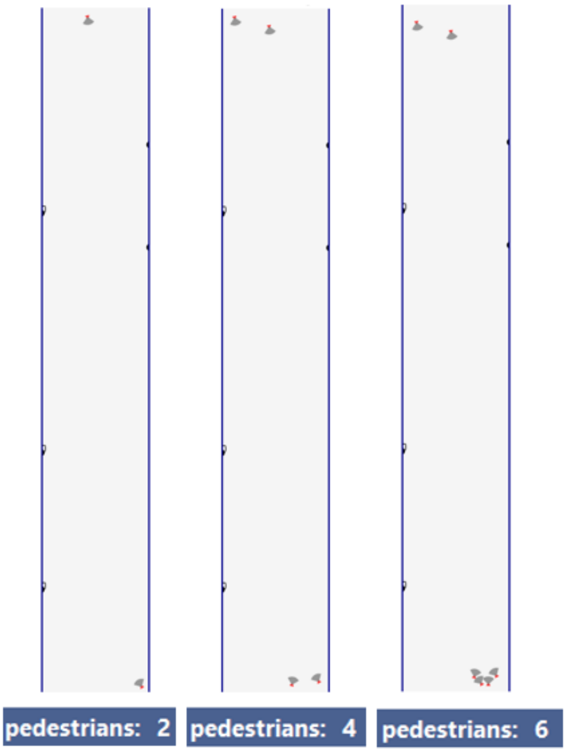


Figure 4.1: Visual verification of agents spawning rate and location

4.1.2 Walking to target: window-shopping, walking the street and exiting early

Window-shopping

The first objective is window-shopping, and the target related to this objective is assigned to the agent as explained in paragraph 3.3.3 In the figure below (figure 4.2), an agent is highlighted that is visiting a storefront on the right hand side of the street (panel 1 and 2). As can be seen in the 'window-shopping' box, it is set on 'true', meaning that the agent is on its way to visit a shop. In panel 3 and 4, the agent has reached its target shop, is within the shops 1-meter vicinity, and the window-shopping box is set to false, meaning that the agent no longer has the desire to visit a shop. The yellow colour of the window-shopping box indicates a recent change. The colour blue for a highlighted agent and the yellow colour surround a variable are used hereafter for these purposes. The grey quarter circle indicates agent's field of vision, as explained in paragraph 3.3.3. Additionally, the field of vision indicates the direction of the agent.

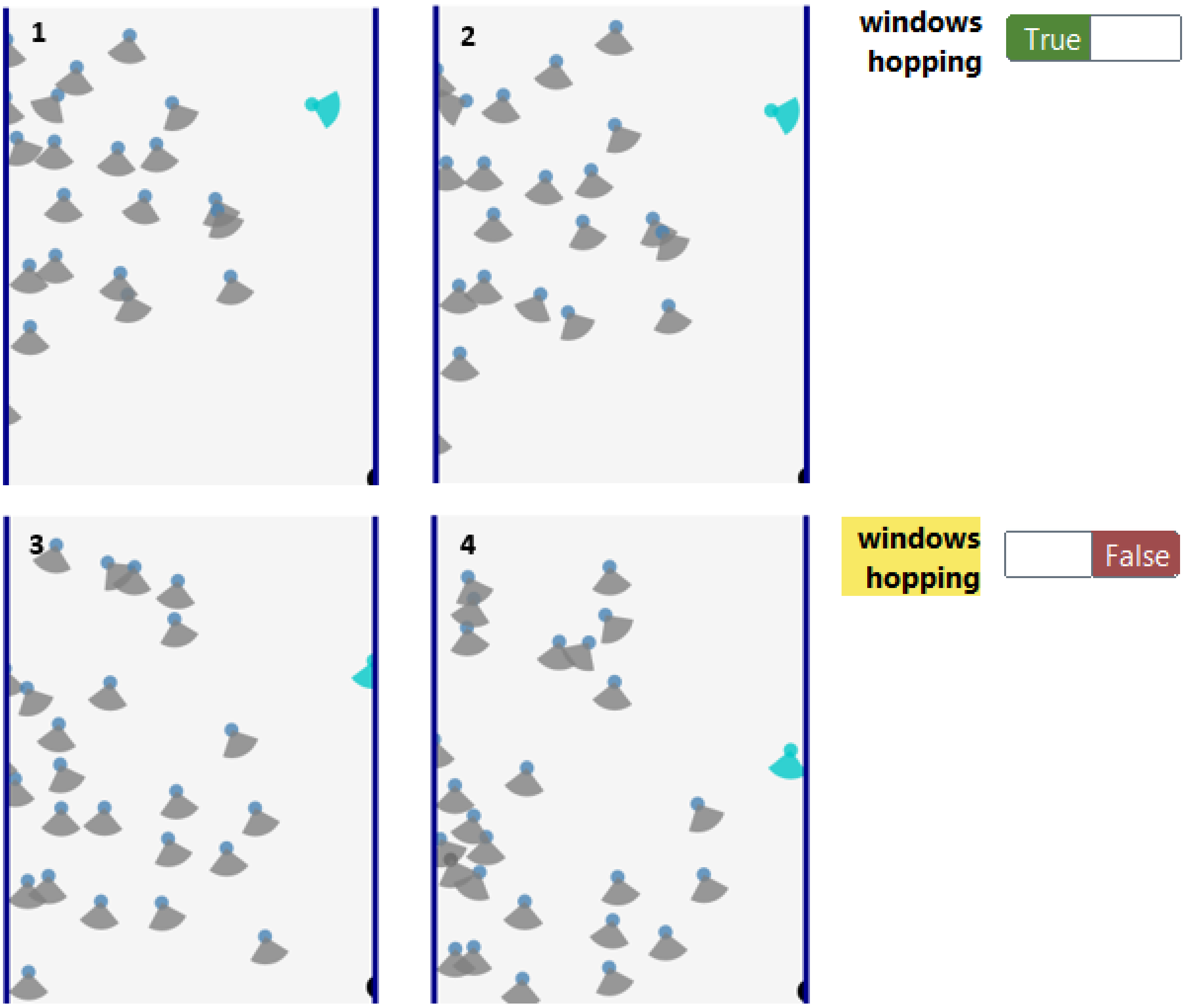


Figure 4.2: Agent visiting a store before walking to the main entrance of the street

Walking the street

The figure below (figure 4.3) shows the model in an advanced state, as can be seen by the bidirectional stream of agents. The agents marked by the red oval show pedestrians moving towards the end of the street, as can be noticed by their relative perpendicular stance towards the end of the street. These agents use the street for passing through.

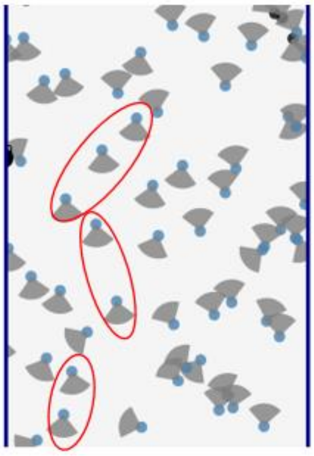


Figure 4.3: Agents using the street just for passage, marked by the red oval

Exiting early

Agents that have experienced high levels of crowding and evaluated these experiences as negative, decide to leave the model area through one of the exits. Figure 4.4 shows an agent, moving towards the black circle on the right side of the street. The grey bar at the bottom shows the agents' name. When reaching this alley, the bottom bar turns red and the text 'dead at step 418' is added to the agents' name, meaning that it is no longer part of the model, and the agent has left the model area through that point.

Agent: people881

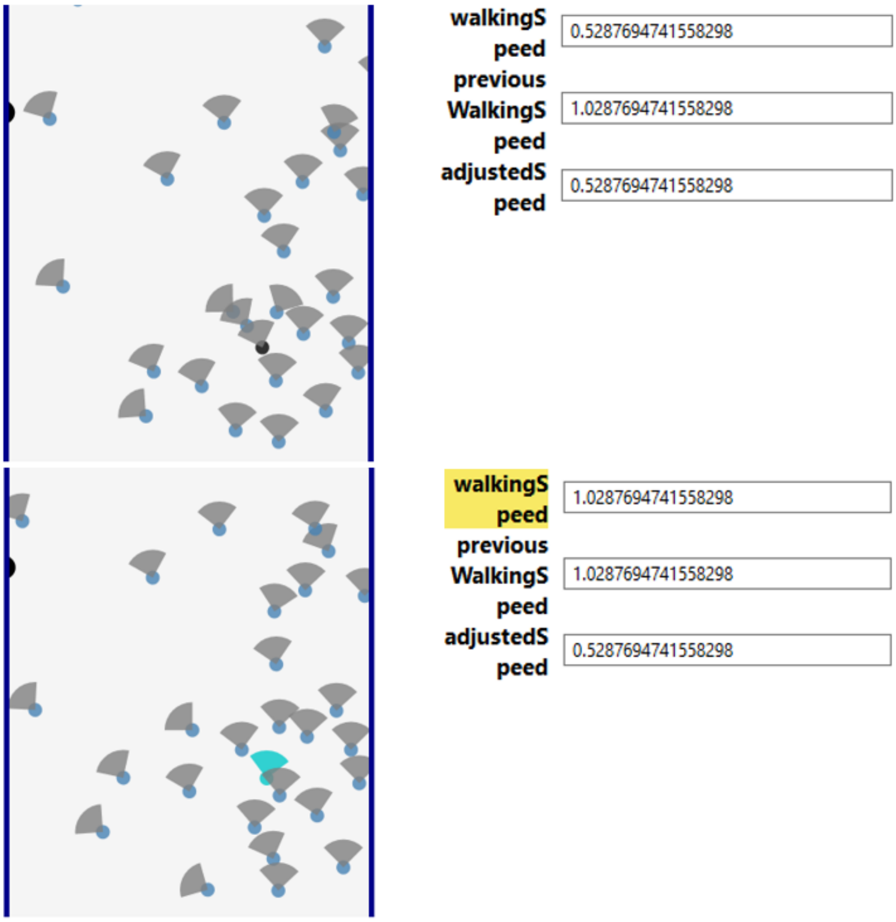
Agent: people881 dead at step 418

Figure 4.4: Agent walking towards the nearest exit and exiting the model

4.1.3 Social force and pedestrian encounters

Adjusted walking speed

The 40 centimeters buffer space between the outer zone of Hall’s (1966) personal space and the beginning of the obstacle repulsion distance is used for adjusting the walking speed instead of adjusting walking direction. In figure 4.5, a situation in which another agent enters this 40 centimeters buffer distance is captured. The model turns the agent colour into black if the walking speed is adjusted. Additionally, the specific agents’ walking attributes are checked to ensure that the agent actually reduces speed. In the figure below, the top panel shows the agent marked in black with its walking speed on right. 3 variables are depicted here, its walking speed at that moment, the walking speed that is originally given to the agent, and the adjust walking speed, which is the original walking speed deduced by 50 centimeters per second. The walking speed that the agent has at that point, is the adjusted walking speed. This is because of the agent which is walking in front of him. This agent is, however, not close enough or inside his personal space enough for it to be considered too close. The bottom panel, now showing the same agent but highlighted in blue, is undone of agents that are in too close of a proximity, and the walking speed is set to the original walking speed that was given to the agent. This can be verified by the yellow colour, indicating a recent change for this parameter.



walkingSpeed 0.5287694741558298
previousWalkingSpeed 1.0287694741558298
adjustedSpeed 0.5287694741558298

walkingSpeed 1.0287694741558298
previousWalkingSpeed 1.0287694741558298
adjustedSpeed 0.5287694741558298

Figure 4.5: An agent’s reduced and normal walking speed, as a result of another agent being too close by

Obstacle avoidance

The figure below (figure 4.6) contains 4 panels, in which two agents are too close to each other. What is considered ‘too close’, is determined in table 3.5. In table 3.5, the variables are mentioned that quantify the willingness of agents to temporarily change direction and the distance in which obstacles are taken into account. In the first panel, the two agents indicated by the red oval are in each other’s personal space. In the second panel, which is 1 cycle later, the agents have both changed walking direction, in opposite sides from each other, while still moving towards their target. In panel 3 and 4, both agents have retaken their original heading using the shortest path to reach their target, but the agents are not in each other's space anymore. This figure illustrates the way social force is implemented in the model, by letting agents being pushed away from each other while simultaneously being pulled towards their target.

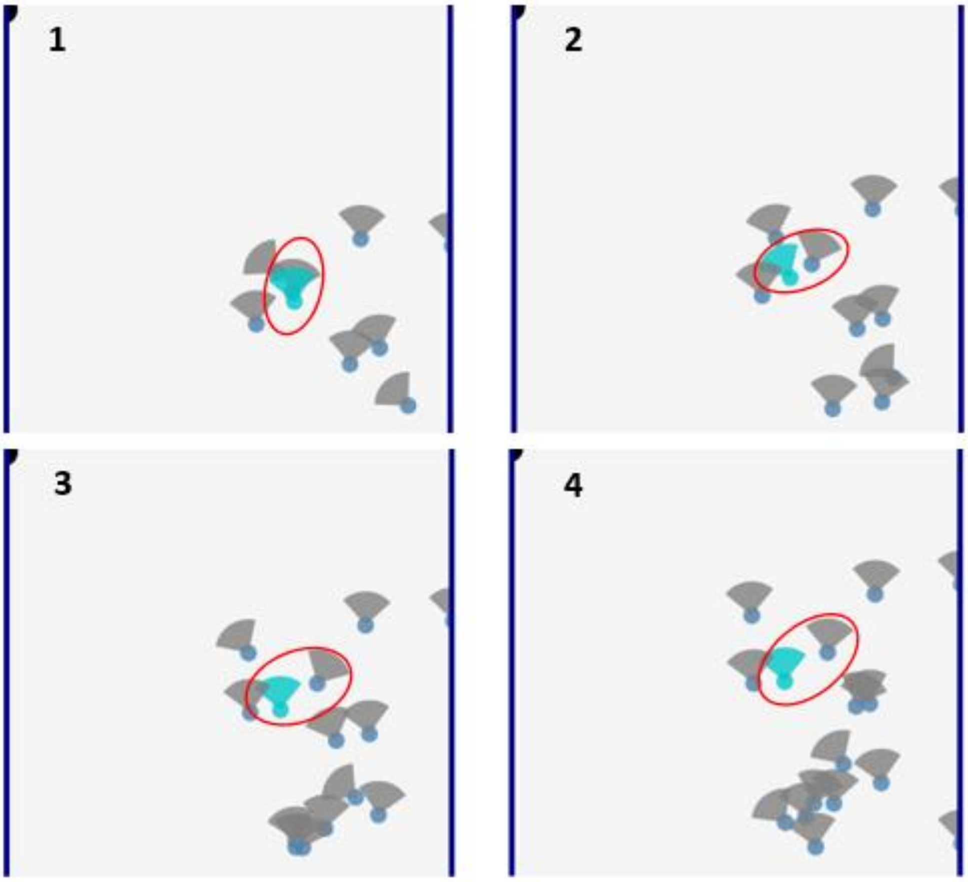
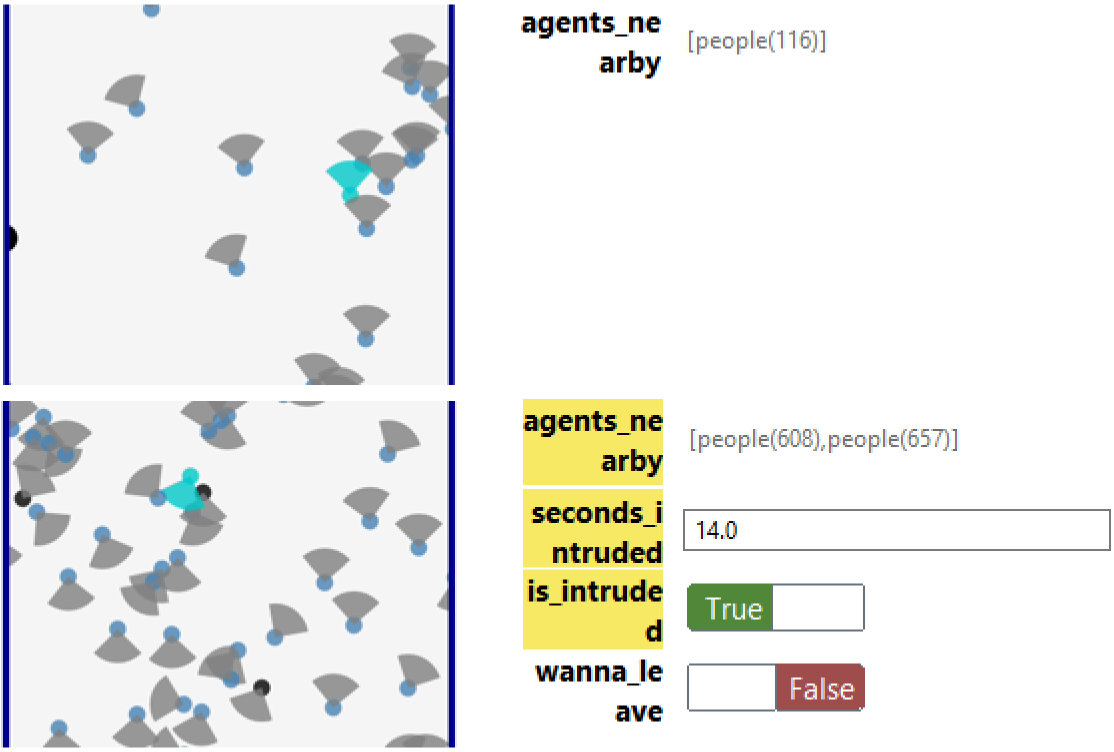


Figure 4.6: 2 Agents exercising social force

4.1.4 Field of vision

The intrusion of personal space is determined by the number of agents' inside one's field of vision (i.e. personal space). The figure below (figure 4.7) shows two panels, the top panel where 1 agent is noticed inside the central agent's personal space, and the bottom panel, where 2 agents are noticed inside the central agent's personal space. In both panels, intrusion of personal space occurs, and the seconds of intrusion time are counted. In this specific case, the agent is at an advanced state in the model. It has encountered previous moments of personal space intrusions (its counter is at 14 seconds). This means that the agent experiences the situations as a whole as crowded (threshold of intrusion seconds is 10 seconds). However, the agent has not evaluated the crowed situation as negative, since the variable of wanting to leave remains at false. The probability of this variable switching depends on the moderated crowding norm and is requested after the 10 second mark of intrusion time.



agents_nearby [people(116)]

agents_nearby [people(608),people(657)]

seconds_intruded 14.0

is_intruded True

wanna_leave False

Figure 4.7: An agent's field of vision

4.2 Sensitivity analysis

For the model validation phase of this study, a sensitivity analysis is performed. In a sensitivity analysis, model uncertainty is assessed by adjusting the parameter that affect the model's behaviour. In such an analysis, it is investigated how the overall model responds to these adjustments (Renardy et al., 2019). The conclusions that can be derived from a sensitivity analysis lead to a higher model reliability (Corti et al., 2020). To determine the effect of the parameters on the system as a whole, alternative values are assigned to the parameters. The effect of these alternative values are tested by means of a 'one-at-a-time analysis', where all parameters are kept at the default value except one, where the alternative value is applied. The parameters that are subject to the sensitivity analysis in this study, are the parameters that influence agents' decision to leave the street early due to crowding. These are intrusion time, saturation of personal space, viewing distance, adjusted walking speed and the general social force variable. The resulting model output is expressed in the output variable early exits, indicating the number of agents that decided to exit the street early due to crowding.

Table 4.1 shows the parameters, default values and range of assigned new values for the sensitivity analysis. The default values are the values for the parameters that are applied when not under investigation. The values in the 'range' section are the values that are subject to the analysis.

Table 4.1: Sensitivity analysis parameters and settings

Parameter	Default value	Range
Intrusion time	10	(5; 10; 15)
Saturation personal space	1	(1; 2)
Viewing distance	1,20	(1,00; 1,20; 1,40)
Adjusted walking speed	-0,5	(-0,3; -0,5; -0,7)

The main social force parameter is the distance in which other pedestrians are considered obstacles. This parameter's default setting is 0.8 meter, as derived from Von Sivers and Köster (2015). The alternative value which is tested, is Hall's (1966) 1.20 meter distance for personal space (table 4.2). The parameter 'Obstacle consideration distance' is tested to determine the impact of the Social Force plugin on the model's behaviour.

Table 4.2: Social force parameter and settings to be tested in the sensitivity analysis

Parameter	Default value	New value
Obstacle consideration distance	0,8	(1,20)

For every value, the model will be run 10 times. Stochasticity is implemented in the model, but not to such an extent that 100 or more runs are required to determine the validity of the model output The random input in the model resides in the spawning location of the agents and the decision if and what store to visit. The stores are supposed to be visited randomly, as every agent has a different motive for shopping. This motive is not further investigated. The randomness of the spawning location is due to agents entering a street, which is never according to the same trajectory, as agents (pedestrians) are physical entities that cannot overlap or be placed inside each other. Chapter 5 offers the results of the sensitivity analysis, and acts as the general results chapter of this study.

5. Results

In this chapter, the results from the sensitivity analysis are presented and analyzed. The analysis, performed as a one-at-a-time analysis, shows the effect of the different parameter values on the critical output variable early exits. The parameters that are tested, are the intrusion time, the saturation point of personal space, the viewing distance, the adjusted walking speed and the obstacle repulsion distance. The results of this analysis are plotted as a function of time, to analyze both the effect of the parameter as well as its behaviour over time. To minimalize computing time, intervals of fifteen minutes are used to derive output.

5.1 Intrusion time

Generally, the personal space is meant to be a private space surrounding a central person where no one else is allowed. In this study, personal space is expressed in terms of that area surrounding a central person, and intrusions of this area are counted in terms of seconds. A single intrusion doesn't directly indicate a crowded situation, as people using a street for both passage and shopping inevitable intersect each other. 10 seconds is taken as the minimum amount of time that the agent's personal space needs to be intruded before determining what the agent's evaluation is about crowding. This time is from hereon called 'intrusion time'. After 10 seconds of intrusion time, the agent determines what to do with that feeling: leave of stay. To check the effect of this parameter on the model's functioning, alternative values for the minimum of intrusion time were set to 5 and 15 seconds. Figure 5.1 shows the effect of the three settings on the absolute number of agents that decided to leave the model before completing their objective. Obviously, the trend of agents leaving (exiting early) as a function of time shows a linear trend. The number of agents entering the model is equal over time, meaning that the number of seconds is the only variable influencing whether agents feel intruded or not. However, the lower the threshold value for intrusion time is set (blue curve), the steeper the curve becomes. This output was expected. When lowering the threshold value for intrusion time, more agents will exceed this threshold, meaning a more agents will have to determine whether they want to leave or not. The probability of leaving remains the same, only the number of agents requesting this probability increases immensely. The other way around, if agents don't feel intruded because of a high intrusion time threshold, they don't need to decide on leaving because this stage in the decision making process is never reached.

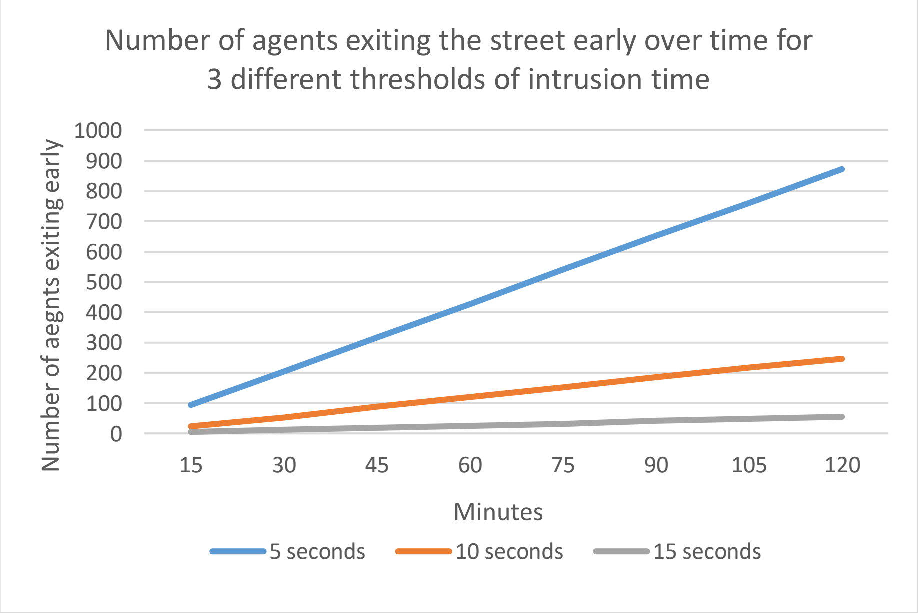


Figure 5.1: Number of agents exiting the street early over time for 3 different configurations of intrusion time

The 2 alternative settings (blue and grey curve) only differ 5 seconds from the default setting, but the difference in resulting number of agents exiting the street early is quite big comparing the 2 alternative configurations. To explain this, a graph showing the average of intrusion time (in seconds) needs to be displayed.

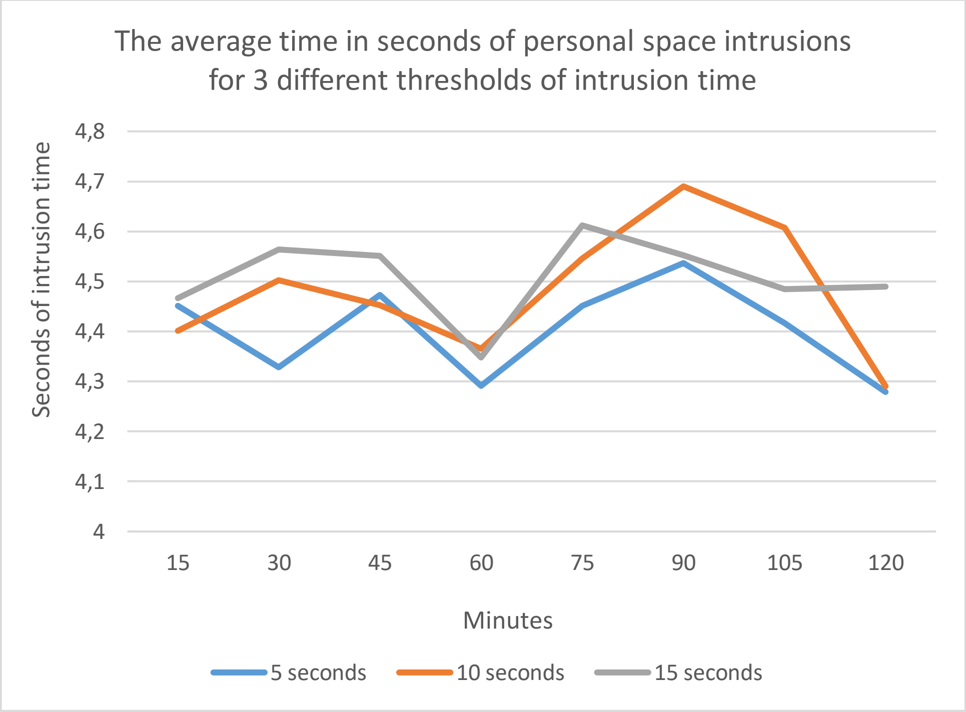


Figure 5.2: The average number of seconds that agents' personal spaces are intruded for 3 different configurations of intrusion time

Figure 5.2 shows the curves of the average seconds of intrusion time for the three different settings. The average seconds of intrusion time is plotted on the y-axis and the model duration is plotted on the x-axis. The three curves show a similar trend of smaller peaks in average intrusion time at the start, alternated by a bigger peak towards the end, ranging over a 1 hour interval. The 5-second curve starts with a small decrease in average intrusion time, in contrast to the 10 and 15-second curves. All three curves, however, do not exceed the 5 second average. This is a critical finding in determining the effect of the three different settings. For any of the three settings, the average of the personal space intrusion time lies around 4,4/4,5 seconds. When evaluating the 15 second setting, this indicates that only few agents ever reach that number of intrusion seconds. This would indicate that setting the parameter on 15 seconds for the minimum of intrusion time would be too high. When evaluating the 5 seconds setting, high numbers of agents exit the model early. The figure tells us that, since the average lies around 4,4/4,5 seconds, this threshold for intrusion time is reached quite often.

To check the effect of the different values per time interval, the number of agents leaving the street early is calculated per fifteen minutes (figure 5.3). A cycle-like trend is visible for agents exiting the street early, where periods of relative fewer agents leaving the street are alternated by periods of relative higher numbers of early exits. Especially for the 5 second threshold, the overall trend shows stronger alternations. Additionally, the 5-second line shows a general increase in agents deciding to leave the model area per quarter. The first 30 minutes of model run time show an increase, after which the trend starts that is visible in the 10 and 15-second line. According to the same argumentation for figure 5.2, the overall number of agents exiting the street early per quarter is higher for the 5-second value than for the other two. The graphs for the 10 and 15-second threshold are, however, relatively close by in comparison to the 5-second graph.

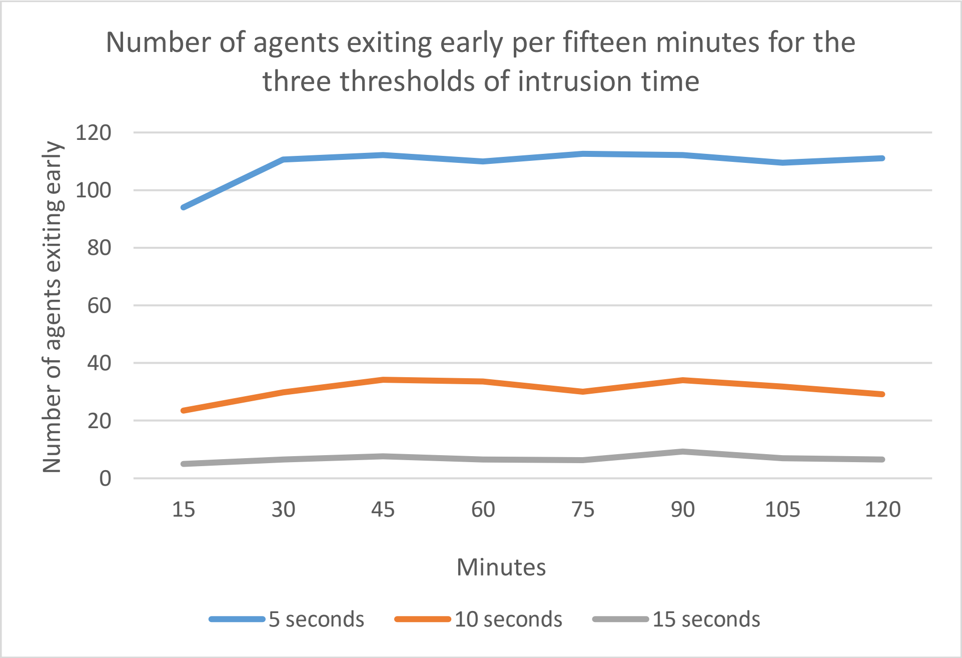


Figure 5.3: Number of agents exiting early per fifteen minutes for the three configurations of intrusion time

Considering the default configuration, the alternating periods are in rule spread out over half hours. There is no specific reasoning as to why these trends would not occur through lower intervals. These trend-based differences in half hour intervals are slightly visible for the 15-second graph, but this curve follows a much flatter course than its 5 and 10 second counterparts.

5.2 Saturation of personal space

In Hall's (1966) specification of personal space, familiarity of people is taken into account when establishing certain geometric zones around a central person. In this study, familiarity of people is not taken into account, and a static distance is taken for the personal space for everyone. The results of the sensitivity analysis for the different sizes of this space are discussed in section 5.3. This section discusses the results of the number of people that are allowed in one's personal space, also called the saturation of one's personal space. The default saturation is 1 person and the general boundary for personal space is 1.20 meters. As feeling crowded is in literature also described as a limitation in the freedom of movement, 2 persons as saturation point of one's personal space is investigated as well.

As turns out, the early exit output variable used for checking the effect of the different settings is unsuitable for testing the effect of the saturation point of 2 persons. In all of the individual runs, zero agents left the street prematurely. Out of the 14400 spawned agents, zero agents reached the 10-seconds intrusion time for 2 persons as saturation point. Thus, no agent actually reached the point of deciding on leaving. This output variable became subsequently useless as a measure of investigating the effect of this setting. In the figure below, the y-axis contains average intrusion seconds instead. The blue line in the figure depicts the average intrusion seconds when a personal space is intruded by 1 other agent. The orange line illustrates the average intrusion seconds for 2 other agents inside one's personal space. A similar trend-like motion is distinguishable when comparing figure 5.4 with the graphs from figure 5.3, where periods of higher intrusion time are alternated by periods of lower intrusion time. This trend, albeit small, is also visible when analyzing the graph representing the saturation of personal space for 2 agents.

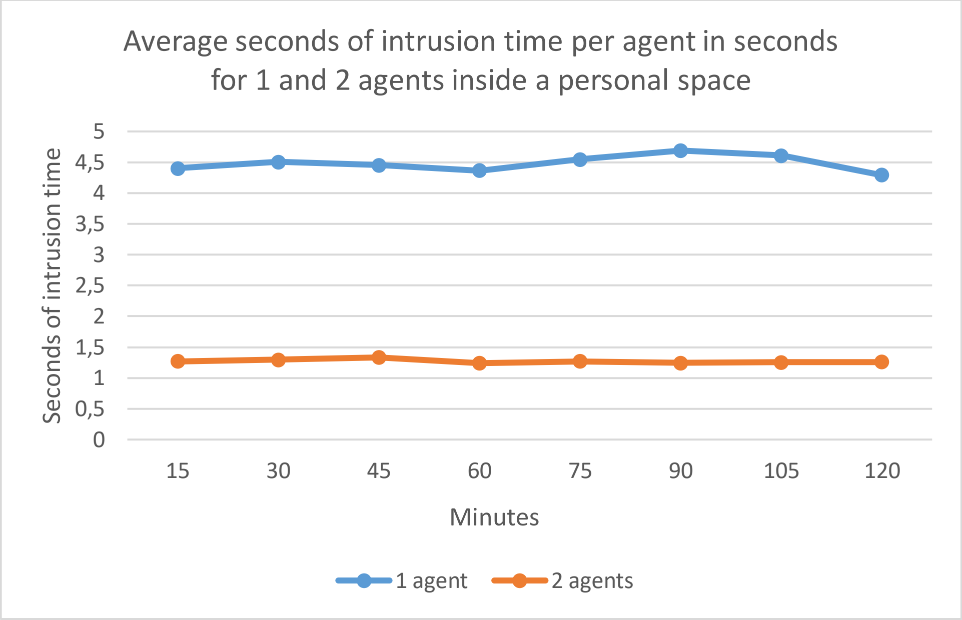


Figure 5.4: Average intrusion time per agent in seconds for 1 and 2 agents inside a personal space

When taking a closer look at the model settings behind the orange graph, the non-appearance of early exits, the low alternation in average intrusion seconds as well as the low number of average intrusion seconds can be explained. The tolerance for feeling intruded is quite high in comparison to the default. Especially when considering that the number of agents spawned in the model is not portraying an extremely crowded situation but more averagely busy day, 2 other agents inside the 1.20-meter personal space generally doesn't occur. Some situations occur where there are 2 other agents inside one's personal space, but when considering that the default for intrusion seconds is set at 10 seconds, the decision of wanting to exit the street early is never reached. Additionally, the model is set up in such a way that every instance of a personal space intrusion is dealt with by directly walking away from the other or decreasing walking speed to increase distance between them and the predecessor. It seems that the combination of saturation point of 2 other agents and 10 seconds of intrusion time are too high.

5.3 Viewing distance

To test the effect of the size of the personal space zone, 20 centimeter is added and distracted from the default value. Viewing distance and personal space are the same in this model, as the viewing distance allows agents to notice others at a certain distance (i.e. intrusion of its personal space). The size of the viewing distance means that other agents are noticed either earlier or later by a pedestrian, thus influencing the time in which crowding can be experienced. The more an agent notices others, the earlier it might feel intruded and decide to leave. Figure 5.5 displays the number of agents exiting the street early, calculated per fifteen minute interval. In comparison to the orange curve, depicting the default value, both the alternative curves show a similar trend. The number of agents exiting early shows bigger alternations for the 1.40 setting than for the 1.00-meter setting. It is remarkable, the vast difference 20 centimeters makes on the total number of agents exiting the street early. The 1.40-meter setting seemingly results in 3 times as much agents exiting the street prematurely. Additionally, the trend-like motion of exiting early is spread out over a longer time period, in contrast to the other settings. The grey curve depicting the 1.40- meter setting has some 'jumpy' characteristics to it, looking less gradual and making it seemingly less reliable as a suitable value to the parameter. Perhaps this is due to the following: when increasing the viewing distance, agents can be noticed at a point farther away. That doesn't necessarily mean that the agents are crossing each other. Agents can almost accidentally be caught in each other's viewing distance, thus being considered an intrusion of personal space, while not crossing paths. Intrusions of personal space and the subsequent ways of dealing with them leads to agents not being able to fulfill their objective. The 1.40-meter viewing distance appears to be too big to check whether an agent is hindered by others in completing their goal in the street, or if another agent happens to just walk by at a farther distance. The current model does not differentiate between those two forms of pedestrian encounters, so this setting seems unsuitable to assess crowding. The 1.00-meter setting appears to be too small. Considering that the model simulates an average crowded situation, agents generally not walk past each other at a 1 meter distance. The blue curve remains flat throughout the 2 hours, with small alternations in exiting numbers. No distinct trend, however, can be derived from this setting, and additional research on a small personal space size and different crowded situations is required. Ultimately, as the 1.20-meter range is derived from literature, this configuration should be kept at its default setting.

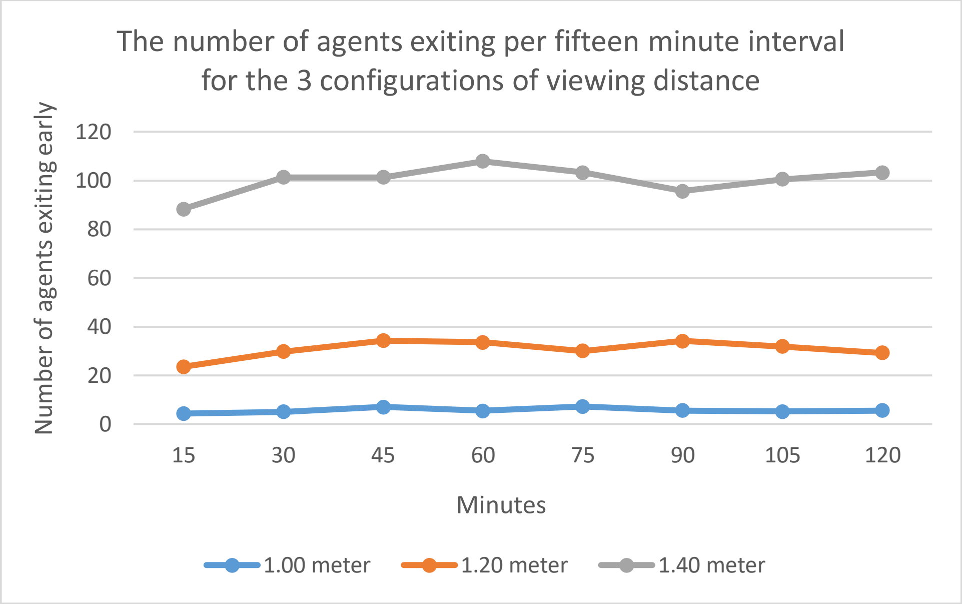


Figure 5.5: The number of agents exiting per fifteen minute interval for the 3 configurations of viewing distance

5.4 Adjusted Walking Speed

When analyzing the results of different walking speed configurations, the same trend is visible that has been seen in some configurations so far (figure 5.6). The deduction of 0.3 and 0.5 m/s have a similar starting point, after which the 0.5 m/s deduction continues growing. It additionally shows bigger alternations, whereas the 0.3 m/s deduction lingers at 27 agents exiting the model per quarter. The deduction of 0.7 m/s led to an overall increase of agents deciding to exit the street early. This can mean that a deduction of 0.7 m/s is too big of an adjustment, leading to congestion instead of ensuring a continuous walking flow. The general walking speed is a distance between 0.8 and 1.35 m/s, meaning that for the agents that already had a slower pace, deducing their pace with 0.7 m/s tends to almost stopping entirely. This can then result in new personal space intrusions for the agents walking behind them. This disrupts the concept of consciously lowering one's pace to have a faster agent 'walk out' of someone's personal space. The adjusted walking speed of minus 0.7 m/s leads to such a disruption of the continuous walking pace of the agents that there is an overall increase of agents leaving the street early comparing early quarter results with late quarter results. For the 0.3 m/s and 0.5 m/s settings, an overall increase over time is visible too, but less explicit.

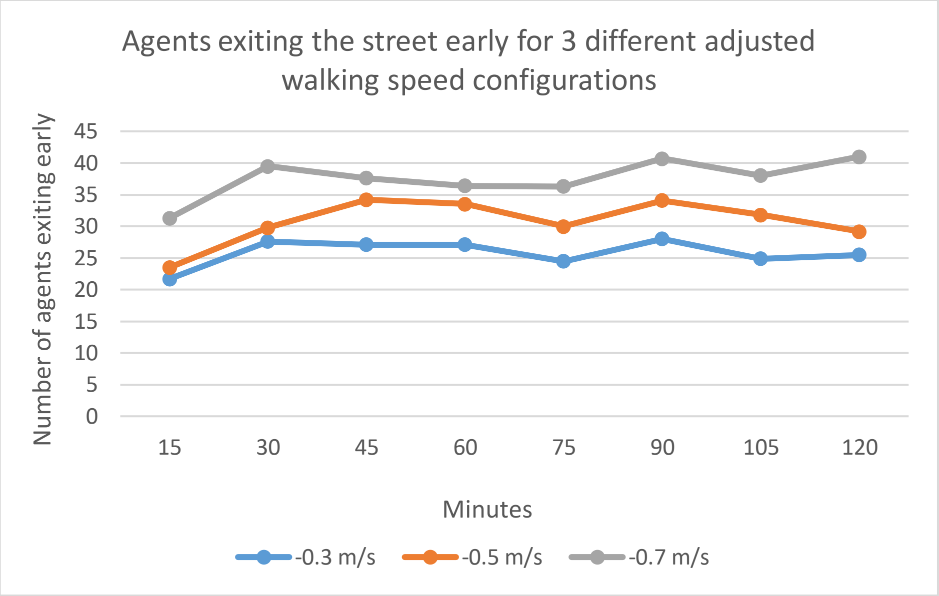


Figure 5.6: Agents exiting the street early for 3 different adjusted walking speed configurations

The figure below (figure 5.7) shows the average intrusion time for the three different settings. The grey curve representing the deduction of 0.7 m/s shows a higher average intrusion time, thus proving the idea that when increasing the adjusted walking speed (i.e. a slower walking pace), the general walkability of the street decreases. The grey curve does not follow the trend that is visible throughout previous settings and shows alternating half-hour periods of in- and decreases of average intrusion time. The blue curve representing the -0.3 m/s configuration also breaks with this trend, but has a similar average intrusion seconds as the default setting. A configuration allowing for certain pedestrians to reduce their pace while simultaneously maintaining the general walking flow of the street appears to be the most suitable.

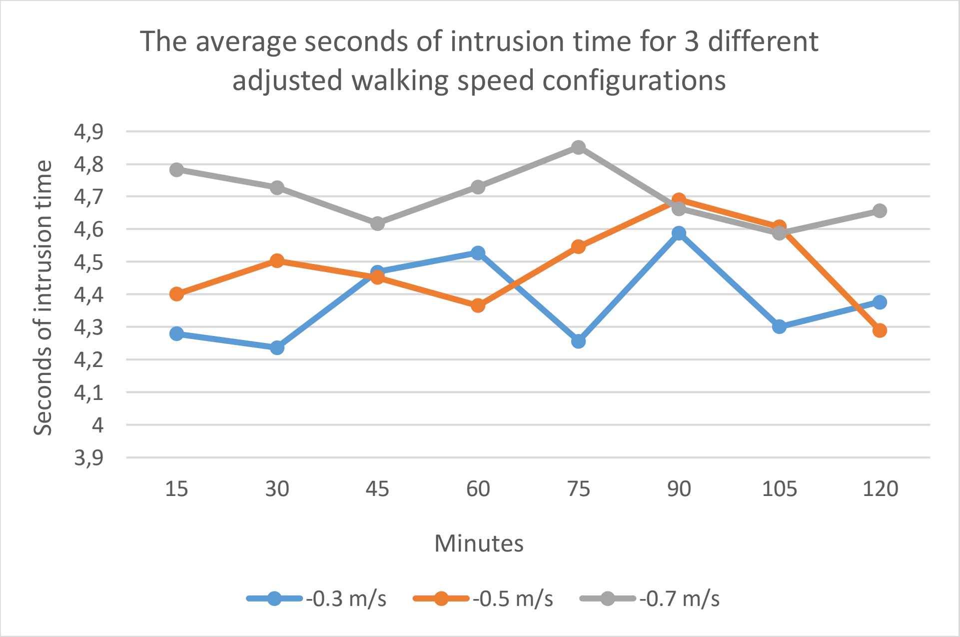


Figure 5.7: The average number of intrusion time for 3 different adjusted walking speed configurations

5.5 Obstacle repulsion distance

The default setting for the obstacle repulsion distance is 0.8 meter (von Sivers & Köster), and the alternative setting is set at the same distance as the personal space zone, 1.20 meters. Figure 5.8 shows the two configurations. An overall increase of agents deciding to exit the street early is visible for the alternative setting. A steep increase in the first half hour is followed by a much slower increase. Only after the first hour is passed, the number of agents exiting the street early stops increasing per quarter. The decrease after the 1 hour mark appears the have the same pace as the period between quarter 2 and quarter 4 and after the seventh quarter, the number of agents exiting starts growing again. It appears that the alternative configuration follows the similar trend-like behaviour, only spanning over a longer period of time. Further research might elaborate on the model behaviour of this setting. The difference in the curves is interesting however. As the four previous parameters have the same values ins the two configurations here, the differences in output are solely caused by a bigger repulsion distance. The extra 40 centimeters have repulsion distance to take into account appears to be make all agents detour in such a manner that they continuously hinder other agents in their path, while seeking an empty personal space for their own. It should not be forgotten that the model network is a relatively small confined area, meaning that they can only circumnavigate to a small extent and finding a place where no personal space intrusions occur is often unrealistic. Additionally, as the obstacle repulsion distance for the alternative configuration is set at 1.20, the avoidance strategy supersedes the strategy to first have agents adjust their walking speed, resulting in a higher number of agents detouring, leading to more personal space intrusions and ultimately to more agents exiting early.

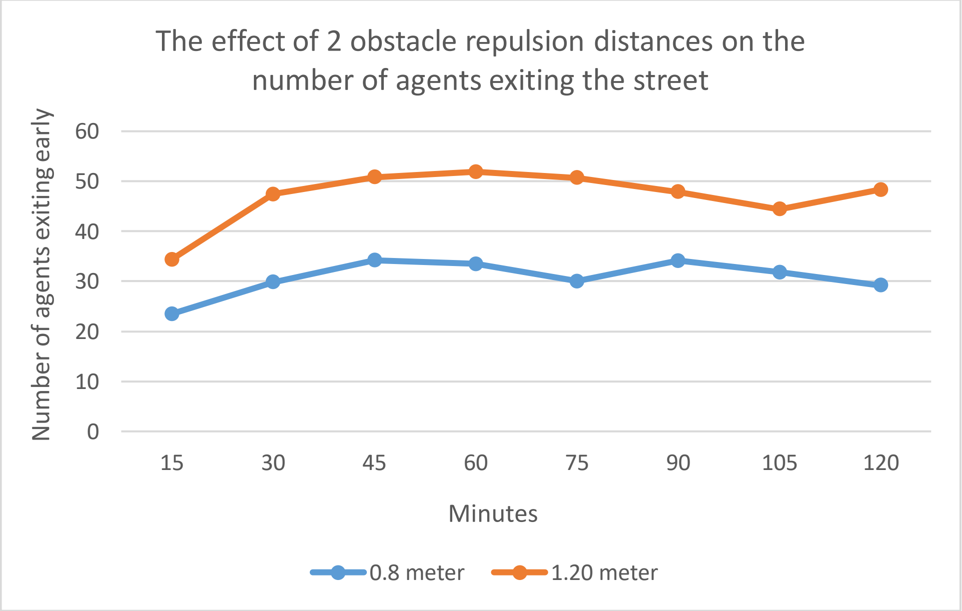


Figure 5.8: The effect of 2 obstacle repulsion distance settings on the number of agents exiting the street

5.6 Conclusion

This chapter analyzed the results from the sensitivity analysis. Default and alternative configurations were determined on the grounds of being derived from literature or being in relation to the environmental aspects of the area to be modelled, such as the size of the street. Seemingly small differences in some of the settings have shown to be of critical impact when determining their suitability for assessing crowding and carrying capacity. Regarding the tolerance of personal space intrusions in terms of seconds intruded, the optimal setting appears to be somewhat around the default value. As the average of intrusion time fluctuates around the 4.5, 5 seconds of intrusion time as a threshold value is reached too quickly. 15 intrusion seconds as a threshold value on the other hand makes feeling intruded too unique. For the saturation of personal space, allowing 2 agents in one's space theoretically complies with allowing certain people inside one's personal space, but it showed unsuitable in this study. First and foremost because familiarity is not added in the model, so there is no distinction possible of who is allowed in what space zone. Secondly, as a result of considering every other agent as an obstacle, 2 agents inside one's space hardly occurs under averagely busy crowded conditions. Chosen is to consider a single agent as an intrusion of personal space. For the viewing distance, the results varied greatly. Interestingly enough, a viewing distance of 1.00 meter lead to almost five times less agents exiting the street early in comparison to the default 1.20 meter, whereas the 1.40 meter viewing distance tripled the number of agents exiting the model early. Beforehand, it was assumed that these numbers would not show such diverging characteristics. Presumably, the configuration with the 1.40 meter viewing distance takes into account agents that are accidentally considered to be too close, as they now fall into the area that is used for the central agent to notice others but still be too far away for the central agent to apply its social force mechanisms. According to the same reasoning, before an agent enters the 1.00 meter consideration zone, social force mechanisms have already been put into play. As the 1.20 meter zone is derived from literature, this setting will remain the same. Regarding the adjusted walking speed, any deduction of pace seems sufficient as long as it doesn't lead to congestion of the general walking flow. For both the default setting and the 0.3 m/s deduction, this does not seem to be the case. The 0.7 m/s configuration causes an increase in both agents exiting early as well as average intrusion time, indicating that this configuration leads to congestion. As the default setting allows for agents to alter their pace while simultaneously allowing a general walking flow, this configuration will be used. The general implementation of social force has an interesting effect on the output. Two settings are tested, the general repulsive distance of 0.8 meter, as derived from literature, and the alternative configuration of 1.20 meter, as a derivative from the personal space zone from Hall (1966). For the four agent-related parameters, the default settings were applied. The adjustment to the obstacle repulsion variable to 1.20 meter has a great impact on the function of the model as a whole, considering it relates to a higher number of agents exiting the street early as well as an (apparent) increase in the fluctuate trend of agents exiting early. Regarding the latter, for this to be actually concluded from the sensitivity analysis, additional research over a longer runtime duration is required. While theoretically it would be valid to consider every other (single) agent inside Hall's 1.20 meter personal space as an object, setting 1.20 meter as a new default value would make its role in the functioning of the model too big, overshadowing parameters such as adjusted walking speed. Taking 0.8 meter as lower limit gives an agent the possibility to first, in the spare 40 centimeters, reduce their pace as a method of implementing social force instead of directly updating its direction. An interesting result from nearly every configuration is that over time, there is an increase in agents that have exited the model early per quarter.

6. Scenarios

In the previous chapter, different settings for the parameters were tested to determine their effect on the systems output. Section 5.6 concluded whether the default settings resulted in reliable outputs or if, based on the results of the sensitivity analysis, new default values should be applied. In the following chapter, two scenarios are implemented to check the model behaviour under different conditions. These scenarios are extreme crowding and different moderating values. Section 6.1 elaborates on the scenario settings, among which are the agents' spawning rate, the number of people partaking in a shopping activity in contrast to using the street for passage and alternative moderating values. Section 6.2 discusses the outcomes of the two scenarios.

6.1 Scenario settings

Scenario 1: Saturday before Christmas

The Saturday before Christmas is known as the busiest shopping day of the year. In the Kalverstraat, more than 100.000 people are expected to make an appearance (RMC, 2017). In 2013, the Kalverstraat was closed down temporarily, due to extreme visitor numbers. Scenario 1 simulates such a Saturday afternoon to investigate the models behaviour under unique but realistic crowding circumstances.

Agent spawn rate

Table 6.1 shows the numbers of agents spawning per quarter, as derived from the municipality of Amsterdam and by the RMC, as displayed in media. Per quarter, 4 agents will be spawned every second, meaning 3600 agents enter the street each fifteen minutes. The model simulates 2 hours, taking place in the afternoon, when shopping streets are expected to be busiest.

Table 6.1: Model duration and number of agents spawned per quarter

	time							
Minutes	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**
Nr of agents	3600	3600	3600	3600	3600	3600	3600	3600

Percentage window-shopping

In the default model settings, 80% of the agents partakes in window-shopping activities, and the remaining 20% of the agents use the street for passage. In scenario 1, the percentage agents partaking in window-shopping activities is set to 95%, and the remaining 5% of agents use the street for passage. In the days before a major holiday, general shopping behaviour of people is assumed to be higher than normal. Additionally, entering an extremely busy shopping street is presumably only done if necessary, and passing for leisure or merely for passage is kept to a minimum if there are other options (e.g. parallel street or alternative routes).

Scenario 2: A different view on moderators

After feeling intruded, the moderated crowding norm determines whether an agents exits the street early or not. This moderated crowding norm is the mean crowding norm multiplied by the moderating variables age and ethnicity, given to the agents upon initialization. The moderating variables are derived from literature, but the values are generally not so static. Even though the values only determine the range in which an agent is probable to exit early, the higher the values, the bigger the chance of an agent deciding to exit early. This scenario tests a variety of different moderating value combinations, in order to determine its effect on the probability of an agent deciding to leave. Table 6.2 shows the different values that are investigated in this scenario. These values are adjusted according to their assumptive effect on perceived crowding, as mentioned in section 2.5. People with an Asian background are generally less negatively affected by crowded situations. People with a non-Asian background are slightly more affected by crowded situations. In scenario 2, the moderating values are adjusted accordingly. Agents in the Asian group are assigned lower moderating values in relation to the default value, due to them being less negatively affected. Agents in the non-Asian group are assigned higher values in relation to the default value. In this scenario, the values regarding age are adjusted according to the same principle. Older people tend to have a higher tolerance on crowded situations than younger people, as younger people are more fond of their personal space. The group of agents in the above 40 group are assigned lower moderating values in comparison to the default value for this category, agents in the below 40 group are assigned higher values than its default. In the table below, values depicted in bold indicate the default value for that moderating variable.

Table 6.2: Moderating variables and their test settings (as derived from Chattaraj, Seyried & Chakroborty, 2009; Jacobsen et al., 2019). Values in bold are the default values

Asian	Non-Asian	Above 40	Below 40
0.4	**1.2**	**1.3**	0.3
0.6	1.4	1.5	0.5
0.8	1.6	1.7	**0.7**

The default model settings are used to examine this scenario. This means the model is simulating an average crowded situation, such as described in table 3.4. Additionally, the default window-shopping rate of 80% is applied.

6.2 Scenario results

Scenario 1: Saturday before Christmas

In scenario 1, the effect of visitor numbers is under investigation. The agent spawning rate in this scenario is in line with the busiest day of the year. With such high numbers of agents active in the model, and continuously spawning every cycle, the computer runtime increased extensively. Additionally, with a 95% window-shopping rate, agents continuously crossed paths resulting in a lot of detour, also taking up quite some computational power.

A similar visualization method of the results of this scenario is applied as was done for the sensitivity analysis, meaning quarterly measures of average agent intrusion time, the total number of intrusion seconds and the number of agents exiting early. The cumulative numbers of agents exiting the street early were calculated to establish the number of agents leaving per quarter instead of showing absolute numbers. In comparison to the default setting, the number of agents leaving the street early in scenario 1 grew linear too. Obviously, the total leaving rate is much higher for scenario 1, due to the double amount of agents walking the street. Subsequently, the average intrusion seconds is far above the 10 seconds threshold, having higher numbers of agents determining whether they want to leave or not. Figure 6.1 shows both curves depicting the total trend of agents leaving the street early.

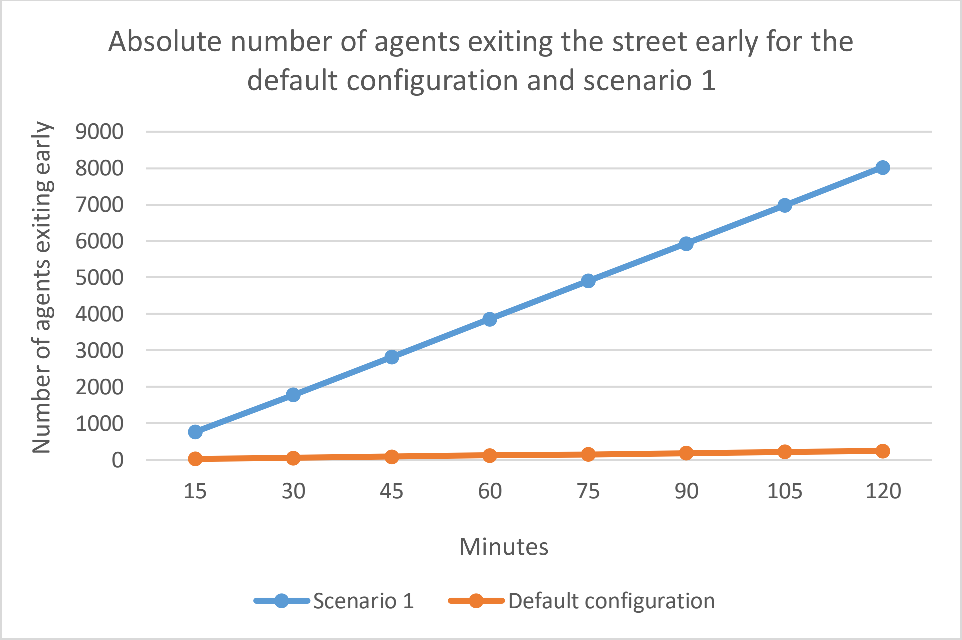
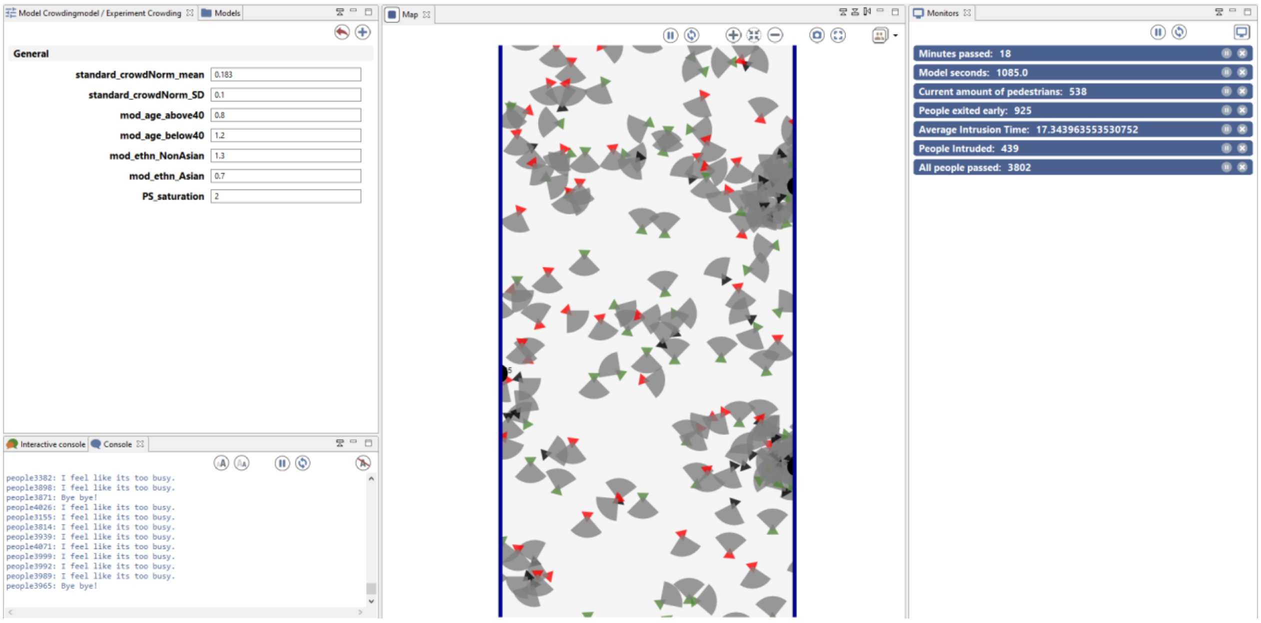


Figure 6.1: Total numbers of agents exiting the street early for the default configuration and scenario 1

Regarding the agent spawn rate, twice as many agents were spawned in scenario 1 than in comparison to the default settings (respectively table 6.1 and table 3.4). When comparing the blue and orange curve, however, the increase in agents exiting early increased massively. Around the 8000 agents exited the model early in Scenario 1 after 2 hours in comparison to around 250 for the default setting, indicating an increase of approximately 32 times. Interestingly enough, as can be observed in the figure above, the path of the blue curve increases steadily with roughly 1000 agents per quarter. This could mean that even though vast numbers of agents use the street and are walking in each other's personal space, there is still a general walking flow. Another reason, as can be perceived in the figure below (figure 6.2), is that there are physical limitations for leaving the model. In figure 6.2, the two top right exits show serious congestion problems, making it impossible for agents to exit the street. This might lead to a distortion in the total leaving number. Agents wanting to leave is the result of having their personal space intruded for at least 10 seconds. Agents moving north generally walk on the right side of the street, and the double congestion in figure 6.2 occurring only at the right side of the street leads to a sudden increase of intrusion seconds. Walking through these instances of congestion could easily ensure many agents too surpass the 10 second threshold, making them decide on whether to stay or not. The resulting number of agents wanting to leave due to these local congestions have little to do with the actual crowding of the street. This problem exposes a modelling flaw, which in further research should be overcome. Agents pick the exit closest to them once they decided to leave. If the motive for leaving is experienced crowding, it doesn't make sense to stand in line for the nearest exit. In future modelling endeavors, agents should pick the nearest, least crowded exit. Especially for the upper right exit this is an awkward problem, as the main entrance, which does not shows excessive congestion at all, is fairly close by.



General

standard_crowdNorm_mean: 0.183
standard_crowdNorm_SD: 0.1
mod_age_above40: 0.8
mod_age_below40: 1.2
mod_ethn_NonAsian: 1.3
mod_ethn_Asian: 0.7
PS_saturation: 2

```
people3382: I feel like its too busy.
people3898: I feel like its too busy.
people3871: Bye bye!
people4026: I feel like its too busy.
people3155: I feel like its too busy.
people3814: I feel like its too busy.
people3939: I feel like its too busy.
people4071: I feel like its too busy.
people3999: I feel like its too busy.
people3992: I feel like its too busy.
people3989: I feel like its too busy.
people3965: Bye bye!
```

Minutes passed: 18
Model seconds: 1085.0
Current amount of pedestrians: 538
People exited early: 925
Average Intrusion Time: 17.343963553530752
People Intruded: 439
All people passed: 3802

Figure 6.2: Screenshot of the network showing congestion at the two top right exits

The figure below (figure 6.3) shows the effect of the crowding conditions simulated in scenario 1 and the default configuration. Where in the average crowded situation (orange curve), an equilibrium-like state was reached of average personal space intrusions in terms of seconds, the effect of extreme visitor numbers (blue curve) on this parameter turns out to be somewhat disruptive. The blue curve in figure 6.3, representing the average of intrusion time seconds measured in scenario 1, shows alternating in- and decreases of this variable, having only quarter 5 and 6 diverting from this trend. Obviously, the higher number of intrusion seconds is due to twice as many agents in the same confined space. Regarding the curve behaviour, it can be assumed that next to the high number of agents wanting to leave anyway, periods of higher intrusion time are followed by an increase of agents leaving, resulting in fewer agents in the street, thus more free space available for walking, resulting in a temporary decrease of intrusion time and thus a decrease in the number of agents wanting to leave extra. An overall decrease of agents leaving is not occurring, as the general average intrusion seconds is never under the 15 seconds.

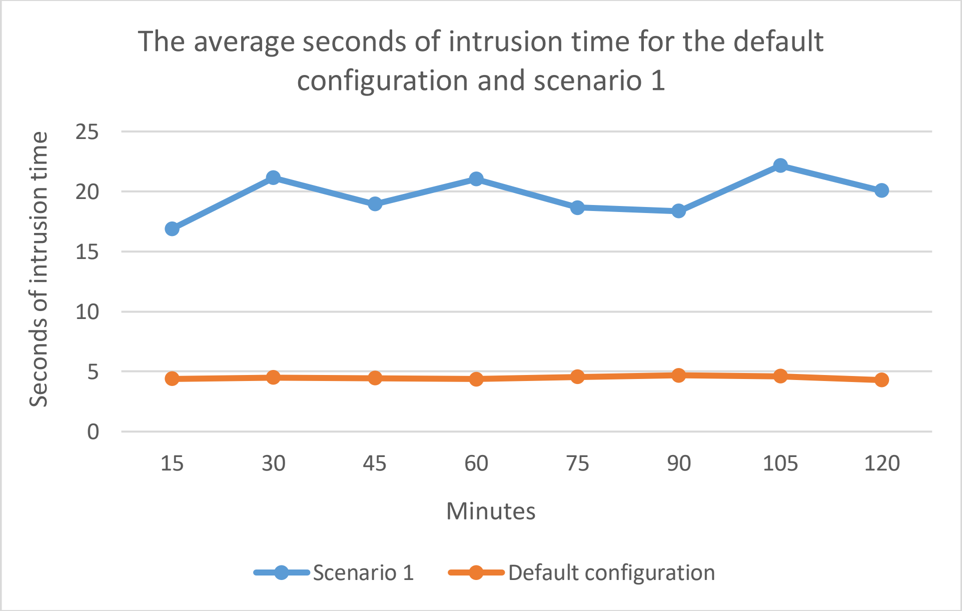


Figure 6.3: The average number of intrusion time for the default configuration and scenario 1

Figure 6.4 shows the cumulative number of agents exiting the street early. The same van be observed in this figure as was noticed in figure 6.1: a steady increase of roughly 1000 agents exit the street each quarter, with the exception of the first quarter. It appears that for the configuration of scenario 1, a critical point is reached. After a steep increase to the half hour mark, the growth is suddenly cut off, followed by a nearly stable curve of around 1000 agents leaving per quarter. This is around 28% of the agents spawned in the same time span (1000 out of the 3600). After the half hour mark, the curve behaves according to trend as seen before, albeit only just. This seemingly upper limit of early exits might be due to the congestion that is occurring around the exits, where agents want to leave but aren't able.

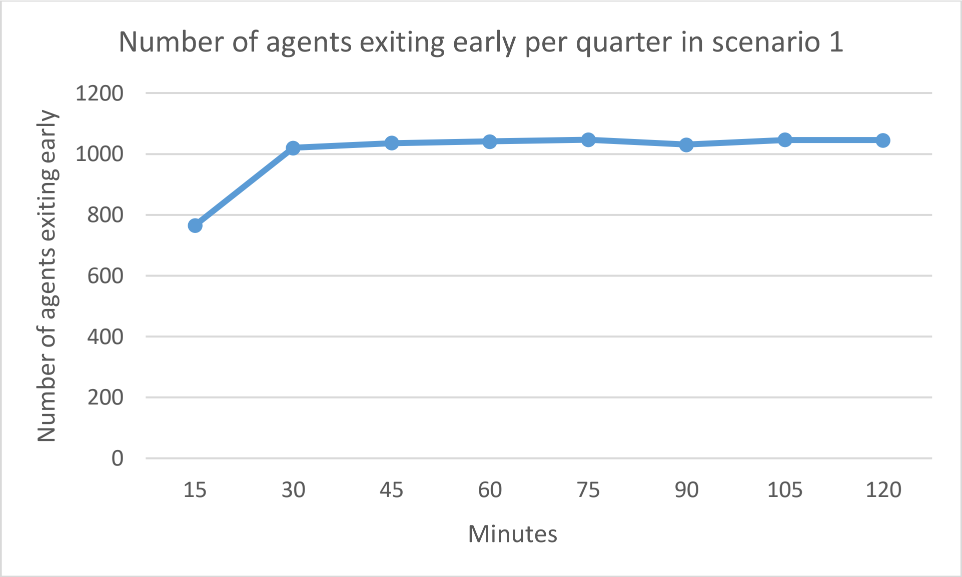


Figure 6.4: Number of agents exiting early per quarter in scenario 1

Once local congestion occurs, it is difficult for the situation to gradually resolve. As every agent behaves according to its Social Force mechanisms, there will not be any 'waiting in line' or other self-organizing methods of exiting the street as soon as possible. This particular type of behaviour is not implemented in the model. Instead, agents that are part of the congestion will continuously update their walking direction as their personal spaces are continuously intruded because of the many agents looking for a place in a confined area (the exit). This makes for a chaotic congestion impossible to naturally resolve, ultimately leading to a bigger congestion.

Scenario 2: A different view on moderators

In scenario 2, the perception of personal space is investigated. This perception is defined according to the moderated crowding norm, and if requested, determines the probability of an agent exiting the street early or not. As mentioned in previous sections, the variables age and ethnicity have a moderating effect on the mean crowding norm. These moderators, which are adapted from Chattaraj, Seyried and Chakroborty (2009) and Jacobsen et al., (2019), are adjusted to determine the effect on critical output variable of exiting the street early. The adjusted values are described in table 6.2.

The method of visualizing the results of Scenario 2 is different than in previous result sections. The reason for this is that the results are derived differently. The results for scenario 2 are not meant to show in-model agent behaviour, but the effect of the moderating variables on the critical output variable of early exits. The batch result function in the GAMA modelling software allows for a set of model runs, where all possible value combinations for the moderators are tested. Retrieving results this way allows for comparison between the model runs and their settings.

Table 6.3 shows some of the value combinations, categorized in specific settings. The default setting is marked in yellow. The full table of combinations can be seen in appendix 1. The default configuration assumes a slightly moderated setting, as is discussed in literature (Chattaraj, Seyfried & Chakroborty, 2009; Jacobsen et al., 2019), where the effect of the parameters on the mean crowding norm is only just. The effect is an early exit rate of roughly 1.5% of all agents.

Table 6.3: Settings for the moderatos and their effect on the percentage of agents exiting the street early

Setting	Above 40	Below 40	Non Asian	Asian	Avg Intrusion time	Perc_exit
Extreme	0.4	1.6	1.7	0.3	5,058064516	2,02469136
Age extreme	0.4	1.6	1.3	0.7	4,342657343	1,81920745
Ethnicity extreme	0.8	1.2	1.7	0.3	4,375	2,24322799
Default	0.8	1.2	1.3	0.7	4,380952381	1,55897291
All high	0.8	1.6	1.7	0.7	4,260869565	2,2627943
All low	0.4	1.2	1.3	0.3	4,549295775	1,3119842

In the table, marked as green, the combination of outlying values is displayed. This combination shows a more extreme form of moderation, where the differences in the moderated crowding norm are presumably bigger. The percentage of early exits is higher than for the default setting, but only just. The two settings marked in orange show a combination of half extreme and half moderation for the two parameters. The 'age extreme' setting has adopted the outlying values for the age parameter, while keeping the default values for ethnicity. The 'ethnicity extreme' setting has adopted the outlying values for the ethnicity parameter, while keeping the default values for age. When comparing the two values for percentage early exits of the two orange settings with the percentage early exits for the green setting, one notices that the early exit percentages of all three settings are fairly close.

When comparing the relative differences of the percentages early exits in table 6.3, the difference are quite high. Especially between the 'age extreme' and the 'ethnicity extreme', the effect on the critical output variable is remarkable. The 'ethnicity extreme' variable is fairly close to the highest measured output variable. Perhaps this is caused by the spread of the agents for the different moderators. As was explained in section 3.3.3 the moderating value is assigned according to the distribution of that moderator in the Amsterdam urban region. With 88.7% of the agents being Non-Asian, a higher multiplier for this group of agents can lead to a higher percentage of agents exiting early. Another test for determining whether the different settings have any effect on the percentage early exits, is testing the parameters at the 'highest' and 'lowest' value combinations. These two settings are named 'all high' and 'all low' and are marked in grey in the table above. The outputs are considerably different in relation to the differences in other value combinations. The all high setting shows an early exit rate of 2,26% in comparison to the 1,31% for the all low setting. The use of moderating variables appears to have somewhat of an influence in the assessment of carrying capacity.

The results depicted in table 6.3 are only a few of all the combinations. For this scenario, all value combinations from table 6.2 were tested, meaning that the total table in appendix 1 consists of 3*3*3*3 = 81 different configurations. Considering that the other 79 configurations all have values between the all low and all high configurations, the question arises how strong the idea of moderating parameters in relation to perceived crowding is.

An influence that is presumably stronger than personal preferences, is crowding expectation. While not included in this study, it is expected to have a critical effect on the carrying capacity of an area. According to Machleit, Eroglu and Mantel (2000), negative emotions and stress occur if high levels of crowding are unexpected and if the individual has a low tolerance. The tolerance part of this statement is accounted for in this study, but the expectation part is not. Especially in crowded situations with people having different objectives, expectation can have a moderating effect on the perceived crowding (Blut & Iyer, 2019). Future agent-based simulation endeavors on the topic of carrying capacity and crowding should go deeper into effect of expectation.

7. Conclusion

The aim of this study was to develop a framework and a simulation model that provides insight into the effect visitors have on the carrying capacity in Amsterdam. In this chapter, the study will be concluded by firstly answering the five research questions and secondly, by elaborating on the main research objective. The conclusions of this study will be presented for each research question.

RQ1: What is carrying capacity and what are its indicators?

In many different fields of study, carrying capacity is used as a concept to illustrate that there is no such things as limitless growth without a system suffering from structural damage. Different authors have come up with alternative definitions for carrying capacity and ways of assessing it, making it a challenge to compress the various definitions in order to apply it in an agent-based simulation. All definitions, however, contain two aspects. The first aspect is a bio-physical component. This relates to an implicit threshold value of a recourse that if exceeded, deterioration as a result of over-exploitation will occur. The second aspect is a behavioural component, relating to the experience causing the exploitation. Crowding is generally associated with situations where an individual perceives that the carrying capacity of an area is exceeded, resulting in some form of displeasure. As agent-based simulations uses autonomous agents (e.g. individuals) to check for possible emergence, crowding was used as defining principle of carrying capacity in this study. Moreover, crowding uses the same two aspects of carrying capacity. It relates firstly to others in a direct vicinity of a central person, and the number of others exceeding the threshold of how many are allowed in that direct vicinity. Secondly, it relates to the experience this provokes. Once carrying capacity is exceeded, the demand for space has overgrown the supply of it. In crowding phenomena, this translates to any situation where an individuals' encounter with another individual results in a higher demand of space. The indicators of crowding are in this study expressed in terms of personal space, ethnicity and age. An additional indicator, which is fixed, relates to place. In this study, this was the physical layout of a street, limiting the demand of space.

RQ2: How can these indicators be formalized into a scheme applicable to agent-based modelling?

The formalization of crowding and its indicators was the next operation in this study. Some of the indicators required to assess crowding were quite obvious. One of these was the implementation of personal space as a way of assessing crowding, by checking how frequently this space was intruded. Some of the indicators remained uncertain such as the effect of moderators (age and ethnicity), and the effect different moderator configurations had on the model. Another uncertainty resided in the question how many seconds of personal space intrusion should be the threshold in order to determine when crowding occurs (and carrying capacity is reached). All indicators were tested in the results chapter and the scenarios chapter. In order to measure the effect of different indicators and settings, an output variable was determined to express crowding. This output variable was the number of agents that decided to exit the street early, because of the agents' experienced crowding and subsequent attitude towards crowding. In this study, the objectives were set as window-shopping or using the street for mere passage. Instances of diverting from achieving one's objective, such as decreasing walking speed or walking around a fellow pedestrian, were categorized as an intrusion of personal space. Intrusions of personal space led to the inability to achieve one's objective. Agent-based modelling was considered a suitable method in determining crowding, as crowding is experienced on an individual scale.

RQ3: What are the spatiotemporal characteristics of the case study area in relation to the carrying capacity indicators?

The spatiotemporal characteristics of the case study area turned out to be critical in the assessment of carrying capacity. Not only is the free space that every pedestrian is trying to obtain for themselves limited by the physical boundaries of the street, commercial and tourist related areas inherently have to deal with varying terms of crowding. Scenario 1 uncovered a key bottleneck in the research area. A 'Saturday before Christmas' situation was simulated by having large numbers of pedestrians making use of the (limited) street space. This resulted in congestion, as too many pedestrians chose to exit the street early due to them feeling crowded. The number of agents exiting the street quickly rose to 1000 after which the curve instantly stagnated and lingered at around a 1000 agents exiting per fifteen minutes. Agents stuck to the exit they wanted to leave through, being unable to physically reach that exit because of them constantly diverting from others as to not have their personal space intruded. By now it is obvious that the limitation of physical space is pressing strongly on peoples' ability in achieving their objective, when visitor numbers increase heavily. Any other day, however, the model behaves properly, and congestion-like instances are not observed either visually or by interpreting the output. This means that at least the temporal characteristics of the area for which the carrying capacity is being assessed is of critical importance. For the spatial characteristics, this is assumed to be the same. As agents are limited by the confined space they move in, a bigger space also means more walking space. Different study areas were, however, not tested in this study. There is a critical limitation in expressing carrying capacity as just a numerical number, and this is the results of the spatiotemporal context of any specific study area. As also confirmed in literature, part of perceiving any situation as crowded, is expectation. Excluded in this model, but seemingly of significant importance, is the expectation of a street being busy. This makes people either not visiting the street in the first place, or adjusting their tolerance of what they are going to expect. As scenario 2 shows some limited influences of the different personal moderators on the percentage of people exiting the street early (roughly 0.95% over a range of 81 different settings), additional studies need to be performed on moderating variables. Especially expectation as a moderating variable can be of critical influence (Blut & Iyer, 2019). With expectation being added into the model, however, the street will not become any less packed with visitors. It is the author's assumption, however, that with expectation as moderator, the model will behave more naturally and carrying capacity will obtain the dynamic character that is underlined by some studies.

RQ4: How is carrying capacity influenced?

The results chapter discusses the influencing factors of carrying capacity. The indicators regarding the size and the saturation of personal space showed the most extreme results. Adding 20 centimeters to the personal space size led to an extreme increase in agents exiting the street prematurely, whereas decreasing the personal space size with 20 centimeters did not show a comparably lower number of agents exiting. It is a powerful indicator, with a big effect on the carrying capacity, but the functioning of the indicator should be investigated more. Perhaps the moderating effects of age and ethnicity should be implemented in the personal space size instead of as a multiplier to the crowding norm, allowing different sizes of personal space to be present in the model. Allowing more agents inside one's personal space, as some form of adding familiarity, also proved to be a powerful indicator, but not in the current interplay of all indicators. The different indicators all have a certain effect on the number of agents exiting the street early, but the different indicators are part of the model as a system, not individual entities. Adjusting one indicator, as is done for the sensitivity analysis, can thus have considerable effect on the output variable. For the saturation of personal space, adding only one extra pedestrian to the tolerance level of personal space led to a dysfunctioning model, where zero agents decided to exit the street early. The number of people that are allowed in ones' personal space seemingly correlates with the size of personal space. The combination of these two indicators appear to have a high potential of determining carrying capacity, but need to be investigated further. Less dominant factors for determining carrying capacity is the adjustment of walking speed, where even though differences in output was observed, it appeared to have little effect. Further research on the collaboration of the indicators and the dynamic character of carrying capacity is advised.

RQ5: To what extent is the model representative to simulate the carrying capacity of a destination according to pedestrian presence?

This model contributes to the exploration of carrying capacity by means of agent-based modelling. It focusses on letting each individual agent achieve its objective (window-shopping or using the street for passage) and determines whether an agent has the feeling its crowded or not based on its personal space being intruded. For a model, which is a simplification of a real world system, this shows promising results. Unfortunately, comparing the output variable early exits with real world numbers on counts of passerby's in the Kalverstraat was not possible. Communication efforts to retrieve actual data on this manner remained unanswered from the municipality of Amsterdam (see chapter 8). Even though contact was established, the correct data to calibrate the model was never sent. By calibrating the model in such a manner that the number of pedestrians exiting the street early would align with real world data, stronger conclusions could be made on the functioning of the model.

Carrying capacity can be related directly to crowding, which is a result of pedestrian dynamics. Pedestrian dynamics are extremely suitable to study by means of agent-based simulation. The simulation on pedestrian dynamics (including the avoidance strategies) seems to have a high degree of face validity. The behavioural preferences that reside in carrying capacity (i.e. crowding norms, personal space sizes and moderators), however, cannot be called valid with the same level of confidence. The model's input data was derived from literature and municipal documents. The model's output, however, was never tested by means of expert validation. Additionally, calibration to tweak the model output didn't take place. This limits the ability to call the model a representative simulation of carrying capacity of a destination according to pedestrian presence and model validity can only be partially awarded.

To conclude, this study was set out to achieve the main research objective:

To determine the carrying capacity at street level in Amsterdam by firstly defining carrying capacity and its indicators and secondly simulating the interactions of visitors in relation to the spatiotemporal characteristics of the research area.

This objective was achieved to such an extent that the model can be used for simulating crowding in front-country (urban) areas. This model has proven to be a functioning system in checking the effect of carrying capacity indicators, and to what extent the model functions if these indicators are adjusted. Simulating behaviour, however, will always be a difficult endeavor. Walking preferences and crowding perception are eminently concepts operating on a psychological level, and are difficult to capture in a model. While this study is a first step in linking carrying capacity to individuals and simulating their interaction, future research should be aware of this.

8. Discussion

In this final chapter, the limitations and recommendations of this research will be discussed. While this study has shown interesting results in the assessment of carrying capacity by means of agent-based modelling, there are some topics that need to be discussed.

To start with, the supposed dynamic character of carrying capacity was not implemented properly. It is mentioned multiple times that carrying capacity is no static concept. Its definition is dynamic as well as the way of assessing it, both in a general understanding of the concept as in a tourist specific context (Chung 2009; Shi, Wang & Yin, 2013; Koens, Postma & Papp, 2018). The implementation of the concept in this study, however, still appears to be rather static. It is assumed that space and time influence carrying capacity (Saveriades, 2000), and the spatiotemporal aspect of carrying capacity was tested in scenario 1. Scenario 1 proved that the number of people as a result of a specific moment in time affects the carrying capacity, but this scenario was specifically designed for that. The underlying dynamic character of carrying capacity was failed to be implemented directly into the model, for instance through another critical crowding indicator: expectation (Blut & Iyer, 2019). Expectation as a moderating effect on the perception of crowding would have made the use of carrying capacity in this study more worthy of its definition. Knowing what to expect in terms of visitor numbers influences either peoples' tolerance levels or has people not visiting at all. This would have contributed to the models' validity, and the current outcomes as a result of missing an expectation variable should be analyzed critically. To continue on this model being too static, the moderators of the crowding norm and the crowding norm itself are missing a dynamic touch. To start with the crowding norm, as derived from (Neuts & Nijkamp, 2012), the percentage of agents that evaluated a crowded environment as negative was taken as norm in this study. While their study displayed a similar situation as this study (tourists in front country urban areas), evaluations of certain situations are highly time and location specific, and such results can hardly be applied in other situations as normative behaviour. The uncertainty that is involved with applying such values is inevitable. Extensive, cohort-like studies exemplifying crowding among tourists in Amsterdam shopping streets would fit this study better, but this information does not exist. Applying results from a different study with different time and location specific characteristics as a normative input to perception leads to the results being a bit uncertain. The same applies to the moderating effects of age and ethnicity, which are implemented statically. Derived from Chattaraj, Seyried and Chakroborty (2009) and Jacobsen et al. (2019), the use of these variables as moderating effect on the perception of crowding makes perfect sense. They have also been empirically proven to differ between groups of people. In hindsight, however, it would have made more sense to link the evaluation of a crowded situation to the personal space of the agents. In the current model, these are two separate entities operating in a sequential manner (the moderated crowding norm is only applied if the agent's personal space is intruded more than 10 times), whereas the model would be more realistic (thus representative) if these two entities are active simultaneously. In future studies, this could be investigated along the lines of different sizes of personal space according to the crowding norm.

A critical note has to be made regarding the personal space or viewing distance of the agents. In the model, the viewing distance had the same extent as what is considered personal space by Hall (1966) and agents only noticed other agents if they were within this viewing distance. While this is the correct way of determining intrusions of personal space, it leaves out the ability for agents to experience crowding on a bigger scale. Literature affirms that crowding is experienced at an individual level (Neuts, Nijkamp & Van Leeuwen, 2012), so again the effort of expressing carrying capacity into individual instances of crowding makes sense. In reality, however, people's viewing distance is much bigger, and noticing other people, subsequently perceiving an area as crowded, occurs outside the viewing distance as well. I assume that pedestrians make routing choices based on a bigger viewing range than just the 1.20 meter range applied in this study. This noticing of agents of agents at a farther distance, subsequently altering their behaviour, can be linked to the previous remark on expectation as a missing variable. Adding a bigger viewing distance for a pedestrian to determine its walking choices would have added to the complexity of carrying capacity.

In this study, the number or percentage of agents exiting early was used as variable to assess the effect of the model. Some of the models' assumptions discussed the walking preferences of the agents, ultimately influencing the early exit variable. These assumptions included agents exercising social force, agents only walking towards their objective, and perceived crowding as a result of agents having to perform avoiding strategies. These assumptions were implemented into the model, but perhaps the assumptions were defined too broadly. Let's take a closer look at agents walking towards their objective, for instance. In the current situation, the agents use a Pythagorean path of visiting a store before exiting the street, resulting in a less realistic use of the street. The shortest way is now determined when the objective is set, meaning either upon initialization or when the objective is changed from store to exiting the street. In the real world, people do not use the shortest direct path towards a store from the point of entering the street, but presumably the path with the least resistance from obstacles. This leads to much less hindering of others, influencing the output variable early exits. It seems that if the assumptions would have been formulated sharper, this could have been foreseen. The walking trajectory as mentioned before is not investigated in this study, but it can be assumed to have a large impact on early exit variable. This shows us that formulating model assumptions influence the model design and output. The current path agents use to reach their objective is not wrong, but if the model assumptions would have been investigated critically at an earlier stage, the model would have portrayed a more realistic situation.

It is unfortunate that the overall functioning of the model was not tested compared with real world data. Efforts made to retrieve data from the Amsterdam municipality on passerby's of the Kalverstraat and data regarding pedestrians exiting the Kalverstraat early remained unanswered. In the past, the municipality deployed Bluetooth and wifi-tracking mechanisms for crowd management. Sensors picked up wifi or Bluetooth signals from people's phones, counting the number of passerby's in the street. For calibration purposes, contact was made with the municipality of Amsterdam to get some of the data that was stored over time. Specifically, data was requested that counted the number of pedestrians using the street, and whether there was a difference in people's phones being captured by two sensors, indicating they completed passage through the street, or by one sensor, as a possible indication of people exiting the street through one of the side streets or alleys. Contact with the municipality on using this data was established, but the data was never received. Checking the model output with real data would have proven extremely beneficial to this study. In addition to this, expert validation is a missing feature. An expert has the ability to share insights that the modeler lacks, resulting in a more representative model.

Regarding the temporal extent of this study, the model's output exposed some interesting trends in agents exiting the model early and in intrusion time. As for the trends, especially when investigating the effect of the obstacle repulsion distance in section 5.5, the 2 model hours that the runtime was narrowed down to seems too little to find any bigger trends. Increasing the model runtime would require additional computational resources, which were unavailable in the scope of this research. Considering that over a 2 hour runtime period, each agent is determining its path to follow while simultaneously checking its direct neighbourhood whether there is no one in its personal space with every step, additionally choosing an obstacle repulsion technique while being physically drawn to their target. Especially when running scenario 1, the actual runtime for a single run can take up one hour. Trend like behaviour was already distinguishable in 2 model hours, however, increasing the model runtime with bigger computational resources would increase the quality of the output. The same applies for the 15 minute intervals in which output was created. Higher detail of results would increase the model's quality and perceptibility of trends, but was deemed insufficient due to the computational recourses required.

For now, the possibility of formalizing carrying capacity indicators lingers at a level of investigating the effect an indicator has on a model. Useful conclusions can be derived from this, for instance whether checking if there is a difference in the maximum of other people allowed in one's personal space. However, due to the inability to cross-reference the model output with the real situation, determining the optimal formalization of an indicator remained unanswered. As a result, this study is a steppingstone to future research on the assessment of carrying capacity on street level by means of agent-based modelling. This study contains recommendations for future modelling endeavors.

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10. Appendices

Appendix A

Above 40	Below 40	Non Asian	Asian	Avg Intrusion time	Early exits	People passed	Perc_exit
0.4	1.2	1.3	0.3	4,55	186	14177	1,311984
0.4	1.2	1.3	0.5	5,01	206	14178	1,452955
0.4	1.2	1.3	0.7	3,97	211	14182	1,487801
0.4	1.2	1.5	0.3	5,06	252	14179	1,777276
0.4	1.2	1.5	0.5	4,32	224	14181	1,579578
0.4	1.2	1.5	0.7	4,26	250	14187	1,762177
0.4	1.2	1.7	0.3	4,53	294	14182	2,07305
0.4	1.2	1.7	0.5	4,48	263	14184	1,854202
0.4	1.2	1.7	0.7	4,17	252	14185	1,776524
0.4	1.4	1.3	0.3	4,7	242	14177	1,70699
0.4	1.4	1.3	0.5	4,54	256	14179	1,805487
0.4	1.4	1.3	0.7	4,67	242	14175	1,707231
0.4	1.4	1.5	0.3	4,56	280	14180	1,974612
0.4	1.4	1.5	0.5	3,78	239	14187	1,684641
0.4	1.4	1.5	0.7	4,54	272	14171	1,919413
0.4	1.4	1.7	0.3	4,25	283	14181	1,995628
0.4	1.4	1.7	0.5	4,1	279	14179	1,967699
0.4	1.4	1.7	0.7	4,1	281	14174	1,982503
0.4	1.6	1.3	0.3	4,07	269	14178	1,897306
0.4	1.6	1.3	0.5	4,4	248	14183	1,748572
0.4	1.6	1.3	0.7	4,34	258	14182	1,819207
0.4	1.6	1.5	0.3	4,45	259	14184	1,826001
0.4	1.6	1.5	0.5	4,4	292	14177	2,059674
0.4	1.6	1.5	0.7	3,73	313	14186	2,206401
0.4	1.6	1.7	0.3	5,06	287	14175	2,024691
0.4	1.6	1.7	0.5	4,01	331	14185	2,333451
0.4	1.6	1.7	0.7	3,78	292	14178	2,059529
0.6	1.2	1.3	0.3	4,21	226	14180	1,593794
0.6	1.2	1.3	0.5	4,64	223	14172	1,573525
0.6	1.2	1.3	0.7	4,96	237	14179	1,671486
0.6	1.2	1.5	0.3	4,74	262	14177	1,848064
0.6	1.2	1.5	0.5	3,97	273	14187	1,924297
0.6	1.2	1.5	0.7	5,09	290	14175	2,045855
0.6	1.2	1.7	0.3	3,89	258	14185	1,818823
0.6	1.2	1.7	0.5	4,48	274	14177	1,932708
0.6	1.2	1.7	0.7	4,48	323	14176	2,278499
0.6	1.4	1.3	0.3	4,89	284	14171	2,004093
0.6	1.4	1.3	0.5	3,83	238	14186	1,67771
0.6	1.4	1.3	0.7	4,56	238	14174	1,679131
0.6	1.4	1.5	0.3	4,78	277	14172	1,954558

0.6	1.4	1.5	0.5	4,39	259	14179	1,826645
0.6	1.4	1.5	0.7	4,95	273	14180	1,925247
0.6	1.4	1.7	0.3	4,85	298	14180	2,101551
0.6	1.4	1.7	0.5	4,67	315	14179	2,221595
0.6	1.4	1.7	0.7	4,68	327	14178	2,30639
0.6	1.6	1.3	0.3	4,54	233	14180	1,643159
0.6	1.6	1.3	0.5	4,81	277	14181	1,953318
0.6	1.6	1.3	0.7	4,48	268	14180	1,889986
0.6	1.6	1.5	0.3	4,31	312	14180	2,200282
0.6	1.6	1.5	0.5	4,7	280	14172	1,975727
0.6	1.6	1.5	0.7	4,76	294	14173	2,074367
0.6	1.6	1.7	0.3	4,22	331	14178	2,334603
0.6	1.6	1.7	0.5	4,88	325	14176	2,292607
0.6	1.6	1.7	0.7	4,38	334	14188	2,354102
0.8	1.2	1.3	0.3	4,83	216	14168	1,524562
0.8	1.2	1.3	0.5	5,03	247	14179	1,742013
0.8	1.2	1.3	0.7	4,38	221	14176	1,558973
0.8	1.2	1.5	0.3	4,7	293	14175	2,067019
0.8	1.2	1.5	0.5	4,34	257	14178	1,812668
0.8	1.2	1.5	0.7	4,84	266	14175	1,876543
0.8	1.2	1.7	0.3	4,38	318	14176	2,243228
0.8	1.2	1.7	0.5	4,68	283	14183	1,995347
0.8	1.2	1.7	0.7	4,32	292	14187	2,058222
0.8	1.4	1.3	0.3	4,03	274	14178	1,932572
0.8	1.4	1.3	0.5	4,13	258	14180	1,819464
0.8	1.4	1.3	0.7	4,74	277	14174	1,954282
0.8	1.4	1.5	0.3	4,85	296	14177	2,087889
0.8	1.4	1.5	0.5	4,63	306	14178	2,158273
0.8	1.4	1.5	0.7	4,24	323	14176	2,278499
0.8	1.4	1.7	0.3	4,83	312	14179	2,200437
0.8	1.4	1.7	0.5	4,7	316	14176	2,22912
0.8	1.4	1.7	0.7	4,86	342	14185	2,410998
0.8	1.6	1.3	0.3	4,28	274	14174	1,933117
0.8	1.6	1.3	0.5	4,31	249	14171	1,75711
0.8	1.6	1.3	0.7	4,86	290	14182	2,044846
0.8	1.6	1.5	0.3	4,25	308	14170	2,173606
0.8	1.6	1.5	0.5	4,37	310	14178	2,186486
0.8	1.6	1.5	0.7	3,94	306	14179	2,158121
0.8	1.6	1.7	0.3	5,25	315	14172	2,222693
0.8	1.6	1.7	0.5	4,62	355	14184	2,50282
0.8	1.6	1.7	0.7	4,26	321	14186	2,262794