Understanding pedestrians' perception of crowdedness at mass events

A simultaneous survey and monitoring study into personal, trip and event characteristics

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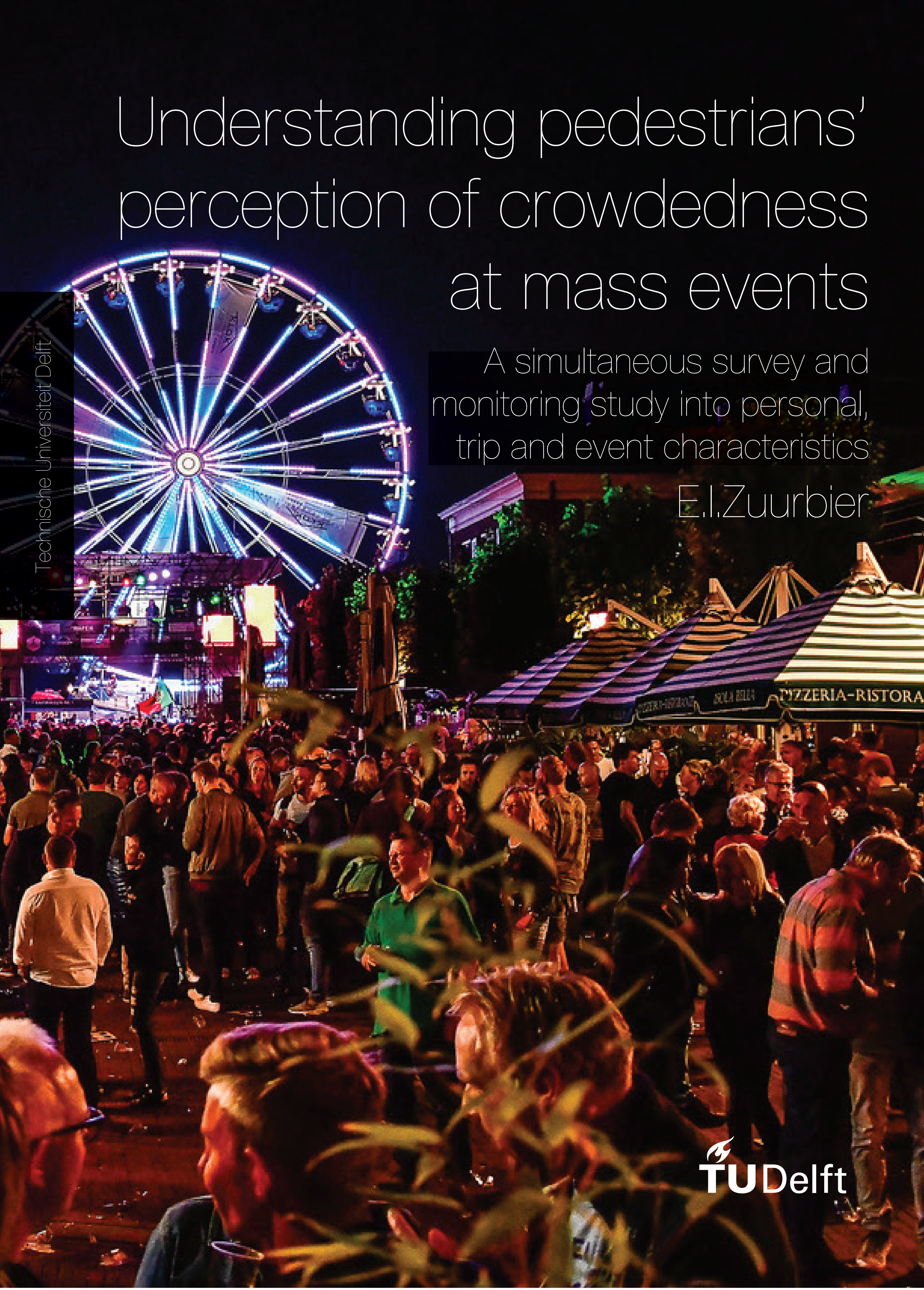

TU Delft

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by

E.I. Zuurbier

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Photograph cover: Property of TT Festival, photographer F. van Bergeijk, 2018.

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E.I. Zuurbier
Delft, 20 February 2018

Summary

Mass events have become increasingly popular in recent years. They can take place in a city centre or at a festival terrain. They offer music, sports or other attractions and can be meant for all age groups and all types of people. Likewise, tourism has grown exponentially. Especially in city centres, due to events and tourist attractions, larger crowds accumulate. Although these mass gatherings are for a recreational purpose, there are also negative aspects related to crowdedness. Panic in bottlenecks can cause death and injuries, such as the accident at the Love Parade 2010 in Germany, where panic in a tunnel caused 21 deaths. Luckily, these types of incidents are not common, but inefficient use of space, by arising jams and blockades is common. Pedestrians can experience crowdedness as *unsafe, unpleasant, frustrating* or *stressful*.

This research is aimed to gain a better understanding on how pedestrians experience crowdedness, in order to provide insights to enhance the experience of pedestrians. For this reason, it is necessary to investigate pedestrians' perception in relation to all factors that could possibly influence pedestrians' perception of crowdedness at an event. The following research question is answered:

"To what extent is a pedestrian's perception and experience of crowdedness influenced by personal, event and trip characteristics?"

From literature, the factors that could influence perception of crowdedness were derived. These can be split up in the categories Socio-demographics, Personal state & Trip factors, Event & Environment factors and Actual crowdedness. Perception & Experience of Crowdedness contain the perception of Crowdedness, Safety, Comfort, Attractiveness of the environment, Atmosphere and Experience of Crowdedness. In a theoretical framework, based on the theory Planned Behaviour, all the categories are linked to each other.

Data collection for this research was done with a simultaneous survey and monitoring study at two events. This made it possible to capture the effects of a variety of factors on perception of Crowdedness. The events chosen for this research were the TT Festival 2018 in Assen and the Red light district in Amsterdam. At both events, three locations were researched on three different evenings. Monitoring data was collected from Wi-Fi sensors and counting cameras. This data is processed to represent crowdedness, by first filtering the data, then applying a simple moving average to capture a specific time window and finally calculating the variables flow, density, volume/capacity and flow proportion. Light and sound intensity measurements were performed every at intervals. Socio-demographic factors, Personal state & Trip factors and perceptions were included in a survey.

At the TT Festival, the main source of entertainment was music, performed on multiple stages throughout the inner city. Each stage had a unique atmosphere and function. Most of the visitors were locals who visited every year. The Red light district is not an actual event, since it can be visited every day of the year. However, it is treated as an event in terms of crowd management and the visitors of the area tend to have an 'Anything goes' attitude. The red-light windows and bars mainly attract tourists, who are unfamiliar with the area and come to walk around in the area.

The analysis method consists of three parts. First, correlations between the explanatory factors and perception variables are tested, to determine which factors are most relevant. Second, an exploratory factor analysis is performed to identify which researched perceptions and experiences form latent variables. Third, Structural Equation Modelling is used to test the hypothesised relations in the theoretical framework. Structural Equation Models have a high explanatory power and can differentiate direct, indirect and pure effects of each of the factors included in the model. Furthermore, Structural Equation models can include measurement models for latent variables.

The results show that for both events perception of Safety & Comfort form one latent variable and perception of Attractiveness & Atmosphere form another. Perception of crowdedness influences perception of Atmosphere & Attractiveness in both case studies. For the TT Festival this influence is positive, while at the Red light district, this influence is negative.

For both events, the crowdedness indicators that correspond to the perception variables best are the processed Wi-Fi and camera counts, opposed to the calculated variables for density and flow. The Wi-Fi counts affect the perceived crowdedness strongly. In the TT case, local 15-minute Wi-Fi counts (Density) capture this relation best, while at the Red light district, the strongest influence is found for global 60-minute Wi-Fi counts. In the TT model, a strong negative influence of camera counts (Flow) on perceived Safety & Comfort is found, which indicates that movement around a person makes one feel less comfortable and safe. Attempts to create a combined model were not successful, indicating that there are many event specific factors at play that were not quantified. Other factors that influenced perception at both events are trip purpose familiarity and emotional state. Noticeably, foreigners at both events have a more positive overall perception.

The relation between perceived crowdedness and perceived safety & comfort was expected to be more prominent, but the results do not show a strong influence. For future research, it is recommended to include multiple questions regarding safety & comfort in a survey, in order to capture specific aspects of these perceptions, such as physical, physiological, facilities, security officers and social aspects. To be able to compare the events better, it is recommended to apply exactly the same processing steps to the monitoring data. In this research, it was not possible to compare measured levels of crowdedness, because the measurement and filtering of the monitoring data was performed differently. For gathering light & sound data, it is recommended to use accurate sensors on fixed locations performing continuous measurements.

For event planners, it is recommended to use monitoring data as an indication of the pedestrians' experience of crowdedness, but to use different boundary conditions to determine a pleasant amount of crowdedness, depending on the function of the location and the characteristics of the crowd that is expected to be present at this location.

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Glossary

Crowd *"A large number of people gathered together in a disorganised or unruly way." 1.1 "An audience, especially one at a sporting event.", 1.2 "A group of people who are linked by a common interest or activity."* - Oxford University Press, 2018.

Crowded *"Filled near or to capacity", "Filled with a crowd"* - American Heritage Dictionary of the English Language, 5th Edition, 2011.

Crowdedness Crowdedness, or "*drukte*" in Dutch, is the degree to which a place or event is crowded with people.

Quantified Crowdedness Crowdedness is quantified by deriving variables from measurement or observation. There are multiple variables possible to describe crowdedness quantitatively. Measures of crowdedness are dependent on the area per person or the distance between persons over space and time Duives et al. (2015).

Perceived Crowdedness The perceived level of crowding by pedestrians. This perception can be influenced by other factors, such as background and environment factors as well.

Level of Service *" a qualitative measure to describe operational conditions of vehicular and pedestrian traffic, based on service measures such as speed and travel time, freedom to manoeuvre, traffic interruptions, comfort and convenience."* - Bloomberg and Burden, 2006.

For different types of pedestrian infrastructure, such as stairways and corridors, the level of service can be categorised based walking speed, pedestrian spacing and the probability of conflict at various traffic concentrations (Fruin, 1971).

Mass event *"A mass event or large scale event is a gathering of a specified number of people at a specific location for a specific purpose for a defined period of time."* - World Health Organisation, 2008.

According to Jago and Shaw (2000), what makes an event special is: *"the number of attendees, the international attention due to the event, the improvement to the image and pride of the host region as a result of hosting the event, and the exciting experience associated with the event."*

In this thesis, a mass event is a gathering of people in a restricted area where a certain type of entertainment is provided.

Monitoring data Any type of data collected through electronic sensors to monitor/observe/count pedestrians. Examples include: Wi-Fi/Blue-tooth/infrared sensors, counting cameras, mobile phone data and GPS trackers. The sensors observe the progress of the pedestrians movements over a period of time. More information on data collection types can be found in 4.2.

Perception *"The neurophysiological processes, including memory, by which an organism becomes aware of and interprets external stimuli."* - Oxford University Press, 2018. In this thesis, perception is seen as a the way an individual observes external stimuli, which is coloured by his/her background and personal state.

1

Introduction

Mass events are becoming increasingly popular. They can take place in a city centre or at a festival terrain, they offer music, sports or other attractions and can be meant for all age groups and all types of people. Likewise, tourism has grown exponentially. Especially in city centres, due to events and tourist attractions, larger crowds accumulate. Although these mass gatherings are for a recreational purpose, there are also negative aspects related to crowdedness.

For example in the city centre of Amsterdam, where nearly 7 million foreign tourists visited in 2017 (Groenendijk, 2018). The whole inner city is very crowded and has reached its maximum capacity. There are more tourists than residents on the streets (van Dun, 2016). Residents have learned to avoid certain areas, because of unpleasant levels of crowdedness. The Red light district, Negen straatjes and the Kalverstraat are monitored by the municipality, because there is a threat of overcrowding. These are situations where the number of people at one location becomes that large, that people start to feel anxious (van Dun, 2016). The Kalverstraat has already been shut down multiple times by the police, to prevent overcrowding (van Dun, 2016). This could be dangerous, because that anxiousness can lead to panic. Moreover, pedestrians in a crowded system cannot be evacuated quickly. Similarly, the Red Light district is another area where there are problems related to crowdedness. The municipality of Amsterdam has to manage the crowd in such a way that panics are prevented and nuisance and discomfort are minimised.

Also at events, high numbers of visitors can cause problems. Events such as the TT festival in Assen and Mysteryland attract respectively 160.000 (Circuit van Drenthe Holding b.v., 2018) and 110.000 (van de Velde, 2017) visitors over the duration of the events. The TT Festival is a free festival that takes place yearly in the city centre of Assen as evening entertainment during a motor racing event and Mysteryland is a large, paid festival in nature with mainly dance music. Even though these events take place at another type of location, have a different public and another type of general atmosphere, both of these events experience similar difficulties. As van de Velde (2017) states, congestion, queues and blockades arise at Mysteryland, because the festival terrain is not fit for the daily 55.000 visitors. This can be frustrating for event visitors, because they cannot move freely. This might lead to feeling unsafe or uncomfortable. Furthermore, behaviour of visitors can be a problem. The TT festival was actually founded to entertain troublesome youths, who were attracted to the city for the TT Races (van Gool, 2018). This concept proved to work very effectively. Even though the same people and the same amount of people gathered, the atmosphere was different.

To summarise, many problems can occur in crowded places. These problems are not purely physical, but also psychological. In the worst case, *panic* can occur. For example, the horrible accident at the Love Parade 2010 in Germany, where a panic at a bottleneck caused 21 deaths (BELGA, 2017), or the stampede at the 2014 New Year's Eve celebration in Shanghai, where at least 36 people died by being trampled or falling of the stairway leading up to a viewing platform (Kaiman, 2015). Luckily, these types of incidents are not common, because crowd management to prevent this is well thought out. However, *inefficient use of space*, by the arising jams and blockades is common. This is frustrating for the pedestrians, because they cannot walk at free flow speed. Moreover, pedestrians can experience crowdedness as *unsafe* (Hoskam, 2017), *unpleasant, frustrating and stressful* (Lee et al., 2001).

Generally, people state that they dislike crowded places, as Galama (2016) found in a stated preference survey. However, the revealed preference for the same situation showed that pedestrians tend to go to crowded places. This is logical, since the presence of a crowd is usually at an attraction. Therefore, it seems that crowdedness is experienced differently, either positively or negatively, depending on the context. For example, when there is an artist performing and the whole crowd is singing along, crowdedness could be seen as something positive altogether, but when a queue arises for a ticket stand, this is seen as something negative. This suggests that perceived crowdedness is dependent not only on the number of people, but also on the context. However, it is unknown how the context influences the perception of crowdedness and which characteristics of this context are important. Understanding the relation between event characteristics and the perception of crowdedness can be useful, because when the relation is understood, event characteristics could be influenced in such a way that the crowdedness is perceived more positively. In other words, this knowledge can be used to provide better crowd management. This could enhance *safety, efficiency and experience.*

1.1. Problem statement

Crowd monitoring is getting more attention as a research topic for *safety* and *efficiency* purposes. Crowd monitoring focuses on data that is observable with electronic sensors, such as Wi-Fi sensors, counting cameras and GPS trackers (Daamen et al., 2016). These methods give much insight in crowdedness that can be measured, but do not consider pedestrians' perception of crowdedness. At an event, next to providing a safe and efficient environment, it is also important to give people a good experience. In what way the level of crowdedness influences peoples perception on crowdedness is unknown. Therefore, to gain a better understanding on how pedestrians experience crowdedness, it is necessary to investigate pedestrians' perception and the relation to crowdedness. It would be quite logical to provide crowd management that does not only enhance objective values, but the subjective values as well. However, the perception of pedestrians is difficult to determine, since a perception cannot be observed directly. Also, individual characteristics such as gender, age and trip purpose cannot be identified with monitoring data alone.

To find out how a perception is formed, it is necessary to investigate all factors that could possibly influence the perception. For pedestrians, there is not that much research available as to what influences the perception, but there is research as to what factors influence behaviour, specifically route choice.

Hoskam (2017) and Grolle (2017) have researched the different ways in which pedestrians perceive crowdedness, safety and atmosphere at a shared space street and on Kingsday at train station Amsterdam Zuid respectively. Factors such as social demographics, familiarity, recent experiences and stimulant usage were found to influence perception. Furthermore, they compared observed/measured crowdedness to perceived crowdedness and found that these are also related. However, they did not yet identify the interrelation between these factors. In order to interpret the influence of individual factors and crowdedness, a model needs to be created that captures all significant effects.

Knowledge gap Pedestrian movement behaviour at large-scale events is receiving more attention in recent studies (Yuan et al., 2016; Daamen et al., 2016), but the research mainly gathers monitoring data. With monitoring data the physical crowdedness can be analysed, but the perception of pedestrians on crowdedness is not considered. This is required to give people a pleasant experience. The knowledge gap that is addressed in this research is to what extent the pedestrians' perception and experience of crowdedness is influenced by crowdedness and which other factors influence pedestrians' perception.

1.2. Research question and objective

To address the problem stated in the previous section, a research objective is defined.

Objective The objective of this study is to gain a better understanding of pedestrians' perception and experience of crowdedness. More specifically, the objective is to find out how crowdedness and perceived crowdedness are related. Furthermore, to understand how crowdedness is perceived, it is necessary to find the other factors that influence the perceived crowdedness beside the actual crowdedness.

For this objective, the following research question is defined:

"To what extent is a pedestrian's perception & experience of crowdedness influenced by personal, event and trip characteristics?"

With the perception of crowdedness, the direct perception of the amount of people nearby is meant. With experience of crowdedness, factors such as safety and atmosphere are meant. It seems from previous research that the perception of crowdedness is coloured by circumstances/context. However, there are other perceptions, sensations and experiences that are crowdedness related. Some of these are mentioned in the introduction, for example: feeling frustrated, feeling anxious, feeling unsafe, feeling uncomfortable and experiencing the crowdedness as unpleasant. Which of these will be included as crowdedness related perceptions/experiences is not yet determined.

Moreover, several types of characteristics are mentioned. These cover all the factors that are expected to influence a person's perception of crowdedness at an event. Personal characteristics are factors that are related to the individual. For example, socio-demographic factors like age and gender can influence a person's perception. Also, emotions that a person experiences can be meant by this. Trip characteristics are typically found in route choice behaviour research and can include trip purpose and group composition.

With event characteristics, two types of categories can be distinguished, which are the crowd/crowdedness and the infrastructure. The crowd and crowdedness characteristics are created by the pedestrians that are present and their movements. Infrastructure characteristics include all other event characteristics, such as location sizes, event layout and stalls, and light and sound systems.

Furthermore, the following sub-questions are defined:

1. How do personal, event and trip characteristics influence perception & experience of crowdedness according to literature and how does perception of crowdedness relate to other crowd-related perceptions?

2. How can perception & experience of crowdedness be explained by a theoretical framework and which hypotheses relate to this?

3. Which data collection methods can be used to study the relationship between perception & experience of crowdedness and personal, event and trip characteristics?

4. How can we analyse/model the relationship between perception & experience of crowdedness and personal, event and trip characteristics?

The sub-questions are related to the content of this thesis in Section 1.4.

1.3. Scope

In this thesis, the focus is on events, even though the definition of an event can be vague. In this research, events that take place in city centres are considered. One is the TT Festival 2018 in Assen, the other is the Red light district in Amsterdam. The main common aspect is that they are large gatherings of people in a limited space for a mainly recreational purpose. The social norms are different at these type of events compared to daily live. The consumption of alcohol and other drugs is considered normal and people behave differently. Other types of events, such as sports events, large festivals in nature and indoor events might have some aspects in common, but are not researched specifically. An important aspect in research into crowds and crowdedness is the population that is researched. In this research, a limited number of surveys is collected, therefore, the number of respondents is not large enough to be seen as a sample of the population present. However, it will give an indication of the population. The difference in population and the effect this has on the perception of this population will therefore be considered mainly by keeping these characteristics in mind while analysing the data. The survey will not be aimed at specific persons or groups, but rather on anyone present at the event, with the aim to gain insight in differences in perception between types of people.

The way the monitoring data is gathered is determined in advance, because this data is used for other studies and practices as well. Therefore, this research will not focus on how this data is retrieved, but more on how the data can be used. The monitoring systems consists of Wi-Fi sensors and counting cameras. A combination of these two is used to find the macroscopic flow variables that describe crowd dynamics. In this research, the focus will not be on complex and detailed analyses which can be done using this data to determine how many people are where and which routes they take. Rather, the focus will lie on finding a good and simple way to describe crowdedness with this monitoring data. Specifically, a way to describe crowdedness that fits in with the way pedestrians perceive the crowdedness.

Up until this point, the perception that is mentioned is the perception of crowdedness of pedestrians. In this research, other perceptions that are related to crowdedness are included as well, referred to as the experience of crowdedness. The reason for this is because crowdedness can be perceived high or low, but to understand whether the crowdedness is seen as something positive or negative, more information is needed. Various ways to define crowdedness related perceptions will be considered in literature and in the analysis. In the conclusion, the relation between perceived crowdedness and other crowd-related perceptions, such as safety and atmosphere will be discussed.

Finally, this research will not be aimed at developing a new Level of Service methodology based on perception. It will merely try to show which factors are relevant in this perspective. The conclusions of this research could be used for such a purpose, but is not feasible in the limited time.

1.4. Thesis outline

The approach for this research is displayed in Figure 1.1. Each step in the methodology is related to one or more research questions. First, the problem statement is constructed, which shapes the rest of the research steps. Second, a literature review is executed.

2. **Literature study**

   How do personal, event and trip characteristics influence perception & experience of crowdedness according to literature and how does perception of crowdedness relate to other crowd-related perceptions?

In this chapter, research in the field of crowd dynamics will be discussed. First, the basis of traffic engineering for pedestrians is discussed. This addresses the event characteristic crowdedness. It has to be determined how crowdedness can be quantified in order to compare this to perceived crowdedness. Subsequently, previous research into the relation between Level of Service offered and the perception of the transportation users is elaborated upon. This is important, because Level of service is one of the ways by which crowdedness can be quantified. In other words, these studies partly cover the relation between perceived crowdedness and quantified crowdedness. Their methods and the factors that they include can be adopted. After that, psychological theory will be consulted, to find ways to explain the relation between personal, trip and event characteristics and perception. This is done by comparing different psychological frameworks, such as the theory of planned behaviour. A framework for this research has to be chosen or created, in order to make it possibly to analyse the effects of all the characteristics combined.

Finally, this chapter will conclude with a section will be dedicated to an analysis per characteristic, to find the relation between that characteristic and perceived crowdedness. Furthermore, various types of perception that are important at an event are identified, such as safety, comfort and atmosphere and their relation of perceived crowdedness.

3. **Theoretical framework**

   How can perception & experience of crowdedness be explained by a theoretical framework and which hypotheses relate to this?

This chapter will begin with a theoretical framework based on the conclusions of Chapter 2. The potential interrelations between the factors will be identified. Based on the framework, research hypotheses can be developed. The framework will be used to determine the model estimation method. The hypothesis will be discussed again in the results.

4. **Data collection method**

   Which data collection methods can be used to study the relationship between perception & experience of crowdedness and personal, event and trip characteristics?

This chapter aims to identify possible data collection methods for personal, event and trip characteristics. To choose a data collection method, it has to be kept in mind that the data has to be collected in such a way that all characteristics can be analysed together. With the knowledge about the possibly important factors (Chapter 2) and the data collection methods (Chapter 4), it can be determined which factors are relevant as well as feasible to take into account for this research. In this chapter, the case studies are also introduced. Why these are relevant for this research is discussed here as well. More than one case study can be performed. A plan of action specifying research locations and times is determined. Also, a glimpse into the data that was gathered and an evaluation will be presented. The case studies are described together with the data collection methods, because the way a case study is performed is determined together with the data collection method.

5. **Data processing method**

   Which data collection methods can be used to study the relationship between perception & experience of crowdedness and personal, event and trip characteristics?

   How can we analyse/model the relationship between perception & experience of crowdedness and personal, event and trip characteristics?

This chapter explains how crowdedness can be quantified using the chosen data collection method. First, it will explain the filtering steps that are necessary make the raw data usable. Next, it is described which formulas and variables are chosen to quantify crowdedness.

6. **Model estimation method**

   How can we analyse/model the relationship between perception & experience of crowdedness and personal, event and trip characteristics?

The analysis method is presented in this chapter. The analysis will consist of two phases. First, a statistical analysis will be performed, in which a detailed look into uni- and bi-variate statistics will be made. This will give a first impression on which hypotheses can be confirmed and which relations are important to model. Second, multiple regression and specifically structural equation modelling will be explained theoretically. It will be explained how this modelling method will be applied and assessed.

7. **Results**

In this chapter, the models that were created will be presented. The aim of this research is to create two event specific models, that best explain the perceived crowdedness at each event studied. Furthermore, a general model that would also be applicable to other events is presented here. The hypotheses of Chapter 3 will be tested to find the relations between perception, crowdedness and other factors.

8. **Conclusion, Recommendations, Discussion**

   To what extent is a pedestrian's perception of crowdedness influenced by personal, event and trip characteristics?

Finally, a conclusion answering the main research question will be drawn based on the analysis. Furthermore, issues for discussion will be provided and recommendations for future research will be given.

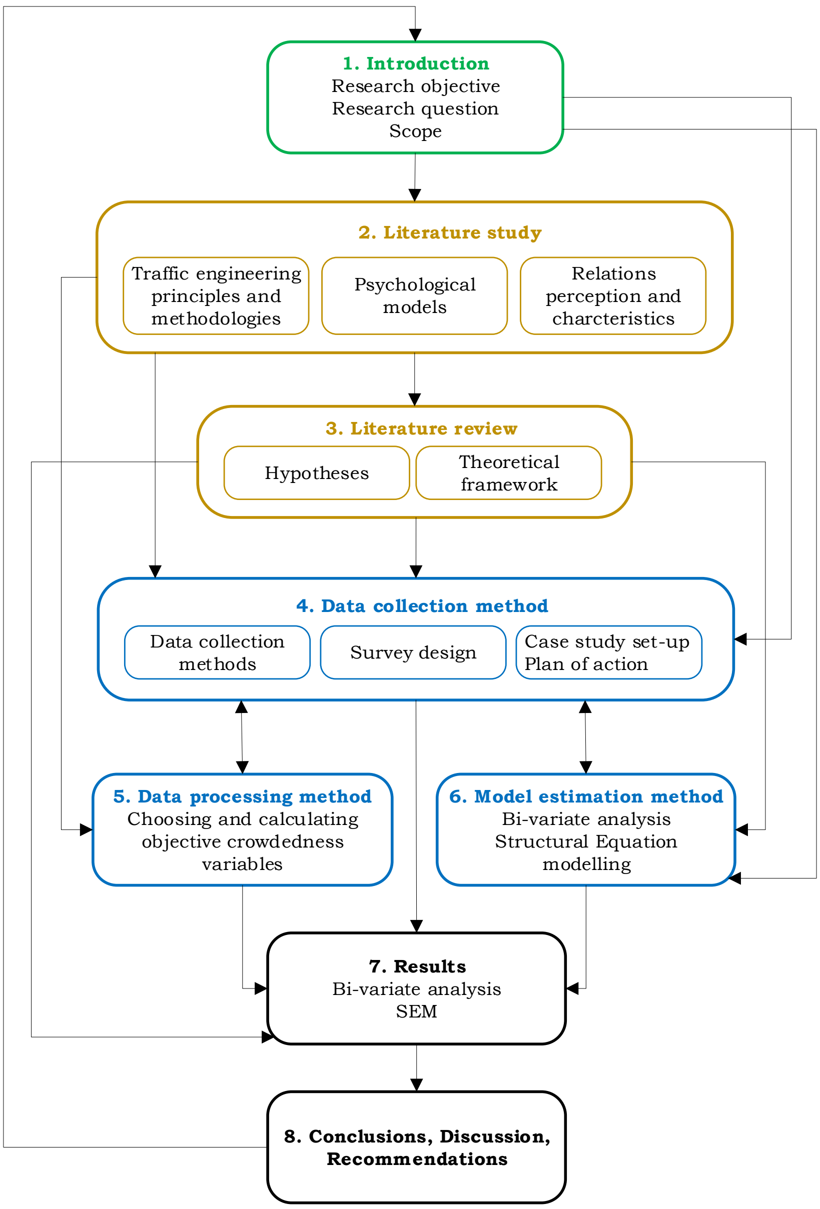

Figure 1.1: Visualisation of the outline of this thesis

I

Literature

2
Literature study

In this literature review, the following research question will be answered:

How do personal, event and trip characteristics influence perception & experience of crowdedness according to literature and how does perception of crowdedness relate to other crowd-related perceptions?

The first section illustrates how pedestrian dynamics in a crowd are often quantified, using macroscopic flow variables (Section 2.1). Second, the Level of Service system is introduced, which is a system that is used to assess the level of crowdedness based on the macroscopic flow variables (Section 2.2). Third, the limitations of this assessment system are discussed (Section 2.3). Fourth, state of the art research that compares crowdedness to the perception of transport users is discussed (Section 2.4). Knowledge of their data collection methods, analysis methods and their results can be used to develop a method for this research. The research method will be further discussed in Chapter 4. The following part of the literature study considers psychological research into the behaviour and perception of people (Section 2.5). This will help to theorise which relations can be found between explanatory factors and perception and help to create a theoretical framework for this specific research. And finally, an extensive literature study is performed to clarify which factors play a role in a pedestrian's perception of crowdedness in Section 2.6.

2.1. Traffic flow theory for pedestrians

This section contains a short overview of traffic flow theory regarding pedestrians. Research into crowds from a traffic flow theory perspective is relatively new, and it is opposed to more challenges than vehicular traffic flow theory.

Generally, traffic states are identified by means of a fundamental diagram, which provides insight in the relations between flow, speed and density. For crowd movements, however, it is difficult to identify these variables, as pedestrians move around in a 2D plane and consequently have more freedom of movement. The macroscopic flow variables are expressed as shown in Table 2.1 for pedestrians.

Table 2.1: Macroscopic flow variables

Variable	Unit
Walking Speed	m/s
Density	pax/m^2
Flow	$pax/m/s$

$$Flow = Density \times Speed \tag{2.1}$$

Examples of fundamental diagrams are shown in Figure 2.1 (Vanumu et al., 2017). In the Flow-Density diagram, the relation between these two variables is shown. The first part of the line is more or less straight in all models and illustrates a free flow situation, where pedestrians can walk in their desired direction at their desired speed. As the line is reaching the maximum, the maximal flow is reached. Here the flow is still stable. After this point, the flow becomes unstable, congestion arises and density increases. At maximal density, the effective flow towards a goal will be 0. There is still movement, but the flow is unstable and multidirectional.

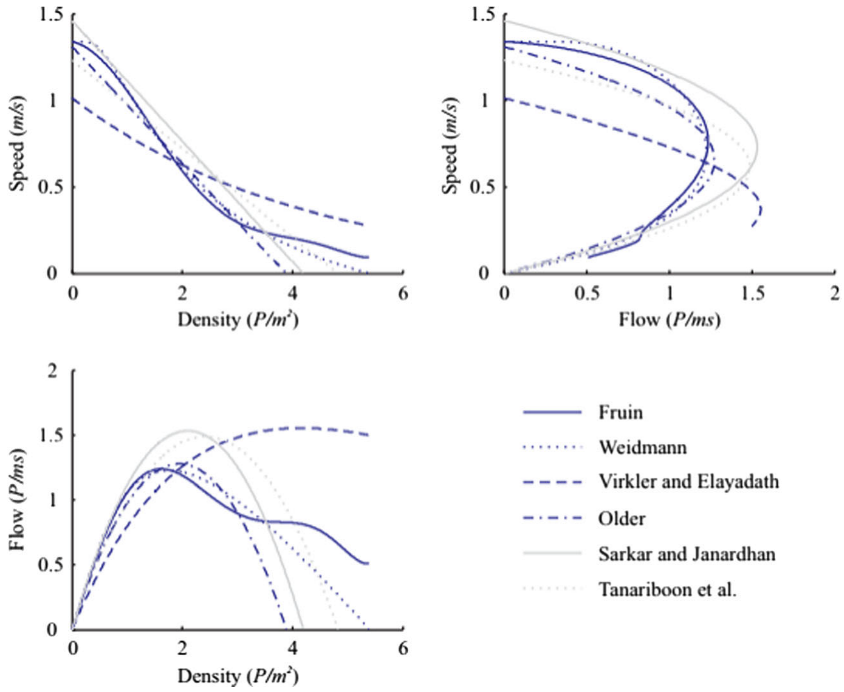

Figure 2.1: Fundamental Diagram Pedestrian (Vanumu et al., 2017)

As can be seen in Figure 2.1, the relations between the variables differ substantially between experiments. There is not yet a consensus on the shape of the fundamental diagram for pedestrians. Moreover, the necessary parameters that need to be taken into account to create consistent fundamental diagrams are not completely clear yet. Most experiments only take a few parameters into account. Geometry, location, time of day, culture and personal factors are found to be significant factors in various researches (Vanumu et al., 2017). For example, in a culture where pedestrians are crowd-minded, the flow remains stable at a higher density (Duives, 2017). On the other side, a pedestrian system where pedestrians are goal-oriented or in a rush, for example in a train station, this can be seen in a fundamental diagram from at higher free flow speed. However, this also means that the flow becomes unstable sooner.

Another form of visualising pedestrian movement is using trajectories. Trajectories offer a different insight in pedestrian behaviour and requires individual tracking. Trajectories can show direction and speed, which can make flow types such as stable/unstable, uni/bi directional, crossing and overtaking visible (Duives, 2017).

2.2. Level of Service for pedestrians

As a way to incorporate the density experience of pedestrian into infrastructure design, Fruin (1971) introduced the Level-of-Service concept for pedestrians. The levels are based on traffic engineering principles, and consider freedom to choose a speed in locomotion functions, overtaking possibilities and crossing the flow. Different occupancy levels are developed for different situations, such as walking a corridor, stairs, queues, people movers, exits/entrances platforms or any kind of pedestrian environment.

In order to calculate the Level of Service, the same macroscopic variables as Table 2.1 are used, with the difference that instead of Density, the reciprocal variable Module ($m^2/ped.$) is used (see Table 2.2). Fruin made this decision to prevent expressing pedestrians in a unit with decimal points. Headway is added in Table 2.2 as well, although it is not used to calculate Level of Service. This results in the flow equation given in Equation (2.2).

Table 2.2: Fundamental variables Fruin

Variable	Unit
Walking Speed	m/min
Module	$m^2/ped.$
Flow Volume	$ped/min/m$
Headway	s or m

$$FlowVolume = \frac{avg.Speed}{avg.Module} \tag{2.2}$$

Fruin (1971) researched pedestrians at various locations to develop the Level of Service system. He found an average free flow walking speed of 80.8 m/min. The Module (Density) required to keep this free flow speed was 3.2 ped/min/m. In Table 2.3, this value can be pointed out as the limit of level A, which is the optimal Level of Service. The following levels indicate decreasing level of service, where level E indicates the beginning of the unstable flow. The available space for a pedestrian is 0.5-0.9 m^2 at that point. When the available space drops even further, the flow stagnates and drops (Level F).

Table 2.3: Levels of Service on walkways (Fruin, 1971)

Level	**Occupancy** (m^2/ped)	**Flow** (ped./min./m width)	**Comments**
A	3.2 or more	23 or less	Free flow No conflicts
B	2.3 - 3.2	23-33	Normal walking speed Minor conflicts
C	1.4 -2.3	33-49	Restricted flow Some conflicts Walking speed controlled
D	0.9 - 1.4	49-66	Conflict Walking speed restricted Difficulty in passing
E	0.5 - 0.9	66-82	Frequent adjustment of gait Walking speed restricted
F	0.5 or less	Variable to 82	Shuffling and bunching Extreme restriction of speed Breakdown of flow

2.3. Criticism on Level of Service

Although the Level of Service methodology has been applied broadly and has been included in the Highway Capacity Manual Rouphail et al., 1998, there is criticism on the system as well. For example, the current LoS methodology is not very sensitive to changes in effective sidewalk width or pedestrian volume. (Bloomberg and Burden, 2006). Furthermore, the methodology does not consider personal pedestrian characteristics, such as age, gender and trip purpose. It is suggested in the Highway Capacity manual to adjust the limits of the levels of service to local conditions (Rouphail et al., 1998). For example, in an area where elderly people live the average walking speed is lower and in a business area the walking speed is higher. This flexibility in the assessment might sound great, but these are general adjustments, meaning that variability is not considered. For example, in a neighbourhood where many elderly live, the average walking speed necessary to calculate the level of service is adjusted. However, this adjusted Level of service is not applicable to all pedestrians, because not all of them are old.

Besides this, critique is expressed about quantifiable factors that are not included such as time spent following, number of collisions and waiting times (Bloomberg and Burden, 2006). Weidmann (1993) states that frequency of forced changes in speed and direction and the number of crossing, meeting and passing conflicts have to be considered in a LoS assessment. Moreover, perception of comfort, safety and convenience are not taken into account. In various studies, it was found that pedestrians' perception of the walking environment affect pedestrian behaviour significantly (Bloomberg and Burden, 2006).

2.4. Level of Service based on user perception

Given the criticisms of the Level of Service method, recent studies have attempted to find a user-based assessment of Level of Service (Landis et al., 2001), which may contain various perceptions, such as perceived crowdedness, safety, atmosphere, comfort, convenience or attractiveness of the (built) environment.

Apart from crowd dynamics, the subject of user-based methodologies to assess Level of Service has been researched for other subjects in the transportation field as well, such as bus services (Madanat et al., 1994), sidewalks (Landis et al., 2001), bicycle lanes (Landis et al., 1997), vehicular traffic on a highway (Papadimitriou et al., 2010), and at train stations (van Gelder, 2018). In the following section, several researches are discussed that use some type of perception and compare it to observed/measured crowdedness. Both their methods and results can be useful for this research. In Table 2.4, an overview of the analysis method, data collection method, the objective and results of each study is shown.

Papadimitriou et al. (2010) studied the perception of car drivers on a stretch of highway by use of a survey and monitoring data. In their research, Papadimitriou et al. found a large dispersion in drivers' assessment of level of service for each volume-to-capacity (v/c) value, especially at moderate traffic conditions. The effect of driver's age, gender, driving experience, familiarity with the road, vehicle capacity, and v/c was researched as well. However, only traffic conditions affected drivers' assessment of Level of Service in this sample. The results of this research conclude that there are only two to three levels of traffic conditions perceived. By using piecewise linear regression, significant slopes and breakpoints are found in the relation between perceived LoS and the v/c ratio.

Landis et al. (2001) developed a Pedestrian LoS model using stepwise multivariable regression. This model quantifies pedestrians' perception of safety and comfort and the roadway and traffic variables that influence this perception. The method is similar to methods used in the Highway Capacity Manual to assess car drivers' LoS. The aim of this LoS model is to help (re-)design roadways and evaluate and prioritise measures.

Lee et al. (2007) studied the satisfaction of car drivers and pedestrians at signalised intersections by using a fuzzy aggregation and a cultural consensus analysis technique. This technique is an improvement to conventional measures for LoS, because the qualitative nature of service quality is better reflected. Lee et al. found that user perceptions vary greatly per individual. The assessment on Level of Service based on the perception of the car drivers and pedestrians does not correspond to the traditional LoS assessment.

Madanat et al. (1994) studied the effectiveness and threshold values for a LoS model for public transport users by surveying bus riders. Bus riders were asked to rate their comfort on a scale from 1 to 6. The LoS designations are found by using an ordered probit model.The method proposed in this paper can be used for designating service levels objectively.

van Gelder (2018) studied the influence of crowdedness on the experience of travellers at train stations by comparing survey data and monitoring data. Surveys were conducted on the platform, where cameras are installed that count the number of people in a demarcated area on a regular basis. Furthermore, socio-demographic, personal and trip characteristics, such as familiarity and travel purpose were included, as well as information about in and outgoing trains. An indirect relation between the station and platform appreciation and crowdedness was found. Furthermore, travellers that are at the station more often, rate the crowdedness higher, experience the crowdedness as more unpleasant and also give a lower rating to the station.

Table 2.4: Overview user-based LoS researches

Paper	Subject	Perception	Objective	Method data gathering	Method data processing	Results
Papadimitriou et al. (2010)	Car drivers, highway	-Level of service	Perception w.r.t personal characteristics and traffic conditions	Survey and monitoring data	Piecewise linear model	- No relation personal characteristics and perception - Perception LoS related to volume/capacity - Only three perceived service quality levels
Landis et al. (2001)	Pedestrian roadside	-Safety -Comfort	Model pedestrian LoS (re-)design, evaluation, prioritisation infrastructure	Observations street experiment	Stepwise multivariable regression	
Lee et al. (2007)	Drivers and pedestrians signalised intersections	- Service quality - Satisfaction	create LoS model which captures perception	Survey experiment video footage intersection	Fuzzy aggregation and a cultural consensus analysis	- Perception differs much between participants - Perception LoS and HCM LoS do not correspond - Three levels of service would be more practical
Madanat et al. (1994)	Public transport users	- Comfort	Develop method for designating service levels	Survey and manual passenger count	Ordered probit model	- Perception LoS and HCM LoS do not correspond
van Gelder (2018)	Travellers, train stations	-Crowdedness -Inconvenience -Station and platform	Perception of crowdedness w.r.t personal and trip characteristics and train information	Survey and monitoring data	Regression	- Relation familiarity/ goal and perception - Relation perceived crowdedness and built environment

From these papers, we can conclude that it is indeed important to take a users' perception into account, because a LoS assessment that is only based on service levels is very different from a perception-based assessment. Perception variables that could be taken into account are: Service quality, Safety, Comfort, Convenience, Crowdedness, the built environment and Satisfaction. Combined research into observed/measured crowdedness and perception has not yet been conducted for event environments, therefore it is currently unclear whether other factors and perceptions are important to take into account as well.

2.5. Psychological paradigm

In travel behaviour research, the Econometric paradigm is often used, because it lends itself well to choice modelling (Kroesen, 2017b). In previous researches, this type of model was applied to develop a route/activity choice model for pedestrians (Galama, 2016; Iliadi, 2016; Ton, 2014). However, for this research, the econometric paradigm is not applicable, since it assumes that people base decisions on complete and objective information. A thought process and perception are not considered.

In the psychological paradigm, there is a focus on the motivation behind behaviour. Consequently, psychological models have a high explanatory power. However, the conceptual models in psychological research are usually complex and often do not lead to surprising insights. Compared to a discrete choice model, the causality between factors is less clear (Kroesen, 2017b).

It is possible to create a hybrid model that combines a discrete choice model with a structural equation model. However, Chorus and Kroesen (2014) argue that these type of models cannot be used to determine policies, because the causality between perception and behaviour is less clear. In Appendix A, more information about the three types of models can be found.

For this research, it is chosen to limit the scope of the research to perception and not include behaviour, therefore the psychological paradigm is chosen.

2.5.1. Theory on perception

In this section, some theories on the formation of perception are stated. This provides insight in which type of factors can influence perception in general and it clarifies the definition of perception.

On perception, multiple theories exist. Gibson's theory (1950) proposed that perception is formed directly as a cognitive recognition of optical flows. In his theory, perception is formed through evolution to recognise patterns in the external environment. However, other research has proven that mental representations and memory also play a role in perception. Also, it is proven that perception changes by learning (Démuth, 2013).

Other theories do include memory and knowledge, the top-down indirect perception theories. These theories propose a system where sensory data must be organised and captured by cognitive functions in the brain and is interpreted on the basis of available knowledge (Démuth, 2013). For example, constructivist theory sees perception as the end product of extracting sensory stimuli, in which individual factors play a role. These factors include expectations, knowledge, motivation and emotion (Démuth, 2013).

Contrary, bottom-up theories belief that sensory stimuli are unconsciously inferred and evaluated (Démuth, 2013). Therefore, the perception of a person is influenced by their background, but subconsciously.

In Neisser's theory (2014), perception does not begin at sensory stimuli per se. By intentional focussing and consciously paying attention, the senses can detect stimuli faster and better. On the other hand, the conscious mind can be triggered to pay more attention by initial detection of external stimuli.

In this research, it is desired to include conscious evaluation as well as unconscious inference of the external stimuli. Further on in this research, this distinction is made clear by using the terms perception of Crowdedness and experience of Crowdedness, where perception of Crowdedness is the unconscious perception that is coloured by a person's background and experience of Crowdedness is an evaluated perception using prior knowledge and conscious consideration.

2.5.2. Theory on behaviour

In order to shape a theoretical framework, a few behavioural theories are elaborated in Appendix A. The following renowned theories are discussed: The theory of Reasoned Action (Fishbein & Azjen, 1980), the Theory of Planned Behaviour (Azjen, 1985), Social Learning Theory (Bandura, 1977) and Habit (Verplanken, 2006). The Theory of Planned Behaviour will be applied for this research, because it gives a clear framework that relates background factors to perception and behaviour in consecutive steps. Furthermore, the factors included in the model correspond with the factors summed up in Section 2.7.

The Theory of Planned Behaviour was created by Fishbein and Azjen as an elaboration on the Theory of

Reasoned Action. It includes background factors, Beliefs, Attitude, Perceptions and Intention as consecutive factors in a thought process leading to behaviour. In Figure 2.2, the framework of the theory is shown.

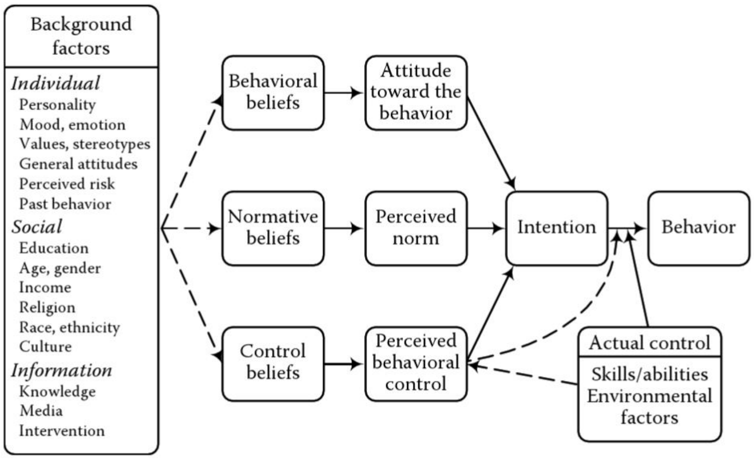

Figure 2.2: Theory of planned behaviour

Figure 2.2 shows that various background factors influence behavioural, normative and control beliefs. The background factors are split up in individual, social and information factors. Beliefs are divided into behavioural, normative and control beliefs. Behavioural beliefs encompass the cost and benefits a certain type of behaviour could have according to the beliefs of the person. By evaluating the outcome of the behaviour, an attitude towards this behaviour is formed (Ajzen, 1991). Normative beliefs are the social norms that a person's beliefs are applicable in certain situations. Based on a persons perception of the situation, the social norm that is applicable at a certain moment is derived. The meaning of Control beliefs according to Fishbein and Ajzen (2011) is the belief people have that they have control over the things that happen in their lives. Perceived behavioural control describes *"a general sense of personal competence or perceived ability to influence events"* - Fishbein and Ajzen (2011).

The Intention, the behaviour that the person in question intents to perform, is determined by the attitude towards the behaviour, the perceived norm and Perceived Behavioural Control. Intention will not always lead to the actual behaviour. Performing actual behaviour is restricted by Perceived Behavioural Control and by Actual control, where actual control depends on a person's skills and abilities, as well as environmental influences.

In previous researches, the theory of Planned Behaviour proved to not be fully able to explain the difference between intention and actual behaviour. Therefore, other researchers have elaborated on the Theory of Planned Behaviour, adding additional background factors and paths to behaviour. Triandis (1979) added Habit and Emotion to the framework. In the figure, Emotions are included as a background factor, influencing a new facet in the framework, namely Affect, which influences Intention.

The term Affect is used to describe general mood and emotional state. Moods can be distinguished between pleasant and unpleasant and activation and deactivation. Figure 2.3 shows the circumplex model of Affect, as developed by (Russell, 1980).

Triandis (1979) added habit in the framework as follows: The frequency of past behaviour is added as a background factor, which goes through a new facet Habit directly to behaviour. A habit is formed by the creation of associations in memory between actions and context in which they are performed (Aarts et al., 1998). Habits may be triggered by environmental cues, such as time of day or location, by internal states, such as particular moods and by the presence of typical interaction partners (Verplanken and Wood, 2006).

Lastly, Bagozzi and Warshaw (1990) add Motivation and Goal pursuit as background factors influencing beliefs.

Psychological models can be defined and measured using Structural Equation Modelling. This method was used by Hoon Kim et al. (2010) for their study at a festival to test the relations between perceived value, satisfaction and intention to revisit. Novelli et al. (2013) used SEM to clarify the relations between social identification, experience of crowdedness and positive emotion at events.

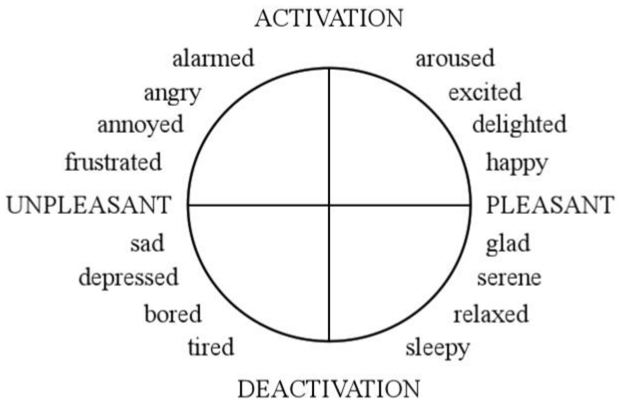

Figure 2.3: Circumplex model of Affect: Emotional states (Russell, 1980)

The psychological paradigm is chosen to research the relation between perception of crowdedness and personal, trip and event characteristics. In this research, the term perception is not only the unconscious interpretation of external stimuli, but it is assumed to be influenced by knowledge, expectations, motivation and emotion. The Theory of Planned Behaviour can be used to explain the relation between personal, trip and event characteristics and perception. A Structural Equation model is used to measure the hypothesised relations.

2.6. Factors influencing behaviour

To identify the factors that could influence the perception of crowdedness, literature about pedestrian behaviour is studied. Gathered from Fruin (1971), Iliadi (2016), Galama (2016) and Daamen (2004), the following factors could influence pedestrian choice behaviour (Figure 2.5). A division is made in four categories: personal, system, event and external.
Personal factors are divided into three subcategories: General factors, trip factors and learning process. General factors include social demographics and personal state and decision style. Trip factors include the situation that specifies the trip, such as group composition and purpose of the trip. Learning process contains typical psychological factors. All these factors are dependent on the pedestrian.

System factors are divided into location and route factors. Location factors are used to determine location choice. The activities available and the dimensions of the location can have an impact. For route choice, distance and travel time are often found to be most significant (Seneviratne and Morrall, 2007). Without realising it, pedestrians tend to choose for the shortest route. The number of attractions, visibility, crowdedness and safety are other route specific factors.

Event factors include the factors that apply specifically to mass events, such as event characteristics, information and crowd management and crowd composition. Event characteristics contain data such as indoor/outdoor, free entrance or paid ticket and the type of activities/music. This might also attract a different type of crowd in terms of social demographics and behaviour. Information contains such things as signs, maps and mobile phone applications.

External factors are the ones that cannot be influenced by humans directly. In this category, weather and environment could play a role.

In the next section, relevant findings about the individual factors in Table 2.5 in relation to perception of crowdedness are discussed.

Table 2.5: Factors influencing pedestrian route/activity/location choice, retrieved from (1) Daamen (2004), (2) Ton (2014) and (3) Iliadi (2016)

Attributes			
Personal factors	**General factors**	Age	(1), (2), (3)
		Gender	(1), (2), (3)
		Familiarity	(2), (3)
		Emotional state	(2), (3)
		Decision style	(1), (3)
	Trip factors	Trip purpose	(1), (2), (3)
		Time spent in an area	(2), (3)
		Group composition	(2), (3)
		Time of day and week	(2), (3)
		Impulse behaviour	(2), (3)
	Learning process	Cognitive learning	(2)
		Habit	(2)
		Choice inertia	(2)
System factors	**Location**	Location dimensions	(2), (3)
		Visibility	(2), (3)
		Amount of shops or other activities available	(2), (3)
	Route	Travel time	(1), (3)
		Distance	(1), (2), (3)
		Crowdedness	(1), (2), (3)
		Comfort	(2)
		Number of attractions	(1), (2), (3)
		Directness	(1), (2), (3)
		Safety	(1)
		Weather protection	(1), (2), (3)
Event factors		Event characteristics	(3)
		Noise	(1)
		Information and crowd management measures	(3)
External		Environment	(2), (3)
		Weather	(2)

2.7. Factors influencing perception

Continuing on Section 2.6, in this analysis, the most relevant insights regarding the relation between personal, trip and event characteristics and the perception & experience of crowdedness are discussed. Furthermore, underlying relations between factors are discussed, as these might introduce interaction effects. When mentioned in literature, behavioural outcomes are discussed as well. Here, it is assumed that a factor that influences behaviour, could also influence perception.

A new classification is used that applies better to perception research. The first category is Social Demographic factors. These were partly covered as general factors in the previous research of Ton (2014) and Iliadi (2016). They are distinguished as one category, because these factors are not influenced by the event characteristics. The next category is Personal & Trip factors, which were previously mentioned in the categories general and trip factors. These factors could be influenced by the event and can differ per trip a person makes. Then, Event & Environment factors are grouped together because from the perspective of an event visitor, the difference between a temporary environment and the built environment is not that important. Furthermore, some of the system factors are included in this category, such as location dimensions. Quantified crowdedness is the final category that is discussed, focussing mainly on the macroscopic flow variables.

2.7.1. Social demographic factors

Social demographic factors are often used as explanatory variables in social research. In Table 2.6, the most relevant Social Demographic factors found in literature are mentioned. These will be elaborated below.

Table 2.6: Social demographic factors

Social Demographic	Age
	Gender
	Height/physical dimensions person
	Residence
	Health
	Education level
	Income
	Culture

Age

According to Bytheway (2011), age is related to individual identity. Furthermore, age is an structural component of organisations and institutions. It influences a person's biology, so it is an indicator of one's physical capabilities. It also shows a person's knowledge and experience. In social research, age is often found to have significant correlation to other factors. According to Démuth (2013), Age influences perception by the development of the cognitive functions (nature) and by psychological and cultural influences (nurture). Hoskam (2017) found that age correlates negatively with perception of Safety.

Gender

Gender, just as the age factor, is often used as an explanatory factor in social sciences. Hill (1982) found that gender influences route choice. From observation, Hill concluded that women tend to choose more complex routes than men. However, in other research, Seneviratne and Morrall (2007) found that there is no difference in route choice between men and women. Hoskam (2017) and Grolle (2017) found that perception of safety and atmosphere differs between men and women, but perception of crowdedness does not. Démuth (2013) states that differences in perception between men and woman exist, but they are not clearly distinguished. According to Démuth (2013), variances between individuals are often greater than the variance that can be explained by gender.

Height/physical dimensions person

In order to determine Levels of service, Fruin (1971) takes space required into account by accounting for a body ellipse that considers the body width and depth of a 95th percentile man. However, as Bloomberg and Burden (2006) state, the average person's size has changed since then. Whether a person's size changes their perception of the situation is not found in literature. In a focus group research of Kendrick and Haslam (2010), physical height was mentioned as a factor by one of the participants, but no further information was available.

Health

A person's health can be of great influence on active mode behaviour. Kroesen et al. (2018) shows that clusters can be created that relate health factors like nutrition, drinking, smoking, physical activity and active mode usage to lifestyles. This means that someone's lifestyle can tell something about their active mode behaviour.

Place of Residence

The place of residence could influence a person's behaviour and perception. Humpel et al. (2004) found that people living near coastal areas walked more in their neighbourhood. This could indicate that environmental attributes influence a person's walking behaviour on a strategic level. Their perception of environmental attributes was not significantly different from the participants living in other areas. Hoskam (2017) found a significant correlation between perception of Safety and Crowdedness and residence population density. Respondents living in more densely populated areas perceived a higher level of Safety and a lower level of Crowdedness in a city street. This shows that people who are *familiar* with crowded city streets have a different perception, because they are used to the crowdedness. Respondents living in densely populated areas have an adjusted reference scale to crowdedness. This acclimatisation to crowdedness seems to lead to an adjusted reference scale to safety as well. Whether the density of place of residence influences the perceived crowdedness at events is unknown. As stated in the introduction, residents of Amsterdam avoid certain areas, because they experience the level of crowdedness as unpleasant (van Dun, 2016).

Education level, Employment, Job type, Income
The factors education level, employment, job type and income could all influence pedestrian behaviour. Education level and income are usually correlated. For example, a person who has a degree from university will have a higher chance of having a high income (Griliches and Mason, 1972). Humpel et al. (2004) gathered data on education level, but it had no significant influence on people's environmental perception. Employment or job type could influence the perception of crowdedness as well. Kendrick and Haslam (2010) included employment type into their research. They found that job type might be related to a different perception on crowds. For example, participants employed as police officers associated crowds with violence.

Cultural background
Culture greatly influences crowd behaviour (Kendrick and Haslam, 2010). For example, crowd-mindedness contributes to a flow that is stable at higher levels of density (Duives, 2017). Culture is learned by a person's surroundings, the country a person's lives in and the people a person is close to. According to Démuth (2013), perception is influenced by cultural background, because it relates to the experience and learning process of a person.

2.7.2. Personal state and trip factors

In this subsection, personal state and trip factors are discussed. These are various factors which have to do with the personal state of an individual at a moment in time while present on the event terrain. In Table 2.7, the personal state and trip factors that will be discussed are stated.

Table 2.7: Personal state & Trip factors

Personal	Emotional state
	Stimulant usage
	Familiarity
	Decision style
	Trip purpose
	Group type

Emotional state
According to Lee et al. (2001), pedestrians experience discomfort, frustration and concern about safety in underground/railway stations. Song et al. (2012) found that emotional aspects were crucial to take into account when perception and behaviour of festival visitors are researched. In the study of Song et al., "Positive anticipated emotion" and "Negative anticipated emotion" are included in a behavioural model that explains the intention of event visitors. Conner and Armitage (1998) shows that anticipated affect is a very strong motivator in the decision making process.

Stimulant usage
While stimulant usage is not a common factor to address, at events it could play a role for perception and behaviour. At events there are more people under influence of some kind of stimulant. The research of Grolle (2017) on the holiday named Kingsday, over 50% of the respondents had used at least one kind of drug. Grolle (2017) found that alcohol use was related to a higher perception of safety. The most common types of stimulants are: Alcohol, Marijuana, XTC and MDMA. The type of substance use is expected to differ at different type of events.

Familiarity
According to Daamen (2004), familiarity with the environment greatly influences route choice behaviour, since it actually influences the decision style. Event visitors who are familiar with the environment can make decisions based on their knowledge, while unfamiliar visitors are more dependent on available information and visual cues. Zomer (2013) found that familiarity with the event influenced the use of information. In her research, Ton (2014) used different frameworks for familiar and unfamiliar people to analyse route and activity choice of pedestrians. van Gelder (2018) found that people who are at the train station more often experience the crowdedness as less pleasant. Hoskam (2017) found that frequency of visit correlated negatively

with the perception of crowdedness.

Decision style
According to Hill (1982), route selection strategies are largely subconscious. Avineri & Prashker (2003) state that decision styles are based on herding behaviour, utility maximisation and habitual behaviour. At events, it can be assumed that route choice is influenced more by impulse, herding, group and habitual behaviour (Iliadi, 2016). When an individual has a specific purpose, for example to see a specific artist, then utility maximisation is the most fitting decision style. In the Theory of planned behaviour (Figure 2.2), these decisions styles are found as well. Utility maximisation is based on the behavioural beliefs, or the expected outcomes of behaviour. Social norms can include group behaviour and herding behaviour. As mentioned in Section 2.5.2, habit can be included in the model is well.

Purpose
Iliadi (2016) distinguishes two types of pedestrians. One group with a predetermined goal and one group that chooses more intuitively. This could be part of the decision style, but it could also be related to trip purpose. When an event visitor has a more particular goal, such as the desire to see a certain artist play this could influence their perception. Iliadi also found that walking has a positive influence on the utility function when it is part of an activity, while it has a negative effect when there is no preference for an activity. Seneviratne and Morrall (2007) found that people heading for work or school pay less attention to the attractiveness of the route. This could also be related to familiarity. This suggests that an urgent purpose changes a person's perception & experience in general. The work of van Gelder (2018) suggests that people with a work or school related purpose experience crowdedness more negatively, since people who visit a train station frequently probably take the train to work or school.

Group type
Hoskam (2017) found that group size correlates positively with Atmosphere. According to Daamen et al. (2017), group characteristics and personal characteristics both influence the route choice behaviour and are intertwined as well. In their research they compared group size to route choice. They found a significant positive correlation between group size and type of performance for men, meaning that the larger the group, the more performance type mattered for the route choice. Furthermore, 64,7% of the respondents to their survey stated that the preference of the group is often important in making a route choice. Group type influences the decision style as well (Hoogendoorn and Bovy, 2004).

2.7.3. Event & Environment factors

Event & Environment factors are grouped together, because they form one whole for a pedestrian. Furthermore, they both require alternative types of data collection. The factors that are studied are summed up in Table 2.8.

Table 2.8: Event & Environment factors

Environment	Information
	Crowd composition & Social identity
	Location
	Light
	Sound
	Time of day/week
	Weather and weather protection

Information
Information, which includes knowledge, mobile phone applications, flyers and route information signs can influence a person's choice behaviour. Zomer (2013) states that whether or not information will be noticed depends on the interactions in a group, familiarity and purpose. For example, when one member of the group is familiar with a city or event, the rest of the group can follow and there is no need to consult (route) information. Furthermore, Zomer concluded that information provided beforehand was more often consulted than information that was available at the event. In the research of Daamen et al. (2017), information was not

found significant with relation to route/activity choice.

Crowd composition and social identity
As Hoskam (2017) and Grolle (2017) found, perception of crowdedness is not purely dependent on the measured density. As Fruin (1971) stated, the size of personal space that is desired between two persons is different for gender, culture and personal characteristics of both persons. Novelli et al. (2013) researched the effect of social identity on perception of crowdedness and the positive or negative emotion towards the crowd. People who identified themselves with the other people present perceived lower crowdedness and more positive emotions.

Location type
There are many location characteristics that could be taken into account. In this case, location size is assumed to be highly relevant. A narrow corridor might be perceived differently, even though the density is the same as in a broad corridor (Kendrick and Haslam, 2010). Furthermore, a location is more than only a sum of physical attributes. A certain location will be a certain ambience, which is created by a combination of all Event & Environment factors, such as lighting and music, but also crowd composition. Moreover, crowds with a common social identity also attach meaning to certain spaciotemporal places (Reicher, 2018). For example, history of a location could play a role in the atmosphere that is perceived at a certain location. According to Health and Safety Executive (2000), retrieved from Li (2019), locations such as entrances and exits, attractions, queues and enclosed spaces should be given extra attention when it comes to monitoring the crowd.

Light
Lighting has a large influence on the perception of safety and can also be used prevent crime (Boyce et al., 2000). Boyce et al. (2000) found that a light intensity of 30 lux at nighttime at a parking lot provided a perception of safety close to the one in daylight. The colour of the light was a minor factor compared to the light intensity. Ariffin and Zahari (2013) found that a small percentage of pedestrians gives "not enough lighting" as a reason not to walk somewhere. Furthermore, different lighting types, such as stage lights and stroboscopes can influence people's emotional state (van Hagen, 2011). Preferred light intensity depends on the situation, the task a person needs to perform and the surroundings (van Hagen, 2011).

Sound
A phenomenon that occurs at events is panic caused by an unexpected sound. In 2010, the "Damschreeuwer" caused panic by screaming at the end of the two minute silence for the commemoration. In the chaos, 63 people were injured (Buis,2014). Furthermore, sounds can also influence the emotional state of a person. Specifically music has been shown to influence mood (Bruner, 1990) and has been used to alter mood in both positive and negative directions. Elements such as tempo, pitch, mode (major or minor) and genre have influence on the mood that people experience (Bruner, 1990). A rising pitch can convey a growing intensity in emotion, songs in higher keys are perceived as happier, music in major expresses more positive feelings and complex harmonies are more sad and agitated (Bruner, 1990). Music that is liked by individuals results in a even more positive effect. In the research of Cameron et al., music likeability reduced the perceived waiting time. Music has also been found to have anxiety-reducing qualities (Cameron et al., 2003). According to Li (2019), noise is a factor that is considered by crowd managers as well.

Time of day/week
In a daily live, time of day is relevant in relation to peak hours, when pedestrians go to work or school. Ton (2014) and Seneviratne and Morrall (2007) researched the difference between peak and off-peak, but did not find a significant relation with route choice. In this research, mainly recreational pedestrians are considered. Different outcomes are expected at different times of day, related to stimulant usage and time spent at the event. Furthermore, time of week could have an influence on the type of visitors. During the weekend, people who work during the week have time to go to events.

Weather and weather protection
From the research of Andrade et al. (2011) it is known that weather influences a person's perception of Comfort. Temperature, wind speed and precipitation all have influence on this perception (Andrade et al., 2011). The presence of weather protection did not influence route choice in the research of Seneviratne and Morrall (2007). According to Li (2019), bad weather can influence the mood of the crowd negatively.

2.7.4. Quantified Crowdedness

Crowdedness can be quantified with a number of variables. Most are mentioned in Section 2.1. Density, flow and speed are most commonly used to describe crowd behaviour on a macroscopic scale (Vanumu et al., 2017). Bloomberg and Burden (2006), Weidmann (1993) and Eijkelkamp (2017) suggest that a local view can be used to give an indication of the crowdedness that a pedestrian experiences, such as the number of (near) collisions, the time spent following and waiting times. Table 2.9 shows the variables that will be discussed.

Table 2.9: Quantified Crowdedness

Quantified Crowdedness	Density
	Speed
	Flow
	Flow type
	Collision/Impedance

Density

The relation between number of pedestrians and available space is the most important determinant for Level of Service (Fruin, 1971). The work of Grolle (2017), Hoskam (2017) and van Gelder (2018) showed that there is a relation between the number of people in an area and the perceived crowdedness of pedestrians. Pécheux et al. (2004), Papadimitriou et al. (2010) and Madanat et al. (1994) all use a number of pedestrians/vehicles in a demarcated time and space to compare this to perception on level of service, comfort, safety and crowdedness.

Speed

A pedestrian has a desired speed, depending on age, gender, time of day, trip purpose and environmental factors (Bloomberg and Burden, 2006). Weidmann (1993) describes 'Free choice of speed' and 'frequency of forced changes in speed' as criteria for assessment of pedestrian infrastructure. At an event, due to the number of people that are standing and walking, it is not always possible to retain a person's desired speed. Subsequently, perception of crowdedness can be related to the walking speed of a pedestrian.

Flow & flow type

The variable Flow is the third macroscopic variable. Flow has a relation to Density and Speed, consequently, it is also expected to relate to perceived crowdedness. Flow considers the movement of all the pedestrians in a system. Density cannot indicate movement, while flow and speed can. Kendrick and Haslam (2010) found that the ability to move (in the desired direction) influenced people's perception of safety and security and their sense of control. Guo et al. (2016) found that pedestrians tend to form lanes for directions. Lee et al. (2005) specified a new Level of Service assessment which included the proportion of flow in two directions for intersections. There are various types of flow that could be distinguished, such as no flow (static crowds), unidirectional flow, bidirectional flow, crossing flow or turbulent flows (Duives, 2017). If a pedestrian wants to cross a steady flow, this will take more time and effort.

Collision/Impedance

Weidmann (1993), Eijkelkamp (2017) Bloomberg and Burden (2006) and Hoskam (2017) use values such as number of (near collisions), control delay and percentage of time platooning as indications for the comfort experienced by pedestrians.

2.7.5. Perception & experience of Crowdedness

The situational perception of a pedestrian is a comprehensive interpretation of the external stimuli. Which of the aspects of situational perception are related to crowdedness has to be determined based on literature. In earlier research Crowdedness, Safety and Atmosphere were considered (Hoskam, 2017; Grolle, 2017). Bloomberg and Burden (2006) mentions Comfort, Safety and Convenience. Landis et al. (2001) also includes Attractiveness of the built environment. Table 2.10 states the perceptions that are discussed in this paragraph.

Table 2.10: Perception & Experience of Crowdedness

Perception	Crowdedness
	Comfort
	Safety
	Atmosphere
	Attractiveness environment

Crowdedness
Since crowdedness is the main topic of this research, this perception has to be included. Based on the findings of Galama (2016), it seems that crowdedness can be seen as a positive as well as a negative factor. Worchel and Teddie (1976) showed that experienced level of crowding is influenced more by the interaction distance than by overall density. Furthermore, the study showed that environmental factors (pictures on the wall) could lower the experienced level of crowding. According to Lee et al. (2001), experiencing discomfort, frustration and concern about safety is possible in underground/railway stations because of congestion and crowded situations. Van Hagen (2011) found that crowding correlates negatively with pleasure and satisfaction and leads to an increase of arousal and stress, because people feel restricted in their available space. However, in a hedonistic environment, such as an event or a club, crowdedness is perceived positively.

Comfort
The Level of Service is often described as the comfort level that is experienced by the pedestrian (Bloomberg and Burden, 2006). Therefore, comfort could be taken into account as an indication of perceived LoS. However, comfort can be interpreted in multiple ways. It can be physical comfort, such as described by Fruin. Comfort could also include social comfort, meaning that a person's comfort is influenced by the behaviour and composition of the crowd. Comfort can also be influenced by time spent. Certain bodily needs can make a person feel uncomfortable. For example, when a person is thirsty, tired of standing or has to use the toilet. This type of comfort can be improved by event facilities, such as benches, water taps and sufficient and strategically placed toilets

Safety
The perception of Safety is related to the perception of Crowdedness, as can be concluded from Hoskam (2017) and Grolle (2017). Grolle found a negative relation between number of people present and perceived safety. Safety is also addressed by Landis et al. (2001), Pécheux et al. (2004) and Kita (2000) as an indicator for perceived crowdedness. Subjective safety is found to differ much from objective safety (Vlakveld, 2009). Often, social demographics can be used to explain perceived safety, such as level of urbanisation. Moreover, familiarity increases perceived safety (Vlakveld, 2009). For safety, there is a difference between social and physical safety. Here, physical safety can be endangered by accidents and oppression in a crowd. Social safety however, concerns the behaviour of other people towards the individual. For example, a person might be mistreated or robbed by another (Hoskam, 2017). Perceived safety is also influenced by past experience and information from (social) media. Event & environment factors, such as clear design of a street, influence perceived safety as well (van den Munckhof et al., 2017). And finally, social control is important. The presence of other people could either increase of decrease perceived safety, depending on the extent to which an individual feels part of that group.

Atmosphere
The perception of Atmosphere is related positively to the perception of Crowdedness and Safety, as can be concluded from Hoskam (2017) and Grolle (2017). Specifically for recreational purposes, considering atmosphere could be important in a person's perception. Atmosphere is a very subjective and intangible attribute, but this might make it even more valuable to identify how crowdedness is perceived.

Attractiveness Environment
Finally, attractiveness of the environment is expected to have a relation to perceived crowdedness and experience. It is expected to be related to perceived safety. Ariffin and Zahari (2013) found that facilities consciously designed for pedestrians contribute to a more positive perception of the walking environment. Humpel et al. (2004) found that men with the most positive perception of the attractiveness of the neighbourhood were significantly more likely to walk more in the neighbourhood.

2.7.6. Conclusion

Many of the factors that were analysed have a relation to perception to some extent, but it is not always clear in what way. Many of the socio-demographic factors influence perception indirectly, because they explain or relate to personal state and trip factors. For example, place of residence relates to familiarity. Age is expected to relate to perceived and experienced crowdedness. However, only a relation to perception of Safety was found. Factors such as culture have influence on perception, but the relation is not clear, because culture in itself is such a broad concept. Emotional state, Substance usage, Familiarity, decision style, trip purpose and group type all seem very important with relation to perception & experience of Crowdedness. All of these are useful to research further, since some have not been researched with relation to perception specifically, or only one research was found. For Event & Environment factors, relations to situational perception and to emotion are found, but not often a relation with perception of crowdedness is found in literature. Therefore, these factors need to be researched further. It is clear that observed/measured crowdedness can be related to perception & experience of crowdedness using various indicators, such as Density, walking speed, flow and impedance. All of these factors are also related to each other. Finally, five perceptions were evaluated. Comfort, Safety, Atmosphere and Attractiveness of the environment have been considered in previous research with relation to perception of crowdedness. These perceptions are influenced by the perceived crowdedness in various ways, but are also influenced by the background factors as well. The effect of perceived crowdedness on the other perceptions (experienced crowdedness) is not always the same. Crowdedness can be perceived as positively or negatively, depending on the context. In the next chapter, the categories will be placed in a framework based on the theory of planned behaviour. Furthermore, hypotheses will be specified based on this literature study. In Chapter 4, data collection methods for these factors are discussed.

3

Theoretical framework

In this chapter, the factors influencing perception found in Chapter 2 will be placed in a theoretical framework based on the Theory of Planned Behaviour, answering the following sub-question:

How can perception & experience of crowdedness be explained by a theoretical framework and which hypotheses relate to this?

In Section 3.1, the theoretical framework that is developed will be explained. In Section 3.2, hypothesis will be presented corresponding to the paths presented in the theoretical framework.

3.1. Theoretical framework

In the previous chapter, factors that could influence behaviour and perception were identified. Already, different categories were used to distinguish these factors. The reason to use these categories is further clarified by the developed framework. The proposed structure of the theoretical framework is based on the Theory of Planned Behaviour (Figure 3.1).

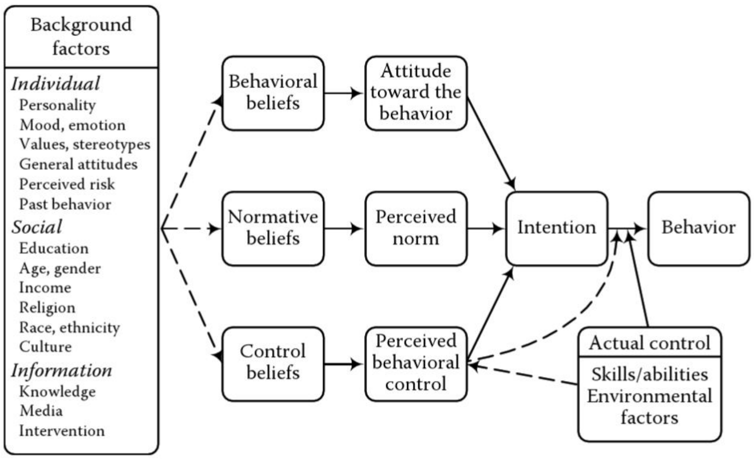

Figure 3.1: Theory of planned behaviour

However, while the Theory of Planned Behaviour focuses on the various beliefs which can lead to a certain type of behaviour, the model specified for this research focuses on the way surroundings and crowds are perceived. Consequently, this newly developed perception model is more dependent on a time and space dependent situation, while TPB is often used to find behaviour patterns that are not dependent on a specific situation (Conner et al., 1999).

Figure 3.2 visualises the new model, which contains the same steps as the Theory of planned behaviour. It visualises the way an individual perceives and experiences crowdedness at an event. The background fac-

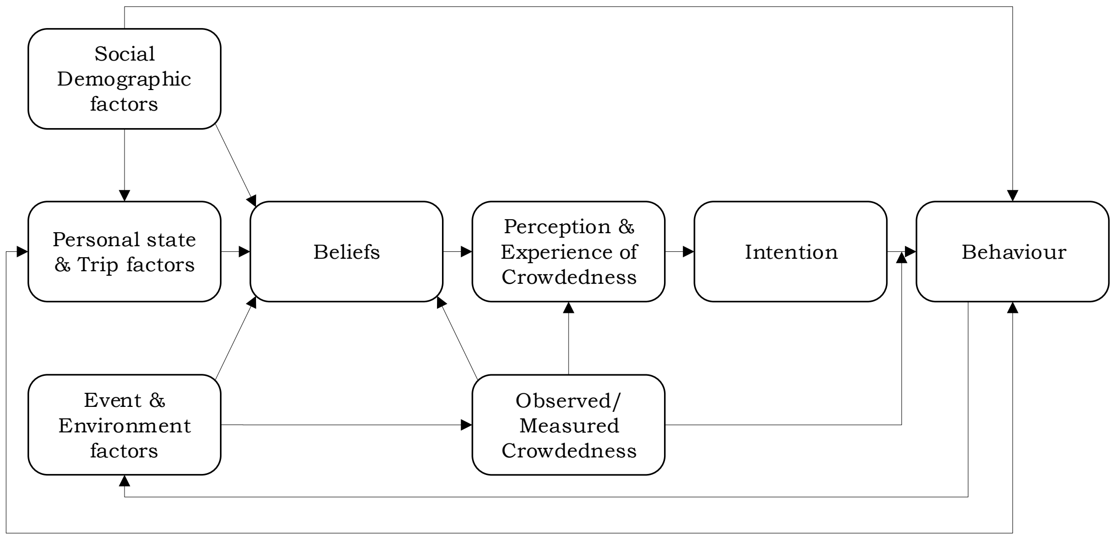

Figure 3.2: Adjusted theoretical framework: Perception & Experience of Crowdedness

tors are split up in three categories, namely Social Demographic factors, Personal state & Trip factors and Event & Environment factors. This division is made, because these categories are related to each other and to perception & experience of crowdedness in a different way. Event & Environment factors are reflected more prominent in the revised framework, as they evidently influence perception of Crowdedness.

Social Demographic and Personal state & Trip factors are both dependent on the individual, and following that reasoning, could be placed in one category. However, they are split, because Social Demographics are typically factors that are constant for a long-term period and are not influenced by other factors in the model. For example, the age of an individual is not changed by their behaviour.

Contrary, the category Personal & trip is dependent on the individual, but can also vary during the event due to the behaviour of the individual. For example, a person can choose to consume alcohol, which changes their personal state. Socio-demographics can also explain personal state & trip factors, which is why an arrow is added between them. For example, age can be used to explain how familiar a person is with a location or event. Both Socio-demographic factors and Personal state & Trip factors can influence behaviour directly in this adjusted model. This relation mainly describes behaviour on the operational level. Age, gender and substance usage can all be used to explain the walking behaviour of an individual.

The event characteristics are split up in Event & Environment factors and observed/measured crowdedness. Event & Environment factors can differ in time and location. In this category, external factors such as weather, which the event organiser cannot influence, are included. On the other hand, Event factors such as number of attractions and music type are included in this category as well. The category Crowdedness includes all types of indicators discussed in 2.1, such as flow, speed, density, flow type and impedance (Bloomberg and Burden, 2006). It is influenced by Event & Environment factors, for example, the width of the passageway is influenced by obstacles that are placed there.

These four categories influence a persons beliefs. In the Theory of Planned Behaviour, beliefs are split up in behavioural, normative and control beliefs. However, since the beliefs will not be researched further, the relation is simplified in this model.

Intention and behaviour include all behaviour that could be influenced by Perception & Experience of Crowdedness. Furthermore, the actual crowdedness influences the difference between intention and behaviour, just as in the original framework. The arrow from behaviour to Event & Environment factors explains the choice of an individual to move from one place to the other. Consequently, the crowdedness will also vary. Intention and Behaviour are not researched further, because it does not fit in the scope of this project.

A simplified model is provided as well (Figure 3.3), which shows only the categories and relations that will be tested. For the interpretation of the results, the full theoretical framework can be used.
Within the category Perceived & Experienced crowdedness, a difference is made between perception of crowd-

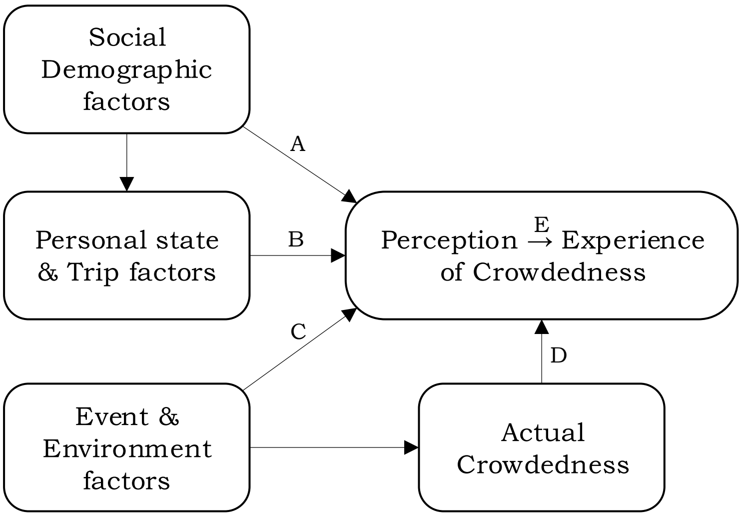

Figure 3.3: Simplified framework for research

edness and experienced crowdedness. Perception of crowdedness contains a person's impression of the people that are present. The experience of crowdedness is a value judgement based on this crowdedness, containing perceptions on safety, comfort, attractiveness of the environment and atmosphere.

3.2. Hypotheses

In this section, the hypotheses based on the literature study (Section 2.7) will be presented. Per category, the relations between the factors in that category and perception & experience of crowdedness are discussed. These relations follow the arrows that are displayed in Figure 3.3. The hypotheses mentioned here are applicable to events in general. In Chapter 4, event specific hypotheses will be discussed.

A. **Socio-demographics → Perception & Experience of Crowdedness**

- Women perceive Safety lower.
- Men perceive Attractiveness of the environment and Atmosphere higher.
- Younger people have a more positive perception towards Safety, Comfort, Attractiveness and Atmosphere.
- Foreign/unfamiliar people perceive crowdedness higher and have another overall perception.
- People who live in a region with a low urbanisation level will perceive crowdedness higher, and comfort and safety lower.

Five hypotheses are formulated regarding the influence of socio-demographics on perception & experience of crowdedness. These relations are all causal, as the theoretical framework shows (Figure 3.2). The hypotheses are mainly derived from the results from Hoskam (2017) and Grolle (2017). For age, Hoskam only found a relation to perceived Safety.

B. **Personal & Trip factors → Perception & Experience of Crowdedness**

- Familiarity leads to a lower perceived level of crowdedness and more unpleasant experience of crowdedness.
- People with a specific purpose will perceive the crowdedness as higher and experience crowdedness more negatively.
- People who are part of a larger group will perceive crowdedness lower and experience crowdedness more positively.

- Positive emotions lead to a more a lower perceived level of crowdedness and a more positive experience of crowdedness.
- Drug and alcohol usage have varying effects on perception. Alcohol makes people perceive level of crowdedness lower and level of safety higher.

The personal state and trip factors each influence the perception of crowdedness in different ways. They are derived mainly from the work of van Gelder (2018), Hoskam (2017), Grolle (2017) and Lee et al. (2001). Drugs and alcohol can have various effects on perception. In the work of Grolle (2017), people who had consumed alcohol perceived safety higher.

C. **Event & Environment → Perception & Experience of Crowdedness**

- At locations with music and activities, perceived atmosphere will be rated higher.
- Loud music and loud noises will lead to higher perceived crowdedness.
- At locations with flashing lights, Crowdedness will be rated higher.
- Atmosphere and attractiveness are rated higher when the weather is warm and sunny.
- At night, Safety is perceived lower and Atmosphere is perceived higher.

Five hypotheses concerning Event & Environment factors are formulated. Since previous research into perception of crowdedness did not focus on events, the effects of lights, sounds and event locations is not yet clear. Therefore, these hypotheses are largely based on the expectations of the researcher and on the literature found (Andrade et al., 2011; Bruner, 1990; Reicher, 2018; van Hagen, 2011). Many of the factors in this category can be used to predict perception & experience of crowdedness, but most of them are not the reason for the change in perception. In this case, the relation is explained indirectly, through actual crowdedness (Figure 3.3). For example, the hypothesis: *"At night, Atmosphere is perceived higher"* is expected to be true, because later at night events are usually more crowded. Still, the effect of nighttime is also expected to have a pure effect, based on people's beliefs about nighttime. For example, nighttime can be found more exiting.

D. **Actual crowdedness → Perception & Experience of Crowdedness**

- Higher density (pax/m^2) causes a higher perceived Crowdedness.
- Higher flow ($pax/m/s$) causes higher perceived Crowdedness.
- The type of flow (uni-, bi-directional, crossing and random) will affect the perceived Crowdedness. When the flow is more structured and even (unidirectional flow or 50/50 bi-directional flow), the perceived Crowdedness will be lower.
- A tipping point can be found for perceived Crowdedness at the tipping point in density between free flow and congestion.

The four hypotheses concerning quantified crowdedness are all based on macroscopic flow variables. They are inspired by the information given in Section 2.1 and Section 2.4. It is expected that both local and global density and flow will affect the perceived crowdedness at one location, because pedestrians are walking around. Therefore, their perception of crowdedness might be based on other locations that they have visited recently as well. It is expected that the relation between perceived crowdedness and flow is not linear, because the relation between flow and density is not linear either. It is expected that the perceived crowdedness for free flow conditions is different than the perceived crowdedness in the unstable phase of flow.

E. **Perceived crowdedness → Experience of Crowdedness**

- In places where crowdedness is perceived very high, people will experience the crowdedness as less pleasant and level of Safety and Comfort will be perceived lower (non linear).
- People who perceive a higher level of crowdedness, perceive atmosphere higher as well.
- It is expected that all perceptions, Safety, Comfort, Attractiveness of the environment and Atmosphere are positively correlated.

The three hypotheses that concern the relations between perceptions and experience of crowdedness are mostly assumed to be positive relations that can be found as a linear correlation. However, the relation between Crowdedness and Safety and Comfort is expected to be more complicated. This depends on whether crowdedness is seen as a positive or a negative aspect. Therefore, the hypotheses state 'very crowded'. Furthermore, it is expected that the perception and experience of crowdedness influences the other perceptions. In other words, a causal order is hypothesised, were the perception of crowdedness determines the other perceptions.

All the hypotheses in this list will be tested. How factors such as familiarity and purpose will be measured will be discussed in Chapter 4. The exact variables that will be used to determine crowdedness will be explained in Chapter 5. The hypotheses will be tested and reviewed in Chapter 7.

II

Research method

4

Data collection method

In this chapter, the research method is discussed. This chapter will answer the following sub-question:

Which data collection methods can be used to study the relationship between perception and personal, event and trip characteristics?

Determining the best data collection method coheres with the choice of research events and locations and with the specific factors that are gathered, as is illustrated in Figure 4.1.

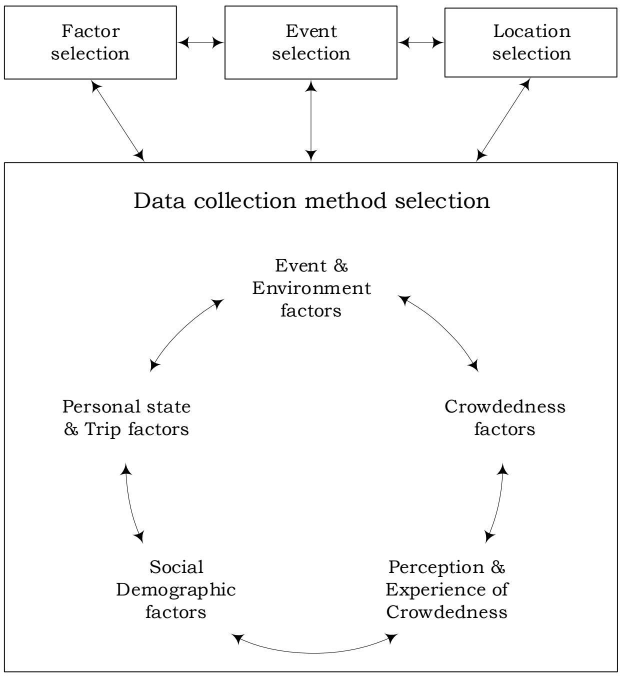

Figure 4.1: The relation between factor, event and location selection and data collection method selection

The choice of factors that are included in the research and the choice of events that are researched are not mutually exclusive. An event is chosen because it can offer insight in all factors and some factors will be included or further specified because of the event chosen. What is meant with the arrow from event selection to data collection method selection is the preexisting presence of sensors at certain events. By choosing an event, the choice for those sensors is inherently made. Those sensors are installed at certain locations. The overarching data collection method must be able to combine all categories for which data must be collected.

For every category, a different data collection method can be applied, as long as it can be connected to the other data. The data collection method should be equal amongst researched events, otherwise it not possible to compare the data. Lastly, the research locations and times have to be determined.

In the first section (4.1), the selection of the events is explained. Furthermore, it is stated which event specific factors need to be kept in mind and what the implications are for the research method. Second, in Section 4.2, data collection methods are discussed for each type of data. A distinction is made between measuring crowdedness, collecting personal & perception data and collecting Event & Environment data. This section will explain why the use of Wi-Fi sensors and counting cameras in combination with a survey was made. Third, Section 4.3 will delve deeper into the set-up of a survey. A selection of factors will be made for this research based on the relevance of these factors that was discussed in Chapter 3 and the feasibility to measure these factors with the chosen data collection methods. Fourth, an overview of the factors selected and the data collection method is given in Section 4.4. Fifth, Section 4.5 will elaborate on the specific research set-up for both events. Finally, the chapter will be concluded with some general descriptives on the data that was collected and a short evaluation of the research performed at both events (Section 4.6).

4.1. Event selection

In this section, the selection of the events will be explained. Two case studies are conducted, one at the TT Festival 2018 in Assen and one in the Red Light District of Amsterdam. It is chosen to research two events, in order to see if perception of crowdedness influenced in the same magnitude by the same factors. Also, two events are researched to find event unique influences to the perception of crowdedness. Why these two events were chosen will be clarified in this section.

4.1.1. TT Festival

The first event that will be researched is the TT Festival in Assen. This event was founded in 1973, as entertainment in the TT night before the races the next day (van Gool, 2018). In the years before the festival, this TT night turned into a riot, where the police had to deal with fighting and trashing youths. After a few bad years, a solution was found: entertainment in the form a fair, a skelter race and a striptease show. The concept worked; the fighting became less. Nowadays, the TT festival is a four day festival that is visited by motorcycle fans, inhabitants of Assen and other people from the region who are looking for a party. Over these four days, there are an estimate of 160.000 visitors. There are eight stages throughout the city centre of Assen, there is a fair, there are activities for children during the day, a nightride and a motorcycle parade (TT Festival Assen, 2018).

Figure 4.2: Crowd at a stage during the TT Festival

This event provides an interesting research area, because of the history of the event. Here, by attracting a larger crowd to various activities, problems with police enforcement diminished. Now, it is a huge event, where extensive crowd management is required. The event has many different areas with a unique atmosphere that can be compared. The event attracts locals as well as foreigners and people of all ages. Furthermore, the effects of light and sound on pedestrians' perception can be researched here, since there are many stages with music and stage lights.

4.1.2. Red Light District

The second case study will be performed at the Red light district in Amsterdam. Although this is not an event as defined in this report, it is a location that attracts large crowds where people have a 'Anything goes' attitude (Livework studio, 2018). The area has been a news topic in the Dutch media this past summer. The municipalities' ombudsman, Arre Zuurmond, called the Red Light District an 'Urban jungle', where it is very crowded and not enough action is taken by the police (van Lieshout, 2018). Therefore, this area is a highly relevant research area. Its special character can lead to new insights compared to the first case study.

The Red Light District or "de Wallen" is an area in the city centre of Amsterdam, which is known for its red-light windows with sex workers, coffeeshops and raucous bars (Nevez, 2018). Ever since the 1300s, the area near the port flooded with sailors who sought entertainment in the various inns and pubs that the area had to offer. Prostitution was not yet legal, so women carried red lanterns to make their profession clear. In the 19th century, prostitution was legalised and only in the the year 2000, brothels were legalised. Since 2007, the municipality has taken action to clean up the area, reducing the number of red-light windows, and eliminating all forms of illegal prostitution, such as human trafficking. Furthermore, they encourage creative enterprises and cafes to set up in the area.

Figure 4.3: Crowdedness in the Red Light District. Foto Marcel Wogram, 2018

Nowadays, the Red Light District is a very crowded area, where many tourists and party-people come to look around. The amount of people and their behaviour is causing various problems in the district. Certain alleys are closed down for brief periods of time to prevent overcrowding (Jorn van Dijk, personal communication, March 12, 2019). There are hosts designated to guide the crowds during the most crowded evenings. The hosts are a recent invention to try to improve the behaviour of the crowd. They do not hand out tickets, but just give people advice on directions, where to walk, where to throw away trash and where to go to the toilet (Livework studio, 2018).

Livework studio (2018) carried out a qualitative research to see how the crowdedness is experienced by residents, entrepreneurs, police officers and passersby. One resident pointed out that the small alleyways are dangerously crowded. It can get so crowded, that it is not possible to move anymore. This leads to a feeling of unsafety. From all the interviews, five main elements were found to influence the perceived crowdedness: the large number of people, antisocial behaviour, the dirtiness of the surroundings, being impeded in travelling and a (physically) unsafe feeling.

The Red light district provides an interesting research area, because it is dangerously crowded and is treated as an event, even though it is actually just a part of the inner city. The area attracts many tourists, but there are also residents of Amsterdam there. Comparing the difference in perception between tourists and residents will enhance the understanding of the effect of personal factors on perception of crowdedness. Also, the activities offered are different from the TT Festival, which is expected to lead to new insights.

4.1.3. Conclusion

The chosen events have some similarities and differences, which makes the comparison interesting. Both events deal with a large amount of (possibly drunk) people, are located in a city centre and both events are public. Differences are that the TT Festival is a yearly recurring event, while the Red light district can be visited any day of the year. Although the Red light district is not an actual event, it is treated as such, because the same challenges in crowd management are faced here as at an actual event. Besides this, another difference is the crowd that is attracted. Whereas the TT Festival attracts mainly local residents who visit the event yearly, the Red light district mainly attracts tourists who are not that familiar with the area. The last difference is that the TT Festival is an outside event, where there are stages with music where people are gathered and reside. At the Red light district, people mainly walk around while looking around. Other than that, the activities are mainly inside and include visiting bars, coffee shops, brothels, museums and shows. To conclude, at both events, it is expected that people's perception on crowdedness is influenced by different personal, trip and event factors, making them suitable events to research and compare.

4.2. Data collection method selection

In this section, possible data collection methods to measure actual crowdedness, personal, trip and event characteristics are discussed. In this research, monitoring and survey data will be combined, to find the relation between perception of crowdedness and personal, trip and events characteristics. The event characteristics can be split up in crowd dynamics and the event environment. To combine crowd dynamics data with personal data, it is necessary to capture both these data sources at the same time and place. Only then can an accurate comparison between perception of crowdedness and measured/observed crowdedness be made.

4.2.1. Crowd dynamics

In this section, the best method to collect data on crowdedness is discussed. In Section 2.7, five indicators of crowdedness were introduced, namely Density, Speed, Flow, Flow type and Collision/Impedance. These are good indicators for crowdedness, therefore, a measurement method is required that can be used to determine these variables. Here, possible data collection methods and the feasibility of using these methods are discussed. In Table 4.1, the methods that can be used to research crowd movements are shown. Collection methods can be divided into a microscopic and macroscopic perspective and between global and local objectives (Daamen et al., 2016).

Table 4.1: Crowd dynamics data collection techniques (Daamen et al., 2016)

		Measurement objective	
		Local	Global
Measurement perspective	**Microscopic**	Video Time-lapse Infrared Laser	Questionnaires GPS Bluetooth, Wi-Fi Mobile phone data
	Macroscopic	Manual counts Video Time-lapse Infrared Laser	Aerial observations GPS Bluetooth, Wi-Fi Mobile phone data

From the literature study in Section 6.1.2, it is clear that Density, flow and collision/impedance is highly relevant in relation to perception of crowdedness. Density can vary every instant and can be determined for different areas. Density such as used in a fundamental diagram is a macroscopic variable, but it is also possible to quantify local densities. For the macroscopic view, Aerial observation, GPS, Bluetooth, Wi-Fi and Mobile phone data can be used.

Although Speed is normally related to Flow and Density, at an event it is possible that the formula that connects these values does not apply. For example, because the desired speed and actual speed of a pedestrian is zero, near a stage. On the other hand, the actual speed can also be near zero, while a person actually wants to walk somewhere, but is impeded by other pedestrians. Therefore, it is a variable that is useful to determine. Speed can be determined on a microscopic or macroscopic level. For this research, speed can either be determined for a certain area or passageway where perception of pedestrians is also determined or the speed of a specific person is determined, of whom perception is also registered. Therefore, a GPS tracker attached to a pedestrian can be used. It is also possible to determine speed from Wi-Fi sensors or counting cameras, as has been done by Yuan et al. (2016).

Flow partially captures density and speed characteristics. The movement of the crowd is best expressed with this value. It can be determined using video, infrared, Bluetooth and counting cameras. Speed distribution and flow patterns can be observed by using video footage of cameras or by human observation.

To quantify variables such as number of (near) collisions, control delay and percentage of time platooning, would require a microscopic perspective. Camera footage can be analysed to find such variables, either manually or with computer software. Stalking and observation are another way to determine such variables, as has been done by Bloomberg and Burden (2006). Survey questions can also be directed to this, which was done by Hoskam (2017).

For this research, it is chosen to collect data about crowdedness using a combination of Wi-Fi sensors and counting cameras, because all macroscopic variables (Density, speed, flow) can be determined using the combination of these sensors. Local density can be derived using a Wi-Fi sensor. Flow is determined with counting cameras. Flow type can be determined as the proportion of in- and outgoing flows. How these sensors operate exactly and how the macroscopic flow variables are derived will be explained in Chapter 5. The only variables that cannot be determined are collisions and impedance, but this could be included in a survey. Moreover, these types of sensors were already planned to be applied to the TT Festival and are installed permanently in the Red light district. These types of sensors are common at large events, because they provide oversight of the amount of people and the movement of the pedestrians over a whole event area. A real-time dashboard is developed to use this data for crowd management (Daamen et al., 2018). Therefore, it is also interesting to see how crowdedness measured with these sensors relates to the pedestrians' perception of crowdedness. This research will be able to show to what extent this data relates to the experience of pedestrians, which can be used to analyse this data in future cases.

4.2.2. Event & environment data

In this section, the reason to gather certain Event & Environment factors is explained. This data will be referenced to as metadata henceforth. Normally, metadata is all the background data for which the main data gathered has to be controlled. In this case, all the environmental factors are dubbed 'metadata', because they are mainly control factors and they are measured with different methods than the survey or monitoring.

Light & Sound data

As was explained in Chapter 3, light and sound can change a persons mood and perception, therefore, it is important to include these factors in the research. Light and sound data can easily be measured with a smartphone application, named Physics Toolbox. It was chosen to measure intensity, opposed to tone/colour/ spectrum, because it is the most easily and accurately measured. Since no separate sensor is used, light and sound data have to be measured with intervals, for example every half hour. It is expected that light and sound conditions will not change that drastically within 30 minutes. Therefore, these measurements can then be used with an interval of half an hour. For every survey entry, the closest measurement is used. From each measurement, an average, minimum and maximum is derived.

Music type

Furthermore, music type is determined using the event timetable, for two reasons. First, the music type can influence a person's mood. Second, it could be related to the number of people that are attracted to a certain location. Music type is categorised in three categories: No music, Background music and Main act. A more specific distinction between genres is not made, because this would require too much time, it would require a value judgement and it would create too many categories.

Weather
For weather, no clear link to perception was found yet, but it is expected to have an influence. Furthermore, it is an important control factor, since the actual crowdedness can depend on the weather. The weather conditions can be derived from the historical database of Accuweather. The data required contains temperature, weather type and daytime (true/false) data per hour.

Location
In Figure 4.4, five types of typical event locations are distinguished. It is expected that depending on the location type, perception will be different. This has to do with a combination of factors, such as area size, type and number of attractions, purpose, music/sound and lighting. To find the influence of these characteristics, data should be gathered at different location types. Therefore, at each event, three different locations will be chosen to conduct the research. For all data, the location where this data is gathered is included as metadata. At the location, photographs will be made to get an impression of the location characteristics.

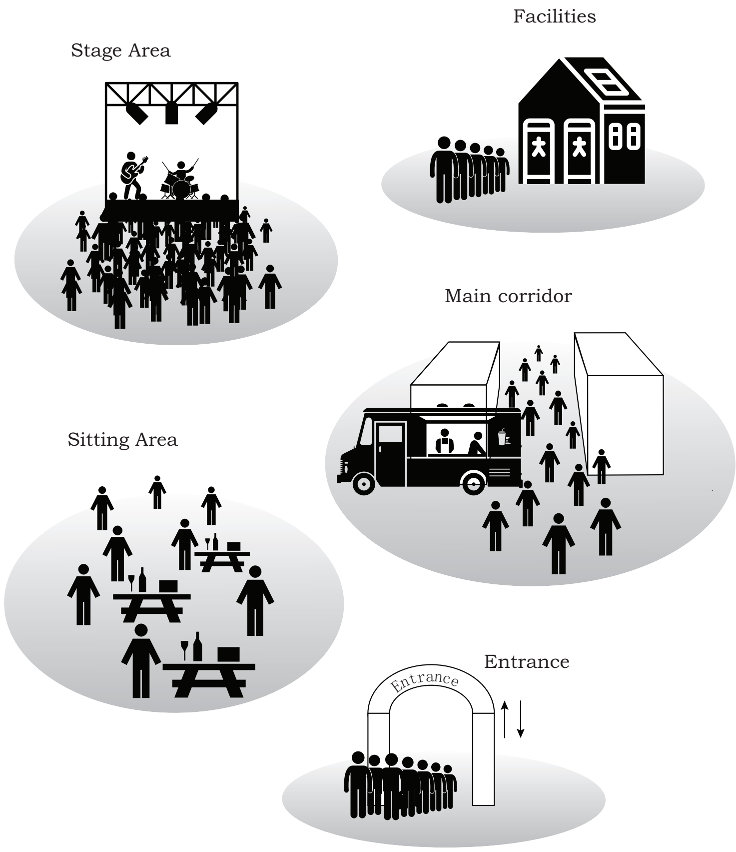

Figure 4.4: Five main festival location types

The Wi-Fi sensors and counting cameras as described in 4.2 are placed at strategic places at an event. For example, at entrance and exit routes, counting cameras are placed to determine in- and outflow. At main corridors, Wi-Fi sensors and counting cameras are placed to determine flow and density. At crowded standstill areas, Wi-Fi sensors are placed, to determine the density.

The location of the sensors is determined beforehand for this research, because it makes use of sensors that are placed for other studies. Therefore, for this research, the only thing that needs to be determined is at which of these locations surveys will be conducted to combine the data. The objective is to collect data at different location types (corridor, exit/entrance, main stage) in order to compare these location types in terms of perceived crowdedness. Per location, the aim is to collect Wi-Fi data and counting camera data, since they correspond to different variables (density and flow) that can be used to describe crowdedness. To combine the survey data with the cameras and Wi-Fi sensors, the surveys will be conducted at the same location. However, it should not be in view of the camera, since this could disrupt the results. In Section 4.5, the chosen locations per event are explained.

4.2.3. Perception, trip and personal data collection

As mentioned before, pedestrians' perception of crowdedness cannot be determined by observation, since this is an internal process. It might be possible to analyse facial expressions, but this type of research is not feasible within the scope of this project. Likewise, an experiment setting would require many resources and would give limited results. It would be possible to acquire information about perceived crowdedness with an experiment combined with a survey. This would have the benefit that all environmental factors can be controlled and specifically tested. However, it would require a very extensive experiment to simulate an event setting. This is not feasible for a thesis project.

Another option to discover pedestrians' perception would be to perform a stated preference survey. However, since perception is expressed in this thesis as *"the interpretation of external stimuli"*, it would be necessary to provide some external stimuli, for example video footage. However, this would only stimulate the visual and audio senses. Furthermore, seeing a crowd on a flat screen has a different effect than standing in the middle of the same crowd. In a previous thesis project, Galama (2016) found very different results concerning the influence of crowdedness between a revealed and stated preference research of the same event. Another way to perform a stated preference survey would be to send surveys to event visitors after they have visited an event. However, it is not realistic to expect that people can exactly recall their perception of crowdedness at specific locations and times.

Therefore, the best method to study perception of crowdedness is by conducting surveys during the event at specific locations. The added value of conducting a survey at a certain place and time, is that the people who are being questioned know how they feel at that moment. Also, factors like lighting and sound, might have an effect on a person subconsciously, meaning these factors will not influence them in a survey setting, but do influence them in reality. Therefore, the influence of these factors on perception can only be determined at an actual event. Furthermore, specific event locations can be researched and compared.

The downsides of conducting a survey during an event is limited amount of time available. This means only a limited number of responses can be collected, which leads to a lower number of respondents than can be collected in a survey after an event. Also, at an event, human labour is needed to approach people for a survey and record their answers. This could lead to bias in the answers, when people are not approached randomly and answer differently because of how a question is proposed. Furthermore, the visitors of the event might not like to spend their time on surveys. This may lead to lower participation than a survey that can be filled in at home, or it may lead to questions answered inattentively. Lastly, at an event there are an infinite amount of factors that influence a person's perception, not all of which can be included in the research. This unexplained variance can lead to lower correlations between explanatory factors and perception. In an experiment, all possible influencing factors are controlled for, decreasing the unexplained variance. Solutions to minimise the downsides of using a survey are presented in the survey design plan. In the survey specification, it is explained how the effects of these downsides are minimised.

4.3. Data collection: Survey specification

In Section 4.2, the reason for using a survey on location was explained. In this section, the number of respondents needed, the factors that will be included and the question form will be determined.

4.3.1. Determining number of variables and respondents

There are several methods to determine a desired number of respondents a to survey. First, a sample size can be determined to have a trustworthy reflection of a population. The formula Equation (4.1) and 4.2 can be used.

$$n = \frac{z^2 \cdot \hat{p}(1-\hat{p})}{\epsilon^2} \tag{4.1}$$

$$n' = \frac{n}{1 + \frac{z^2 \cdot \hat{p}(1-\hat{p})}{\epsilon^2 N}} \tag{4.2}$$

Where:

n = population size
n' = sample size
z = standard error
$\hat{p}$ = estimated standard of deviation
ϵ = margin of error

(Surveymonkey, 2018)

However, for this research, determining the population size is not as straightforward, because the 'population' is space and time dependent. Therefore, sample size will not be determined this way. The aim will be to acquire a large dataset (N>120) (Molin, 2018a).

Since the survey will be conducted at multiple locations per event, more data is required to obtain a representative view per location. It is probably not feasible to acquire large data sets (N>120) (Molin, 2018a) for multiple locations separately, because there is limited time to conduct the surveys at the events. Therefore, a maximum of three locations should be researched per event. The aim will be to collect at least 75 surveys per location.

Moreover, the number of respondents is important in relation to the number of variables that are tested. Common practice is to have 10 to 20 times the number of participants as there are variables (Inc, 2018). For example, if 20 questions are posed, 200 - 400 respondents are needed. This will be kept in mind while determining how many factors are included.

4.3.2. Factor & perception selection

The inclusion of factors is based on the relation with the perception of crowdedness or other crowd-related perceptions. The relation with the perception variables determines the *relevance* of a factor. When a significant relationship is found in multiple researches, it is necessary to take this factor into account, because not doing so would result in an incomplete explanation. When previous research provide contradicting results, it could be important to take that factor into account, because it is not completely understood yet. However, it could also mean that the factor is too complex to measure and the result will be largely dependent on the research method used. When there is little or no clear research performed yet, this could either be a knowledge gap, or a non-relevant factor. Knowledge about previous research can be found in Chapter 2.

The *feasibility* is determined by looking at previous research methods used and available research methods. One or more research approaches are suggested per factor. An overview is given in Table 4.2.

In the category Socio-demographics, Age, Gender and Residence were found to be relevant in relation to perceived Safety (Hoskam, 2017) and are easily included in a survey. Residence was also relevant in the research of Hoskam (2017) for perceived Crowdedness and Atmosphere. The relevance of Person height/size and Health are not clear for perception. The feasibility of including these factors is low, because they are quite personal. For determining Health, multiple questions are needed. Education level and Culture will not be included, because there are no clear signs that these influence perception of Crowdedness. Furthermore, it might be easy to determine cultural background based on country of origin/residence, but to understand someone's cultural *beliefs*, many questions are needed about a person's history.

Table 4.2: Overview relevance and feasibility of factors. *only included in the TT research. **only included in the RLD research

Category	Include	Factor	Relevance	Feasibility	Method
Socio-Demo	Yes	Age	High	High	survey
	Yes	Gender	High	High	survey
	Yes	Height/Person size	Unknown	Middle	survey
	Yes	Residence	Middle	High	survey
	No	Health	Middle	Low	survey
	No	Education level	Middle	Middle	survey
	No	Culture	Middle	Middle	survey
Personal	Yes	Emotional state	High	Middle	survey
	Yes	Stimulant usage	High	Middle	survey
	Yes	Familiarity	High	High	survey
	No	Decision style	Middle	Low	survey
	Yes	Trip purpose	High	High	survey
	Yes	Group type	High	High	survey
	Yes	Time spent*	Unknown	High	survey
Environment	No	Information	Low	Middle	Information
	No	Crowd composition	Unknown	Low	Observation
	Yes	Location	High	High	Observation
	Yes	Light*	High	Middle	Phone application
	Yes	Sound	High	Middle	Phone application
	Yes	Time of day/week	Middle	High	Metadata
	Yes	Weather	Middle	High	Accuweather
Crowdedness	Yes	Density	High	High	Wi-Fi sensor
	No	Speed	Middle	Middle	Wi-Fi and camera
	Yes	Flow	High	High	Counting camera
	Yes	Flow type	Unknown	Middle	Counting camera
	No	Collision/Impedance	High	Low	Observation
Perception	Yes	Crowdedness	High	Middle	survey
	Yes	Comfort	High	Middle	survey
	Yes	Safety	High	Middle	survey
	Yes	Atmosphere	High	Middle	survey
	Yes	Attractiveness	High	Middle	survey
	Yes	Crowdedness experience**	High	Middle	survey

In the category Personal state & Trip factors, Emotional state (Hoon Kim et al., 2010), Stimulant usage (Grolle, 2017), Familiarity (Hoskam (2017); Grolle (2017); Ton (2014)), Trip purpose (Hoskam (2017); Grolle (2017); Ton (2014); van Gelder (2018)) and Group type (Daamen et al. (2017); Hoskam (2017) Grolle (2017)) are marked as highly relevant. These are typical factors that are important at an event and are found to be significant in various researches.

Measuring a person's Decision style using a survey is difficult, since a person might not be aware of their own decision style. Furthermore, a mixture of decision styles can be applied by one individual. Emotional state and Stimulant usage might be difficult to record with a low number of questions and might not be answered willingly, so the feasibility is classified as *Middle*.

Finally, questions regarding perception are required for this research. Crowdedness (Hoskam (2017); Grolle (2017); van Gelder (2018)), Comfort (Landis et al. (2001); Madanat et al. (1994)), Safety (Landis et al. (2001); Hoskam (2017); Grolle (2017)), Atmosphere (Hoskam (2017); Grolle (2017)) and Attractiveness of the environment (Ariffin and Zahari (2013); Humpel et al. (2004); van Gelder (2018)) are all found to be important in relation to each other. The feasibility of these perceptions is classified as *Middle*, because they are difficult to express in numbers.

4.3.3. Determining question form

The survey design is based on example survey questions typically seen in research. The survey is designed to be filled in quickly, in order to keep the participants' patience and to be able to perform many surveys in a limited time frame. For example, typing is minimised (only for municipality) and questions that are not applicable are automatically skipped, such as group type when a person is alone. The questionnaire starts out with simple Socio-Demographic questions, which are easiest for people to fill in. Then, Personal state & Trip factors are addressed. Here, sensitive subjects (emotional state and substance usage) can be skipped. It has to be taken into account, that people might lie about their age. It is found that people are more honest when categories can be chosen (Bytheway, 2011). The following categories, also used by the Office of National Statistics in the UK (Bytheway, 2011) will be applied: 16-24, 25-44, 45-54, 55-64, 65-74, 75 and over.

The question about emotional state will use the emotions named in the Affect circle from Triandis (1977) as answers (2.3). The answers can be re-categorised into two binary variables by classifying the answers for every participant to arousal: active/not active and valence: pleased/displeased.

Familiarity has to be quantified in some way. A survey question could be targeted to find out whether the visitor has been at the location before, at the event before or at specific locations, stages and routes of the festival before. This will be specified per event.

As to Purpose, the question is formulated as follows: *"Where are you going at the moment?"*. The answers provide concrete examples, for example, *"walking around randomly"*, *"going to .... stage"*, *"going home"*, *"going to work"*, etc. For the analysis these will be re-categorised to: no purpose, a recreational purpose and an actual purpose.

Group type will be addressed using three questions. First, Group size will be determined, then Group type (family/friends/couple/colleagues/combined) and finally Group composition (only men/only women/combined).

The survey ends with five questions concerning perception. The questions are formulated in a similar way as in the survey of Hoskam (2017). They follow the format: *"How would you rate the level of **Crowdedness** at this location?"*. It is chosen to let respondents rate this on a 5-point likert scale. This is a common method psychological research. The full questionnaires can be found in Appendix G and J.

4.4. Factor & perception selection

In Table 4.2, an overview of all the factors is given. Feasibility and Relevance are rated *'Low, Middle or High'* based on the literary study from Chapter 3, the measurement methods and the researcher's own insights.

In conclusion, three types of data will be gathered simultaneously. Measured crowdedness will be gathered by Wi-Fi sensors and counting cameras continuously at fixed locations. At these locations, surveys will be conducted gathering socio-demographics, personal state & trip factors and perception of crowdedness and other crowd-related perceptions. The survey data will have a timestamp and a location attached, so it can be connected to the measured crowdedness. Event & environment factors will be gathered in two ways: Light and sound intensity will be measured every 30 min at the survey locations. Weather data is gathered from Accuweather per hour. Figure 4.5 shows a summary of all the data that is gathered which will be combined to be analysed simultaneously.

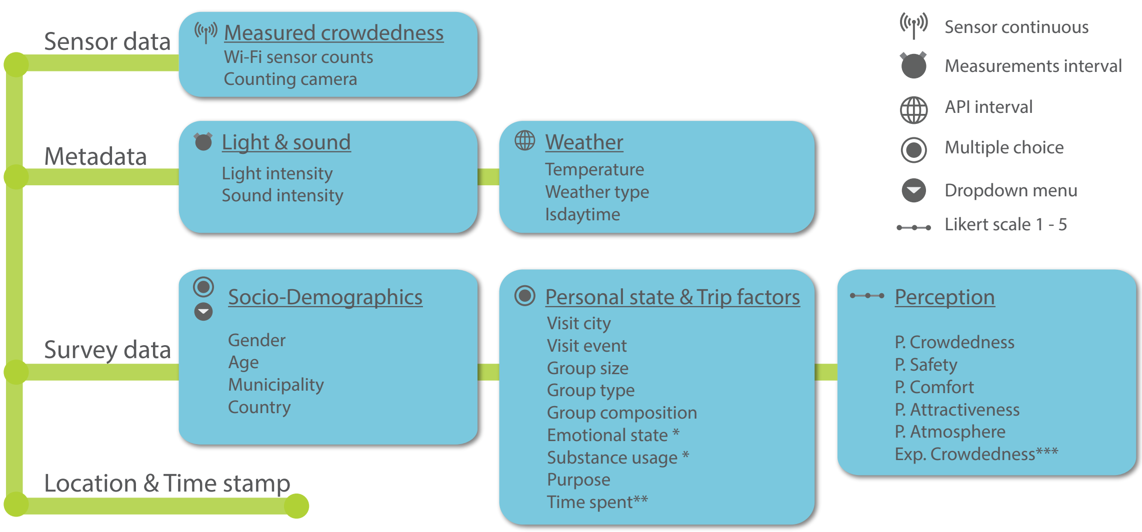

Figure 4.5: Summary data collection and data types: * not mandatory, ** only included in the TT case, *** only included in the RLD case.

4.5. Location and time selection

In this Section, the data collection is further specified for both events. In order to make the event comparable, the same sensors, survey and data processing methods are applied. Furthermore, at both events, surveys were conducted on three evenings on three locations.

4.5.1. Research plan TT Festival

This event took place from Wednesday till Sunday morning, June 27 - July 1. The research was conducted on the three busiest nights, which are Thursday, Friday and Saturday. On Thursday, there were five stages with a line-up. On Friday and Saturday, there were ten (TT Festival Assen, 2018). The pedestrian flows were expected to be different on these days, since other stage locations are used.
For this event, three locations were chosen to conduct the survey. These locations were chosen, because they are different location types and both a Wi-Fi sensor and a counting camera were present. The first one is the *'Kermis'* or fair. This is a location where many people walk by, to go from or to the city centre from the TT fair. The second location is *'Koopmansplein'*, which is near the main stage of the festival. The third location is *'Stationsstraat'*, which is an entrance path from the station to the event.

Figure 4.6: TT Festival: Sensor locations. Left Counting cameras, right Wi-Fi sensors

In Figure 4.6, the locations of all the sensors are shown. The sensors are spread over the terrain and cover almost all entrances and exits, often a counting camera and a Wi-Fi sensor are placed together. Location W3 *'Kermis'*, W4 *Koopmansplein* and W5 *'Stationsstraat'* were planned to be researched. However, location W5 *'Stationsstraat'*, seemed too quiet to be researched. Therefore, this location was changed to location W15 *'Markt'*. This is a location where a stage is present, although people are mainly there for the bars and the atmosphere. Unfortunately, this location was not equipped with a counting camera. A timetable for conducting the surveys is constructed in such a way that the three locations are covered at different times every night. The surveys were conducted by two persons at the same location at the same time. The full plan of Action for the TT Festival can be found in Appendix F. The survey topics as specified in Figure 4.5 are addressed. The full survey can be found in Appendix G.

4.5.2. Research plan Red light district

For the Red light district, research was done to find an appropriate date and time for the research, since the Red light district can be visited every day of the year. The aim is to gather a data-set that is comparable to the TT Festival.

In Figure 4.7, the number of people over time is shown for one sensor location in the Red light district. As can be seen, Friday and Saturday evening are by far the most crowded, with a peak value of over 6000 people. Sunday is also more crowded than the other weekdays in the afternoon. Therefore, it is chosen to conduct the research on Friday and Saturday evening, since the TT Festival research was also conducted in the evening. The chosen dates are Friday the 19th, Friday the 26th and Saturday the 27th of October.

As with the TT case, the research was executed on three evenings on three locations. The locations that were chosen are all equipped with a Wi-Fi sensor and counting camera. Furthermore, location GAWW-02 *'Oude Kennissteeg'* is a small alleyway in the middle of the area, location GAWW-06 *'Oudezijds achterburgwal'*

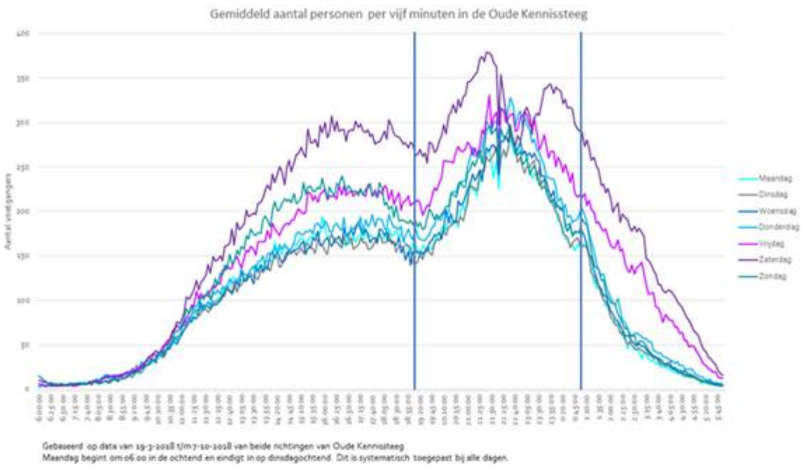

Figure 4.7: Average crowdedness per five minutes at the Oude Kennissteeg Red Light District.(Jorn van Dijk, personal communication, March 14, 2019)

is a slightly broader street along a canal and location GAWW-07 *'Stormsteeg'* is an alleyway that can be seen as an exit/entrance to the red light district. Again, the research was conducted on three evenings, alternating the time of day between locations per every research day.

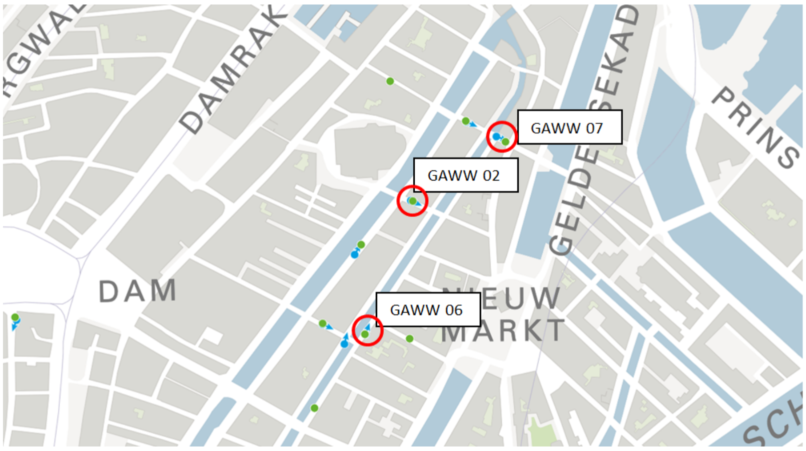

Figure 4.8: Red light district: Sensor locations. Blue arrows are counting cameras + orientation, green dots are Wi-Fi sensors

Since the research at the TT Festival already took place, survey questions could have been changed for the Red light district. However, it was chosen to keep the same questions, to be able to compare the two cases. Even so, one extra question was added to the end of the survey, addressing how the crowdedness is experienced, on a scale from one to five. One being very unpleasant and five being very pleasant. The question about time spent is left out, because this is more difficult to determine for the red light district. Pedestrians may have been walking through the city centre all day, passing through the Red light district multiple times. All questions, except substance usage have been changed from multiple answer to select one answer questions to make the data-set simpler.

4.6. Execution and Evaluation

In this section, the execution of the case studies is described. This background information will give insight in the data that is collected and will help to interpret the results that will be presented in Chapter 7.

4.6.1. TT Festival

Overall, the execution of this case study went according to plan. As a result of the pilot, some questions were adjusted. Furthermore, one survey location was changed. The Stationsstraat did not seem suitable as a survey location, because there were not that many pedestrians along this route as expected. Instead, the Markt (W15), was chosen as the third survey location. This location has a unique atmosphere. Many people gathered there for a drink, making it a crowded, but otherwise relaxed area. Unfortunately, this location was not equipped with a counting camera. Therefore, it will not be possible to determine the flow for this location. In Figure 4.9, some bar charts represent the data that was gathered.

Overall, the survey was conducted smoothly. Many people were willing to participate in the research. The general atmosphere was relaxed and pleasant. It became clear that many visitors are from Assen or the province of Drenthe and were regular visitors that participated in the event every day and every year. Many people visited the event with family members.

Figure 4.10 shows that the level of crowdedness is perceived omnifarious, ranging from not crowded at all to very crowded. The other perceptions are quite positive.

In Figure 4.9, it is shown that there are many frequent visitors and that there are people of all age groups present. Many people do not have a specific purpose, but are just wandering about. More than a quarter of the respondents were on his way to a specific stage.

From conducting the surveys, apart from the actual questions, some things were learned about the visitors of the event. First, people seemed to compare the current crowdedness with the crowdedness at an earlier time, the previous day or previous years. This lead to a variety of answers for perceived crowdedness compared to the actual crowdedness. It becomes clear that expectations, or beliefs, are very important in a person's perception. Therefore, this might have to be included in future research after all. Second, the question about comfort was generally filled in 4/5. It seemed as if the question was formulated too vague, since people often asked what was meant by this question. When answering the question about safety, participants often pointed out that they had seen a police officer or guard and therefore they felt safe. This indicates that people mainly think about social safety when asked this question.

The sensors have had some problems during the event. There are holes as well as peaks in the data. The peaks are often caused by police equipment. Missing measurements are caused by malfunctioning sensors and changing light conditions. Peaks and missing data are interpolated as described in Section 5.

The light and sound data had a few problems. First, the measurement device is not accurate enough to measure light in nighttime. Second, the measurements have not been executed accurately every half hour, some data points are therefore missing. Third, as can be seen from two measurements taken only two minutes after each other, the values can be very different every minute. On June 29th at the Kermis, light and sound data was collected at 21:05 and 21:07 facing other directions. The average values measured are respectively 99.09 dB vs. 95.59 dB and 65353 lux vs. 2030 lux. In future research, if light and sound data are chosen to be taken into account, accurate sensors on fixed locations performing continuous measurements are required.

The weather circumstances during the TT Festival were ideal. The weather was hot and sunny during the whole event. At the locations where the research was performed, no major incidents occurred. However, on Facebook a call-out was made to start a fight at one of the other locations (Doevenkamp). This was noticeable in the atmosphere there, which was uneasy. In the end, nothing happened, but the police and security were very much on the alert for troublemakers.

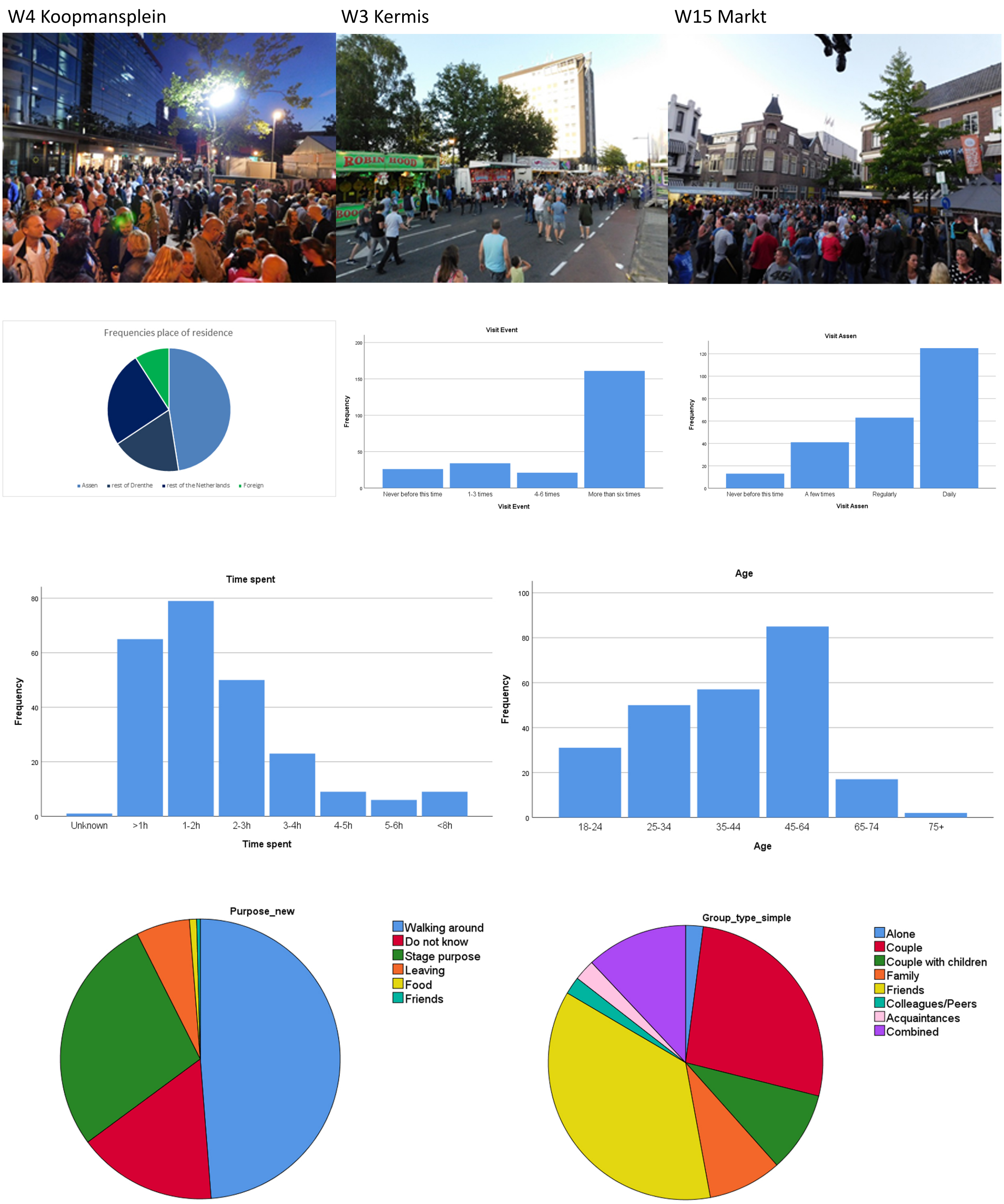

Figure 4.9: TT Festival: Info-graphic survey data

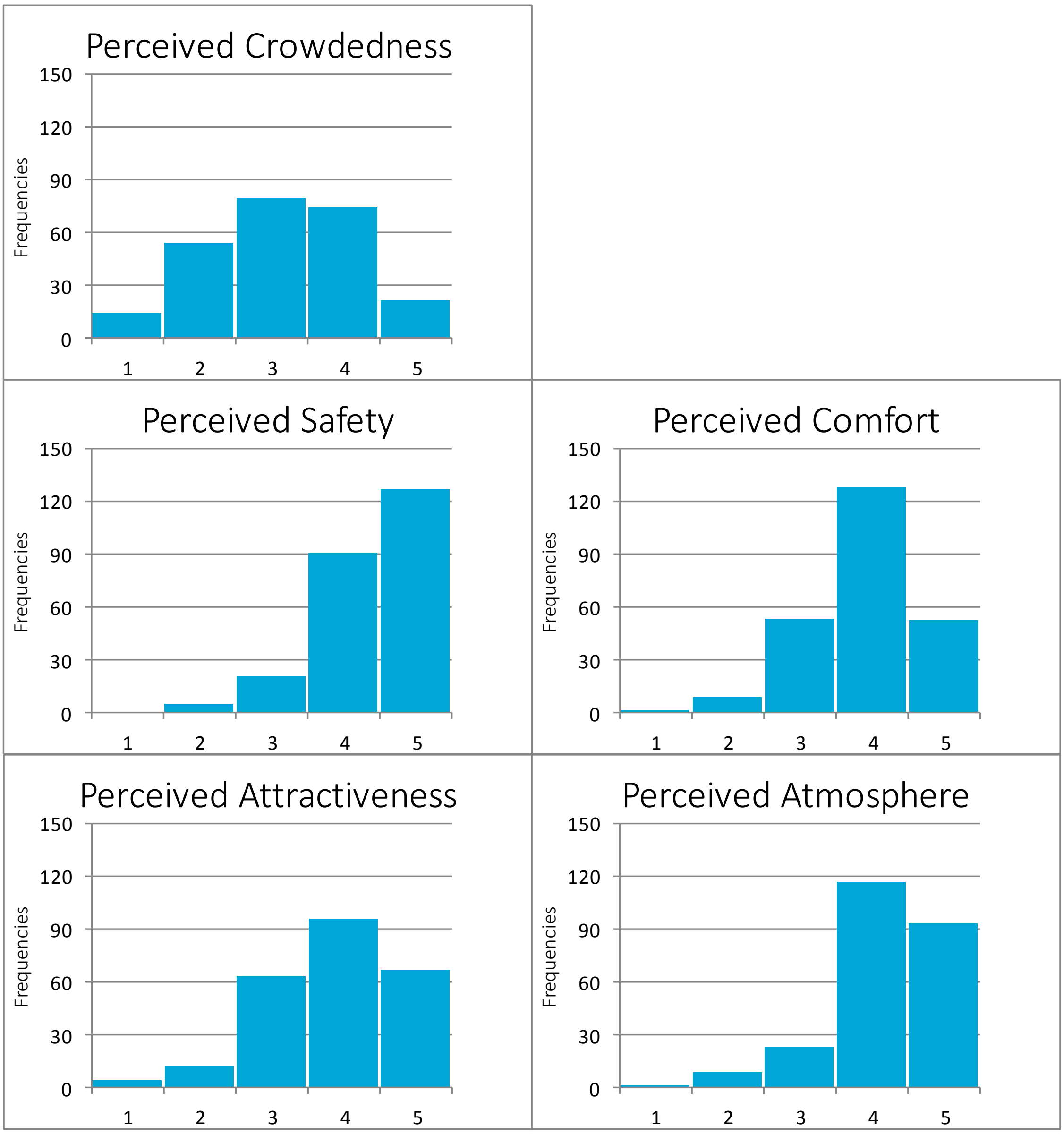

Figure 4.10: TT Festival: histograms perception

4.6.2. Red light district

Overall, the research at the Red light district was conducted successfully. The first day of the research, the weather was normal. That evening, the Amsterdam dance event was also happening in the city of Amsterdam. This was also mentioned by a few of the participants. Overall, this evening was less crowded for a Friday evening than normal (Gemeente Amsterdam, 2018a). The second day of the research it was raining, which resulted in a low number of surveys conducted that day (N=36). Furthermore, it was even less crowded than the first survey day. The last survey day was a Saturday. The weather was normal and it was very crowded.

Since it was overall still very crowded, it was difficult to find a place to stand and conduct the survey calmly. Taxis and Taxi bicycles were driving by on occasion leaving almost no space to stand. There were less people willing to participate in the research. It was also more difficult to approach people. When approached, many people completely ignored the surveyors and walked by. Still, there were enough people willing to participate pleasantly.

Contact was made with the hosts present, to notify them about the research. While conducting surveys at location GAWW-02 *'Oude Kennissteeg'*, some of the actions that they perform could be observed. For example, they asked people to walk on one side of the alley and people who were standing still were asked to do so further away from the small alley. This was quite necessary, since the alley way a bottleneck where the effective flow was 0 at some point.

Most of the pedestrians were tourists, as is also shown in Figure 4.11. This figure shows that there were people from all over the world. The frequencies are merely an indication, due to the small sample size (N= 182) and the bias in the data-set through willingness to participate. The tourists were often quite positive in their perception of Safety, Comfort, Attractiveness and Atmosphere. The experience of crowdedness was more often rated a bit lower. Residents of Amsterdam were often more negative in their perception. Only 11 respondents lived in Amsterdam.

As can be seen in Figure 4.12, the perceived crowdedness is rated higher than the TT Festival. The histograms for Safety, Comfort, Attractiveness and Atmosphere have a quite similar shape and show that overall, people had a positive perception. The question regarding the pleasantness of the number of people shows that opinions differ more.

Figure 4.11 shows that most people do not have a specific goal. Most respondents are young people (25-34). 53.8% of the respondents was male. The most common Group type was Friends, followed by Couples. Most groups were small (2-3 persons). There are quite some people by themselves. Most groups are mixed (54.8%), followed by groups of males (20%) and groups of females (15%).

The affect question was sometimes difficult for people to answer. The most frequent answer is Happy, followed by relaxed and neutral. It is expected that the word happy was chosen often, because it is a word most people know. Since the survey could only be taken in English or Dutch, this could influence the results. Some people wanted to express their surprise, confusion, or feeling weird, but these answer possibilities were not included. In those cases, people often chose for an answer such as relaxed, which is quite different.

Figure 4.11: Red light district: Info-graphic survey data

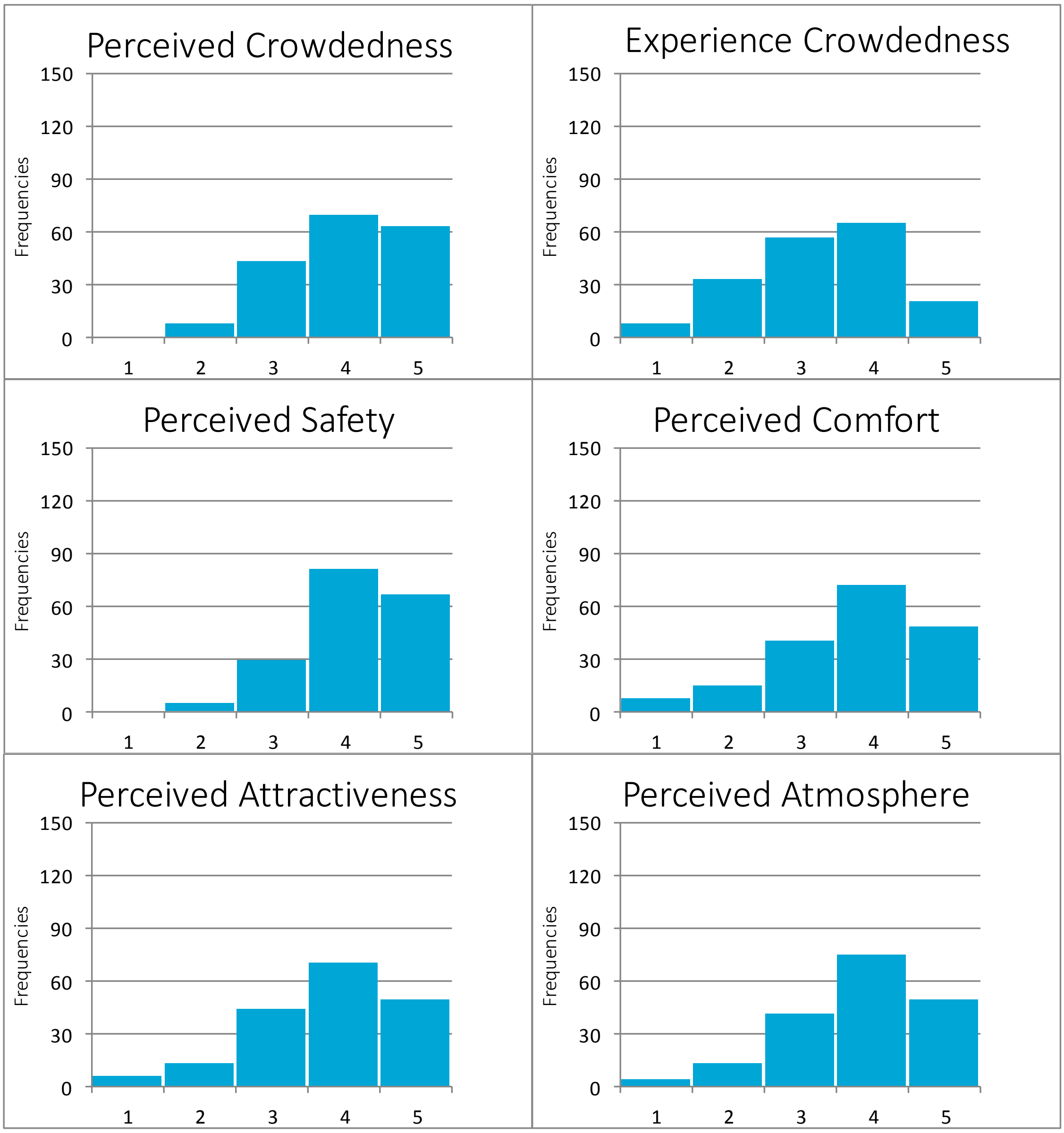

Figure 4.12: Red light district: histograms perception

5 Data processing method/Quantifying crowdedness

In Chapter 4, it was determined that Wi-Fi sensors and counting cameras would be used to collect data. How this data can be used to calculate macroscopic flow variables is explained in this chapter. In Section 5.1, the operation of a Wi-Fi sensor is explained. This knowledge is required to determine how the data has to be processed. In Section 5.2, it will be explained how and why certain processing steps were made. Section 5.3 explains which variables are chosen to represent crowdedness. The chapter ends with a short conclusion (Section 5.4).

5.1. Wi-Fi sensor operation specification

Wi-Fi sensors are a useful data collection tool that recognises MAC addresses of (mobile) devices that are active and nearby. The data collected from the Wi-Fi sensors contain hashed MAC-addresses, sensor IDs and the first and last detection time stamps. The Wi-Fi sensors have a range of approximately 25m (Duives et al., 2017), but the range is dependent on the number of signals picked up. The more signals there are, the smaller the range becomes. The MAC addresses are hashed, so the privacy of the people is not violated. The exact operation of a Wi-Fi sensor depends on the event, the location placement and the company who places the measuring devices (Daamen et al., 2018). This means that it is difficult to estimate exactly what percentage of the devices are measured. Furthermore, other Wi-Fi enabled devices, not corresponding to one person, could also be detected. For example a police officer can carry more than one device that transmits a MAC-address, resulting in a high number of measurements, while these do not provide insight on the number of people. Moreover, some newer types of smartphones use dynamic MAC addresses that change every time they are asked for identification (Duives et al., 2017), resulting in a higher number of unique devices measured. Therefore, the data received from Wi-Fi sensors needs to be calibrated. At the SAIL event, around one third of the counts of a camera were detected with the Wi-Fi sensors (Yuan et al., 2016), 50% of these were unique. The counting cameras at this event had an accuracy of maximally 98%. However, when the intensity of people increases, the accuracy decreases, to 92% in high density conditions.

5.2. Crowdedness quantification method

The monitoring data that is collected needs to be processed in such a way, that it will give us accurate intensities and flows at the survey locations. The following steps, based on previous work of (Daamen et al., 2016; Duives et al., 2015; Yuan et al., 2016; Duives et al., 2017) need to be taken in order to come to the desired data. This method is a mixture of earlier research, but has been slightly simplified and adjusted to fit in with this research objective.

1. Determine a time window to count the number of unique MAC addresses.
2. Filter raw data by means of a blacklist
3. Remove dynamic MAC addresses

4. Interpolate to estimate missing data or to remove high peaks

5. Determine accuracy of cameras by means of ground truth footage

6. Determine a conversion rate for the Wi-Fi data by using the data from the counting cameras.

7. Apply a Moving Average to smooth data and capture a certain time window.

8. Calculate desired variables to describe crowdedness and flow.

9. Connect the monitoring data to the survey data

5.2.1. Determine a time window for measurements

The raw Wi-Fi data is a list of MAC addresses and timestamps. It is not possible to compute densities per timestamp, because the number of devices that are detected per timestamp fluctuate too much. For example, one active device could be registered for only three timestamps in a minute, while the device was in that area the whole time. Therefore, a time window needs to be chosen to determine the unique number of MAC addresses for that amount of time. According to Duives et al. (2017), this parameter needs to be determined for specific use cases. In free flow conditions, a pedestrian can pass through the region a Wi-Fi sensor (approximately 50m) in 37.3 seconds Duives et al. (2017). So theoretically, after this length of time, the density could be completely different. However, it is not expected that the density will change so drastically, because at many places, the walking speed will be fairly slow and pedestrians will often stop. Therefore, a time window is chosen that sufficiently captures the change in density and also reflects the density experienced by pedestrians.

For both researched events, there is Wi-Fi data available, which has already been transformed into counts per time window. However, one data-set (Red Light District Amsterdam) is per minute, while the other one (TT Festival Assen) contains the number of unique devices that has passed the sensor in three and fifteen minutes per minute. Those data-sets cannot easily be translated into one another, because the unique devices that are measured can differ. To illustrate this, an example can be given. In Figure 5.1, we see an area where a Wi-Fi sensor registers the number of devices. For different time instances, there is another number of people. For the TT method, the time windows are overlapping. The number of unique devices (visualised by human icons with unique colour) measured in the first three minutes is $n(t_(1:3)) = 5$. With the RLD method, the number of unique devices are determined per minute. Because it resets after a minute, adding the first three measurements gives another total than the TT method, $n(t_(1:3)) = 7$.

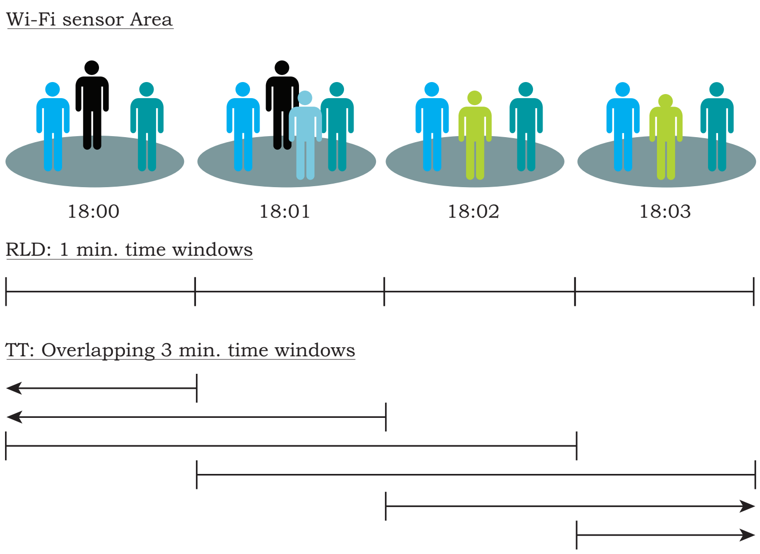

Figure 5.1: Wi-Fi sensor counting methods. Top: RLD method; 1-minute time window every minute. Bottom: TT method; 3-minute time window every minute

Furthermore, it was already stated in Section 4.2 that not all active devices might be detected, especially when it is more crowded. Other than that, there are also devices that are not registered at all, because they move through the Wi-Fi sensor area quickly. Therefore, it can be difficult to compare the results of these methods. The counting camera data for both events contains in- and outflow per minute. This data will be used with a moving average for three and fifteen minute time windows. This way, it is expected to correlate better with the three and fifteen minute Wi-Fi data.

Section 5.2.7 explains how the data of the TT Festival and the Red light district is edited to come to three and fifteen minute time windows.

5.2.2. Filter raw data by means of a blacklist

Both data-sets received have already been filtered by means of a blacklist. A blacklist is a set of MAC addresses that are known to cause noise and do not correspond to a person. For example stationary devices. These can by recognised, because they often occur in the measurements and always at the same sensor. For the Red light district data, this list is reset every night between 02:00 AM and 04:00 AM, and builds up throughout the day (D. de Wit, personal communication, 6 December 2018). The blacklist of the TT Festival is created during the whole event. When high peaks in the data occur, this can often be caused by a group of police forces. This can be validated by using camera footage. Figure 5.2 shows the difference between filtered (yellow and purple) and unfiltered (blue and red) data. The difference is enormous and is also divided unequally over time (more difference between filtered and unfiltered when it is crowded). This graph shows that this step is essential in the data processing.

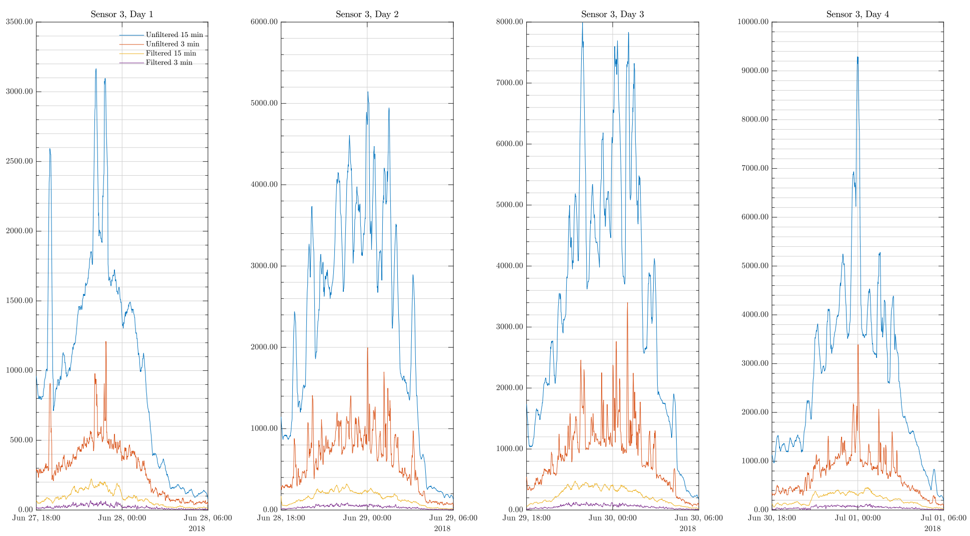

Figure 5.2: TT Festival, sensor 3 Kermis: Wi-Fi data filtered and unfiltered, 3 and 15 minutes

A problem in the TT case is that there are still high peaks that seem improbable. This can be caused by a dynamic MAC addresses. In step 4, the method that is used to remove these peaks is discussed.

5.2.3. Remove dynamic MAC addresses

Removing dynamic MAC addresses is possible using the MAC addresses and the bssid (hashed MAC address of the wireless access point). Distinct patterns can be found in this data using an algorithm, to spot the use of a dynamic MC address (Duives et al. (2017).

For the TT Festival, the data-set was used that still contained dynamic MAC addresses. The reason for this is that the procedure of removing them is quite complex and would take too much time to be included in this research. Because it is known that there is a higher number of measured unique devices, the conversion rate (see Section 5.2.6) will be different than when they would have been removed. However, it is expected that these types of devices are spread all over the event, so their influence on the data will not be too influencing. For the RLD data, it is unknown whether the dynamic MAC addresses are removed.

5.2.4. Interpolate missing data and sudden peaks

After the first few steps, there could still be missing data from malfunctioning sensors, or sudden high peaks that seem improbable. Therefore, in this step, interpolation for missing data is explained. Peaks are detected by an increase in counts higher than 50 in three minutes for the TT festival. Missing data is detected when there are more than three consecutive values of zero. When there is missing data for a certain time period, a line is drawn between the last and first data points that were collected that seem to fit the rest of the data. These alterations are only performed for times that correspond with survey times.

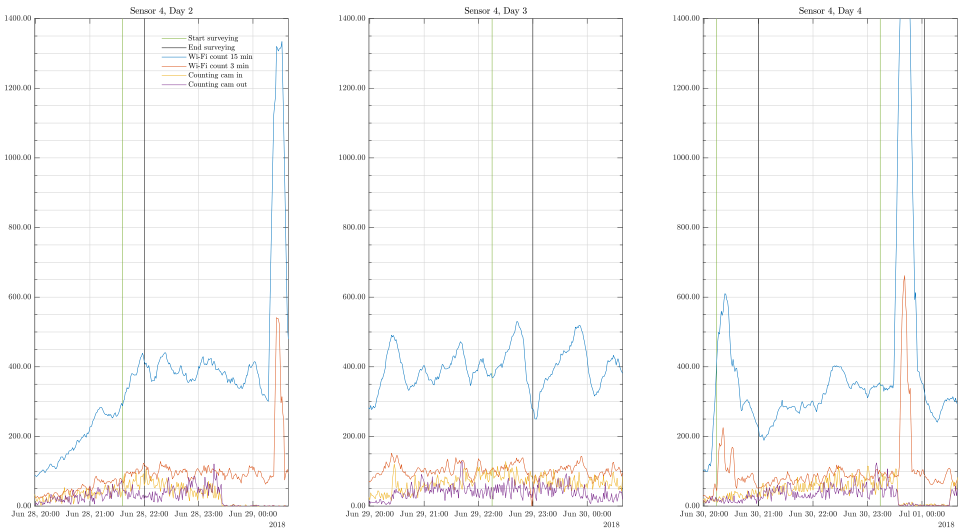

Figure 5.3: TT Festival, Sensor 4 Koopmansplein: Wi-Fi and counting camera data before interpolation

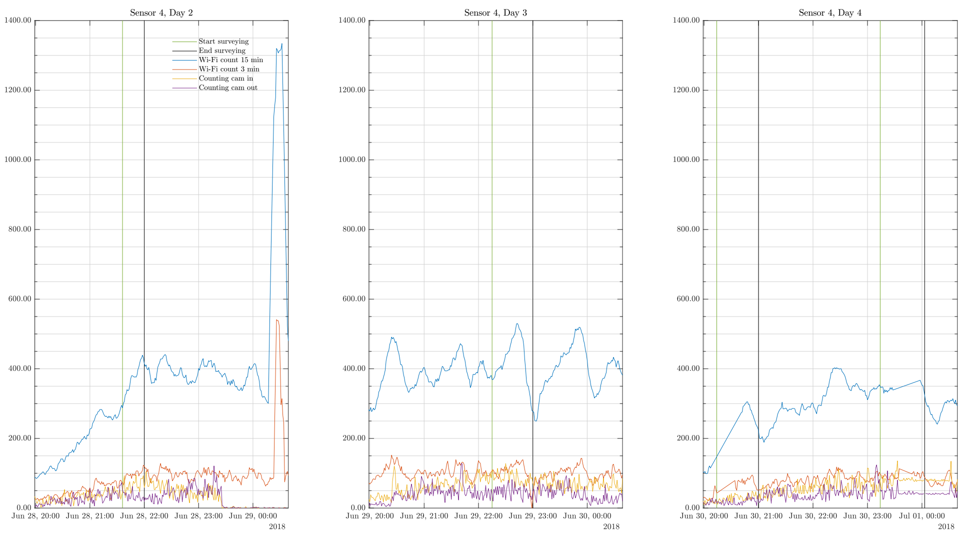

Figure 5.4: TT Festival, Sensor 4 Koopmansplein: Wi-Fi and counting camera data after interpolation

For the location Koopmansplein in the TT Festival, the data before and after this step is shown. As can be seen in Figure 5.3 and Figure 5.4, peaks have been removed in the Wi-Fi data on day 2 and day 4 and the missing counting camera data on day 4 is added. For the Red light district data, these adjustments were not necessary.

5.2.5. Determine accuracy counting camera

For the counting cameras, both data-sets contain in- and outflow per minute. The average accuracy of a counting camera of ViSense is 95% (Daamen et al., 2018). A counting camera can theoretically be 98% accurate, but goes down to 92% as the event becomes more crowded (Yuan et al., 2016). Accuracy is influenced by the type of camera, the settings, the weather, lighting and the location of the device. It is possible that there are false positives (example: a tree is recognised as a pedestrian) and false negatives (a pedestrian is not recognised).

To account for the accuracy of a counting camera, camera footage (of a video camera!) can be used as a ground truth. To validate the accuracy precisely, multiple location, times, and levels of crowdedness have to be checked. Then, a conversion factor has to be determined. For simplicity's sake, one constant conversion factor can be used. Otherwise, a conversion factor dependent of the level of crowdedness can be applied.

Since there is only limited time for this project, this step in the process has been skipped. It is expected that the variation between 98% and 92% accuracy does not influence the end results that drastically.

5.2.6. Determine and apply conversion rate

Wi-Fi sensors only measure a part of the crowd, but can be used to estimate density. Yuan et al. (2016) describes a method to estimate density between sensor location from Wi-Fi sensor and counting camera data. However, this method cannot be used, because it requires pairing devices (MAC addresses) between two sensors, which is not possible with the data available. Therefore, another method has to be found that can be used. For this purpose, a comparison with the counting camera data is made. In Figure 5.5 and 5.6, we see comparisons of this sort for the Red Light district, created by Gemeente Amsterdam (2018b). For both data types, the same time window is applied. The left axis shows the values of the counting cameras and the right axis those of the Wi-Fi sensor.

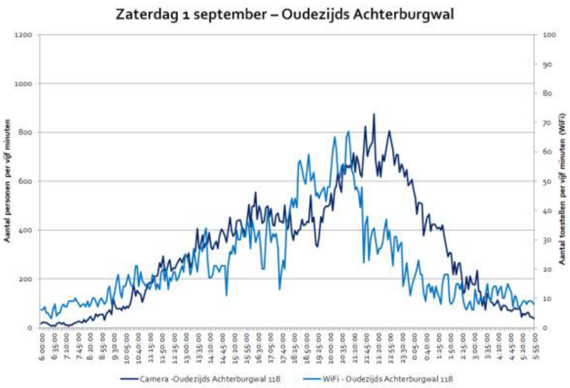

Figure 5.5: Red light district, sensor GAWW 06: Comparison Wi-Fi and counting camera data

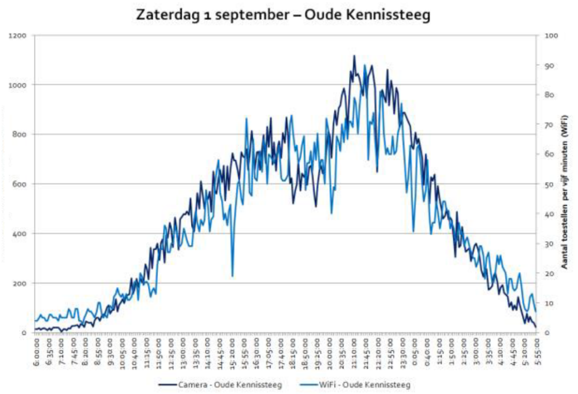

Figure 5.6: Red light district, sensor GAWW 02: Comparison Wi-Fi and counting camera data

Figure 5.6 shows a similar pattern for the Wi-Fi and counting camera data, but Figure 5.5 does not. It is expected that the pattern should be the similar, if the sensors are placed in a demarcated corridor where pedestrians walk by within the chosen time window. However, in reality this is not the case. First, a Wi-Fi sensor measures an area and a counting camera counts the pedestrians that walk by a certain point. In other words, they cover a different area. This difference becomes more important when a more open area is measured. For example, a Wi-Fi sensor that is installed on one side of a canal might detect devices on the other side of the canal as well. A counting camera covers a certain area more clearly. Next to this, the time window that is best to measure these counts might be different. In the graphs presented, it is not clear how and why a 5 minute time window was applied. Third, it is expected that both sensors handle standstill people differently.

To make the most trustworthy comparison, a comparison has to be made for a sensor that is in a walk-by (not standstill) area and the time window of the counting camera needs to be adjusted to the time window of the Wi-Fi sensor. For the TT Festival, sensor 1 is chosen for this purpose. It is not one of the locations where surveys are conducted, but it has both sensors and it is an exit/entrance route, not a place with activities. In Figure 5.7, the Wi-Fi camera data is shown for the same time window.

A conversion rate will be determined based on day 2 (20:00-23:00), day 3 (20:00-21:30) and day 4 (20:00-

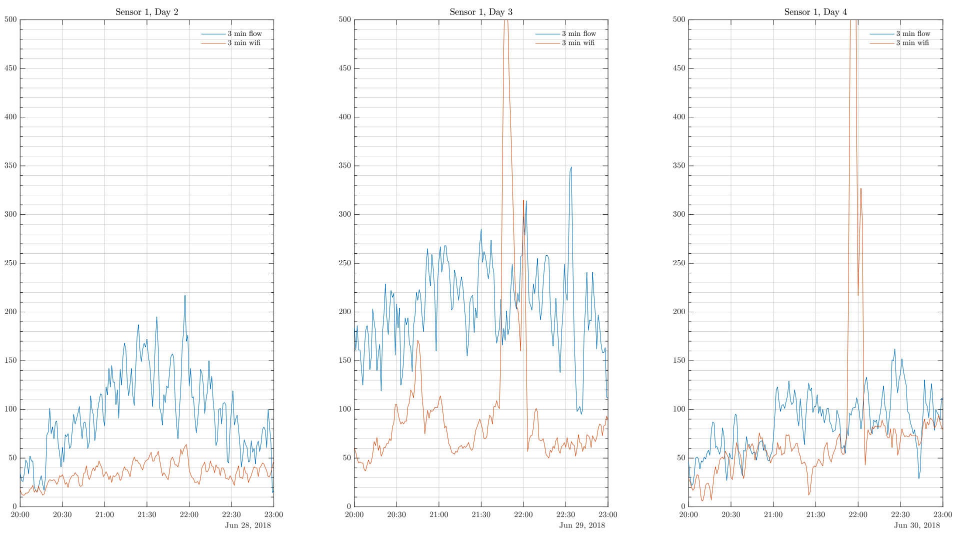

Figure 5.7: TT Festival Sensor 1: Comparison Wi-Fi and counting camera data

21:30), when the data seems normal. The conversion rate will be determined using the method of least squared errors, using the following formula:

$$minimize \quad MSE = \frac{1}{n}\sum_{t=1}^{n}\left(c \cdot w_t - cc_t\right)^2 \tag{5.1}$$

Where:

MSE = mean squared error
n = number of data points
c = conversion factor
w_t = wifi counts
cc_t = counting camera counts

As can be seen in Formula 5.1, it is chosen to apply one simple conversion factor, because it explains well and is easy to handle. However, this also means that some of the variance will be missed. The formula is solved by finding the minimum value for MSE by adjusting c. The conversion factor $c = 2.23$ for three minute Wi-Fi data and $c = 3.1$ for 15 minute Wi-Fi data is found.

For the Red light district, the calculation is made using one minute Wi-Fi data and one minute camera data of sensor 2 and 7. The conversion factors $c = 0.76$ and $c = 1.12$ are found. These conversion factors are unexpected, because in earlier research, camera counts were much higher than Wi-Fi counts for the same time window. It is assumed that a filtering step applying a conversion rate has already been taken for this data. Therefore, the RLD data is not adjusted with a conversion rate.

5.2.7. Apply a Moving Average to smooth data and capture a time window

It is assumed that pedestrians base their perception of crowdedness on crowdedness of the past x minutes. The time window on which the perception is based is uncertain and can vary between people. Moreover, change in perception is expected to be less volatile than one minute counts. Therefore, a moving average is applied. On top of that, an average value is less sensitive to errors in the data. A moving average calculates an average value for the Wi-Fi or counting camera counts, for a certain time window. The formula is presented below:

$$\hat{w}_t = \frac{1}{n}\sum_{t=1}^{n-1} w_{t+i} \tag{5.2}$$

Where:

$\hat{w}_t$ = simple moving average of w_t for time period n
n = number of data points
w_t = Wi-Fi count at time t

For both events, a moving average of three and fifteen minutes is applied for the counting camera data. For the Wi-Fi counts, a moving average of three, fifteen, thirty and sixty minutes will be applied. The reason for this difference is that it is assumed that Camera data, which can be used to calculate flow, is influencing pedestrians in a shorter term, while Wi-Fi data, which can be used to calculate density, is influencing pedestrians for a longer time.

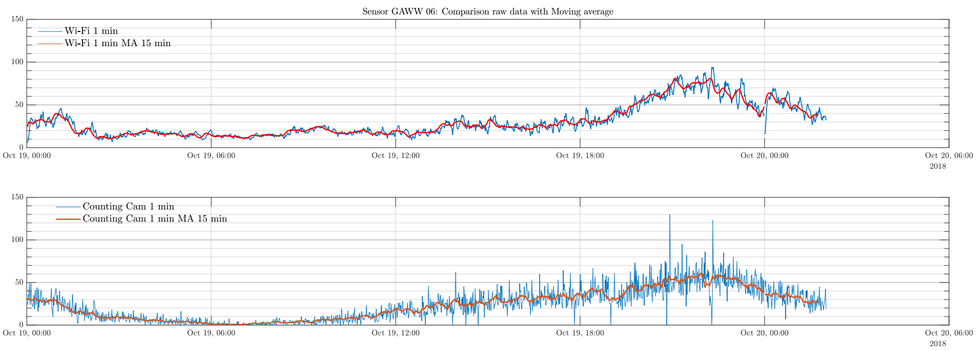

Figure 5.8: Red light district, sensor GAWW 06: Wi-Fi and counting camera data compared to Wi-Fi and counting camera data with a 15-minute moving average

In Figure 5.8, the difference between moving average data and the original data is shown. The data is smoothed, but still moves along the same trend. The longer a time window is chosen, the smoother the line will become. It is excepted that three and fifteen minute data will still capture enough of the fluctuations that occur in the density and flow and that extreme differences per minute are cancelled out.

5.3. Selection of variables to describe crowdedness

From the literature review (Chapter 2), it is learned that Flow and Density are highly relevant indicators of crowdedness and are related to perceived crowdedness. Therefore, Density and Flow will be estimated using the simple formulas stated in Equation (5.3) and (5.4). To determine area, Google earth was used. A radius of 25 meters was retained, while only counting the area where people could stand and where the reach of the sensor was not blocked by obstacles. The width of the passageways is determined from photos made during the research and Google earth. These are not very accurate measurements. For one, it is not known if the reach of the Wi-Fi sensor was exactly 25 meters in every direction. Other than that, determining the exact area where people can stand is an arbitrary process. Shy distance (distance kept from obstacles and buildings (Fruin, 1971)) and smaller temporary obstacles are not taken into account.

$$\hat{k}_t = \frac{\hat{w}_t}{A} \tag{5.3}$$

$$\hat{q}_{tot} = \frac{\hat{c}c_t}{w} \tag{5.4}$$

$$\hat{q}_{prop} = \frac{\hat{q}_{in} - \hat{q}_{out}}{\hat{q}_{tot}} \tag{5.5}$$

$$\hat{w}_{frac} = \frac{\hat{w}_t}{max(\hat{w})} \tag{5.6}$$

Where:

$\hat{k}$ = Density
$\hat{w}_t$ = Wi-Fi counts with a moving average
A = Area in m^2
$\hat{q}_{tot}$ = Flow
$\hat{cc}_t$ = Camera counts with a moving average
w = Width passageway
$\hat{q}_{prop}$ = Proportion of flow
q_{prop} = -1 if only outflow
q_{prop} = 1 is only inflow
$\hat{w}_{frac}$ = Proportion of $\hat{w}_t$ compared to the maximum $\hat{w}$

Because of these inaccuracies, it is chosen to use the Wi-Fi counts and the camera counts as crowdedness indicators as well. The Wi-Fi counts correspond to density and are expected to yield similar results. The Wi-Fi counts can be seen as density, because a Wi-Fi sensor counts the number of people in the area of the Wi-Fi sensor. The camera counts correspond to flow, the only difference being that the width of the passageway is not accounted for. Furthermore, another variable that presents a form of density is calculated in equation 5.6. The averaged Wi-Fi counts are divided by the maximum measured number of devices measured at one time instance during the event at the same sensor. It is assumed that this number comes close to the capacity of that area in terms of its function. For example, a passageway will never be as crowded as the area in front of a stage. Finally, flow type will be calculated by using the proportions of in- and outflow for the counting cameras (see Equation (5.5)).

5.4. Conclusion

This chapter provides insight into the processing steps that have been applied to the monitoring data. The data for the TT Festival and the Red light district are different in many ways. For one, the time window for the raw Wi-Fi counts of the TT Festival was in three and fifteen minutes. For the Red light district this was a one minute time window. Second, the blacklist of both events is set up differently. Third, a conversion rate is applied to the TT festival Wi-Fi data. It is expected that a conversion rate is applied to the RLD data as well, but the conversion factor might be determined differently.

Several choices have been made to come to the variables that represent the actual crowdedness. Time windows of three, fifteen, thirty and sixty minutes are chosen for the Wi-Fi data, in order to find out what fits best with pedestrians' perception. The variables that will be compared to the perception data are: local Wi-Fi counts, global Wi-Fi counts, local densities, local proportion of people compared to the maximum for that location, local camera counts, local flows and the proportion of in- and outflow.

Some of the processing steps are not performed as thoroughly as desired. For the TT Festival, the dynamic MAC addresses were not removed. For the Red light district it is not known whether this step is executed. For the TT Festival data, some extra interpolation was necessary to correct sudden peaks and missing data. Furthermore, in both cases, the data has not been validated using a ground truth, because of the limited time available for this part of the research. Also, the choice to use a simple conversion rate, opposed to a crowdedness dependent conversion rate is expected to influence the results. Variables such as the area of a Wi-Fi sensor were not determined accurately. All of these problems lead to less reliable data, which will be further discussed in Chapter 8. Overall, the data collection and processing could have been done more thoroughly, but the steps that have been followed are deemed to be sufficient to draw conclusions from this data. The differences between the data-sets, the possible shortcomings of the processing method and the choices that were made regarding the variables that represent the crowdedness will be further discussed in Chapter 8.

6

Model estimation/analysis method

The aim of this chapter is to find the appropriate way to model/analyse the data. This chapter will answer the following research sub-question:

How can we analyse/model the relationship between perception & experience of crowdedness and personal, event and trip characteristics?

The analysis method consists of two parts. First, the purpose of performing a statistical analysis is explained in Section 6.1. The aim of the analysis in SPSS is to gain an impression of the data gathered and the probable relations within. Second, the method and reasons to create a model are discussed (Section 6.2). This section will explain why a Structural Equation Model (SEM) is required for this research. Section 6.3 will further specify how SEM can be used to create a better understanding of the relations found and how a model has to be built. Section 6.3.5 gives a conclusion of this chapter answering the research sub-question.

6.1. SPSS statistical analysis

A statistical analysis has to be performed for this research for multiple reasons. First, it is useful to give an summary of the data that is gathered (see 4). Second, it is used to find one-on-one relations between perception of crowdedness and the explanatory variables, to get an indication which factors are useful to include in the model. For example, a test is performed to see if there is a relation between the age of participants and their perception of safety. Also, some answer sets to questions might have to be re-categorised. For example, the question: *Where are you going at the moment?* had eight possible answers. For this research, the aim of this question was to find out whether there is a difference in perception between people with a clear purpose or without a purpose. What is important to find out is how the answers should be re-categorised to extract a meaningful relation. Finally, an exploratory factor analysis is performed to determine how the perception variables are related to each other.

6.1.1. Bi-variate analysis

For the bi-variate relations, a few types of tests have been performed, to find the relation between ordinal, nominal and interval/ratio data combinations. There are four types of data available. The following table illustrates what are the characteristics of these date types (Molin, 2017a).

Table 6.1: Four levels of data types explained: Nominal, Ordinal, Interval and Ratio

Data type	Characteristics	Example
Nominal/Binary	Distinction between categories	Gender, Location type, Group type
Ordinal	Distinction and order	Perception, Group size, Time spent
Interval/Ratio	Distinction, order and equal differences	Density (pax/m^2), Sound intensity (dB)

The tests that are used are summarised in Table 6.2. These tests are further explained in Appendix H.

The next step is to create some scatterplots and regression tests for the quantified and perceived crowdedness. These can show the fit between these variables and to see whether this relation is linear.

Table 6.2: Summary of applied bi-variate tests

Statistical test	Data combination
Kendall's tau & Spearman's Rank	Ordinal - Ordinal Ordinal - Interval/Ratio
Mann Whitney U test	Binary - Ordinal Binary - Interval/Ratio
Kruskal Wallis	Nominal - Ordinal Nominal - Interval/Ratio
Bonferroni correction	Multiple tests, pairwise tests for multiple categories

6.1.2. Exploratory factor analysis

Factor analysis can be performed to find factors that are overlapping, to simplify the dataset (PCA) or to come to a more reliable latent variable (Factor analysis) (Molin, 2018b). Normally, in psychological research, multiple questions are asked regarding one latent/unknown variable. Perceptions, attitudes and intentions have to be measured with more than just one question to find an accurate value on a continuous scale. In other words, when it is desired to know how a person perceives safety in a crowd, questions like: 'How do you perceive social safety in the crowd? To what extent do you think safety is compromised in case of panic? How safe do you feel regarding the number of police and security here?' These could all be measurements for the one latent variable Safety.

In this research, 5-6 questions regarding perception on the crowd and surroundings are asked. It is expected that these questions are partially overlapping and might be seen as factors for one latent variable as well. Therefore, an exploratory factor analysis is performed in SPSS. If two or more perceptions are very much related, this indicates that they are in fact both caused by the same underlying latent variable. Modelling the relation in this way leads to a stronger model.

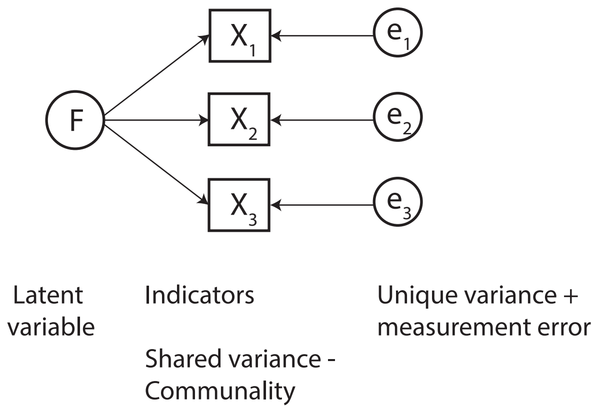

Figure 6.1: Factor model

In Figure 6.1, the construction of a factor model is shown. In this example, three variables are measured. The measured variables are indicated with rectangles. With these measured indicators, the unobserved, or latent variable is described (illustrated as a circle). The indicators are overlapping, but also have some unique variance, that cannot be explained by the latent variable. This is indicated by the error variable, which is also unobserved.

Figure 6.2 gives an example of three survey questions aimed to find the latent variable, perceived Safety. On the left side, the correlations that are found between these three questions is shown. On the right side, this is translated into a factor model, were the correlations between these questions are explained by the underlying variable, perceived Safety.

The exploratory factor analysis in this research will be used to see whether perceived Crowdedness, Safety, Comfort, Attractiveness of the environment, Atmosphere and Experience of crowdedness are actually ex-

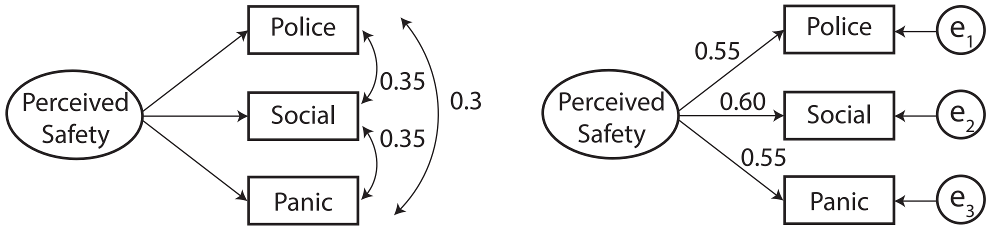

Figure 6.2: Example of a factor construct

plaining one latent factor, since they are all related to crowdedness in this research. The results of this exploratory factor analysis will be presented in Chapter 7. More explanation on factor analysis can be found in Appendix E.

6.2. Multivariate data analysis techniques

In order to find out which factors influence the different facets of perception and how the perception of crowdedness relates to the quantified crowdedness the following requirements have to be met:

1. The model can be based on theory/hypotheses.
2. The model can find the pure effect of a variable, controlled for other variables.
3. The model can detect a spurious effect.
4. The model can test indirect relations.
5. The model can include latent variables in a measurement model.
6. The model can make use of ordinal and nominal data together with interval data.

In the next Section, it is explained why these effects are important. In Section 6.2.2 and 6.2.4, multivariate regression and structural equation modelling are explained.

6.2.1. Why do we need to model control, spurious and indirect effects

Drawing conclusions only from simple bi-variate regression is not sufficient for multiple reasons. The effects that are missed in bi-variate analysis are illustrated in Figure 6.3 and are further clarified with examples in Figure 6.4.

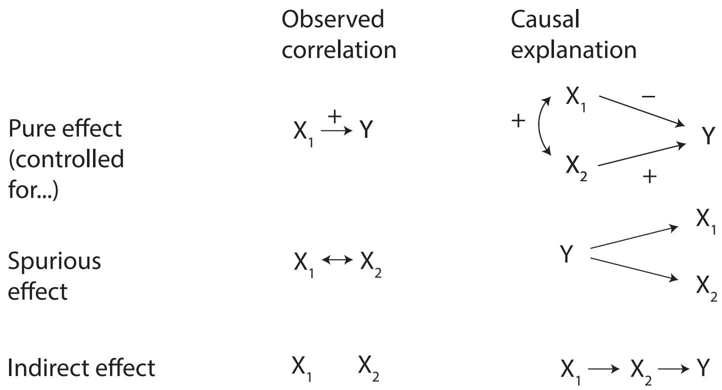

Figure 6.3: Pure, spurious and indirect effects

Direct effects can be found with a simple, bi-variate regression. The problem is that this does not consider causality. A correlation between two variables could mean that one causes the other, that the effect works both ways, or that it is caused by another variable (spurious effect). There could be correlations between the explanatory variables, which influence the relation between the explanatory variables and the perception variables. In a experimental choice set, the choice sets are designed in such a way that correlations between explanatory variables is avoided. Since a survey is used, it is possible that the independent variables are correlated.

In the first example in Figure 6.4, no significant direct relation between density and perceived safety is found using a bi-variate test, but from theory it is be expected that there is an indirect relationship between Density, perceived Crowdedness and perceived Safety. To find this relation, a multivariate model is required.

In the second example, a positive correlation between perceived Crowdedness and perceived Safety is observed. However, when tested in a multiple regression, controlling for perceived atmosphere, the pure effect of perceived Crowdedness on Safety is actually negative.

The third example illustrates how time of day is used to predict the perceived Comfort. However, this correlation is not a causal explanation. Actually, it is hypothesised that Comfort drops because of the time spent at the event. Logically, time spent is correlated with time of day, since an event starts at a certain time.

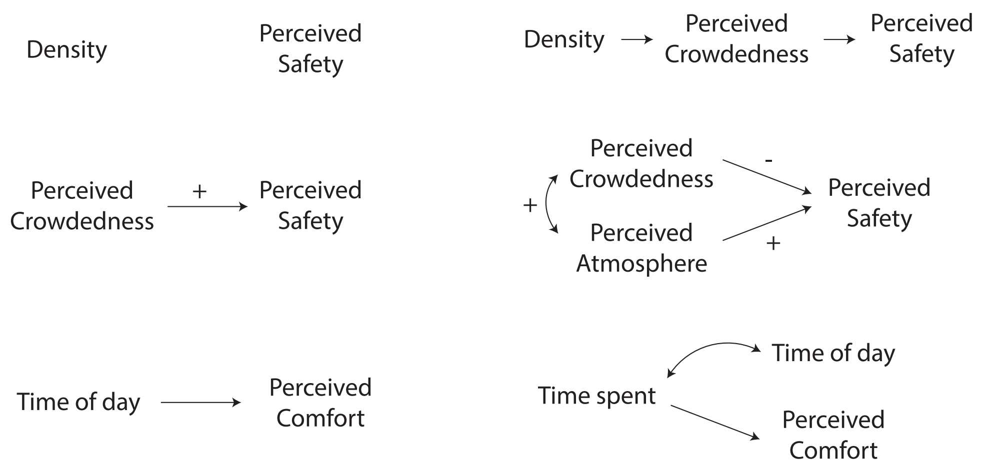

Figure 6.4: Examples of pure, spurious and indirect effects

Finding the indirect effects, pure effects and spurious effects, opposed to only correlations is very important to actually be able to understand the causal relation between variables. When the causal relation is understood, it is possible to influence the right factors in order to change pedestrians' perception in a positive way. In the next Section, the operation of a multivariate regression and a Structural Equation Model are explained. At the end of this section, it can be concluded which model is needed for this research.

6.2.2. Simple regression

Based on the outcomes of the bi-variate statistics, a multivariate regression can be set up. The purpose of this multivariate regression is to find the pure effects of each of the explanatory variables, and their interrelation with each other. What is meant by 'pure effect' is the actual relation between a dependent and an independent variable, while controlling for the other variables. A simple regression can be explained with the following equation:

$$\hat{Y} = C + \beta X \tag{6.1}$$

where:

$\hat{Y}$ = Dependent variable to be predicted
β = regression coefficient parameter
X = Independent variable or predictor
C = Constant, intercept

(Molin,2018a)

Simply stated, linear regression is the relation between the independent and dependent variable expressed as

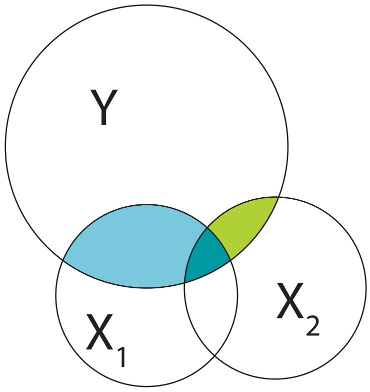

Figure 6.5: Regression with two predictors: blue and green are unique variance, turquoise is joint variance

a straight line. The constant C determines the starting point of the line and the regression coefficient shows the standardised increase of Y for one step of X. By estimating these two parameters a line is fitted that has the least residual error, also the method of least squares (Field, 2009). The formula that describes the actual relationship between the dependent and independent variables is the following:

$$Y_i = \beta_0 + \beta_i X + \epsilon_i \tag{6.2}$$

Where:

Y_i = Dependent variable
β_0 = Constant, intercept
β_i = Standardised regression coefficient
X = Independent variable
ϵ_i = Random error term

(Field, 2009)

The error term ϵ_i, represents the difference between the predicted $\hat{Y}$ and the actual Y_i. When a regression is performed, the explained variance R^2 is calculated to interpret how well the independent variable X explains the dependent variable Y. This is calculated by dividing the total sums of squares with the residual sum of squares (Field, 2009), as described in the equation below:

$$R^2 = 1 - \frac{SS_{tot}}{SS_{res}} \tag{6.3}$$

When the regression line fits the data perfectly, all the variance is explained and $R^2 = 1$. Otherwise, R^2 shows the part of the variance that is explained by X.

6.2.3. Multiple regression

A multiple regression contains the same basic components as described above, but with more than one independent variable. Multiple regression is used to explain a larger part of the dependent variable and to find the pure effect of each of the independent variables. When more independent variables are included, the explained variance R^2 will increase. However, this is not achieved by simply adding up the scores of the independent variables, because these independent variables could correlate with each other (Molin,2018c). This can be clarified in Figure 6.5.

As can be seen, both X_1 and X_2 can explain some of the variance of Y. The part where X_1 overlaps with Y (light blue) is the variance of Y explained by X_1. The green part is the unique variance of Y explained by X_2. The turquoise part is the joint variance of Y explained by X_1 and X_2 (Molin,2018c).

It is also possible to include binary variables in the multiple regression. In that case, predictor X is either 0 or 1. This means that for a simple regression using only one dummy variable, the outcome is either the constant C or $C+1*\beta$. It is possible to include nominal variables as well, by splitting them in separate dummy variables. The number of dummies required is the number of categories minus 1, since one category will be the reference point which has the constant as an outcome (Molin,2018d). To conclude, a multiple regression meets part of the requirements stated, but is not able to detect spurious and indirect effects. Furthermore, latent variables cannot be included.

6.2.4. SEM Model

A Structural Equation model is a combination of various models. A SEM model works with the same principles as multiple regression, but it can be used to model more complex relations. A SEM model consists of two parts, a structural model and a measurement model.

Path/structural models

A path model can be used to find direct, indirect, spurious and suppressor effects. These effects are all important to understand the perception of crowdedness. In a path model, the magnitude of the indirect effect is the multiplication of both path coefficients $\beta_1 * \beta_2$. Indirect effects will therefore be small, but they can be found.

Measurement model

The second part of a SEM model is a measurement model. This is a construct to include latent variables, that are not directly measurable. A measurement model has the same construct as was explained in Section 6.1.2. A measurement model should include at least two factors, but preferably three or more (Molin, 2017b). The factor loadings (the causal relation between the factor and the indicators) should be higher than 0.5 and preferably be higher than 0.7.

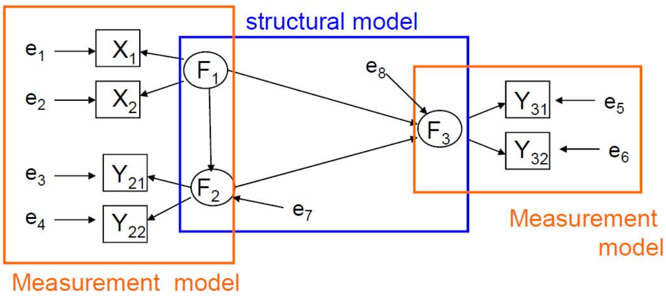

Figure 6.6: Structural Equation Model: Structural (path) model and measurement model combined

Figure 6.6 illustrates how a SEM model can be constructed. A SEM meets all of the requirements stated at the beginning of this section. The model can be based on theory, can find pure, indirect and spurious effects and can include constructs for latent variables.

6.2.5. Conclusion

Multivariate regression is a useful data analysis technique, which can test theories and can find pure effects of a predictor. However, it cannot test indirect relations and cannot include a latent variable. A SEM model does offer the possibility to include indirect relations and latent variables, with the use of a path model and a measurement model. Therefore, the data from the research will be analysed by using Structural Equation Modelling. It has a high explanatory power and can be used to analyse complex relations.

6.3. SEM building, testing and analysing

This section will explain how a SEM is created, fitted and analysed.

6.3.1. SEM modelling rules

When creating a model, a person needs to take into account the modelling conventions displayed in Figure 6.7 (Molin, 2017c). Furthermore, the difference between exogenous and endogenous variables is important. In a causal order, exogenous variables are not caused by any of the other variables in the model. For example, Socio-Demographic variables are not caused by any of the other variables, but they could be correlated to other variables. For example, age could be correlated with having a purpose. Endogenous variables are caused by other variables in the model. An endogenous variable can be recognised by a causal path coming in. Endogenous variables are always modelled with an error term, see also Figure A.2. This error variable represents the unique variance of the endogenous variable, that is not caused by the predictor variable. Two endogenous variables cannot be correlated, but need to be connected with a causal path. The only exception to this rule is when two endogenous variables are at the same level of a causal order such as the Theory of Planned Behaviour (Molin, 2017c). For example, the experience of crowdedness variables are on the same level of the causal order, as can be seen in the theoretical framework 3.3.

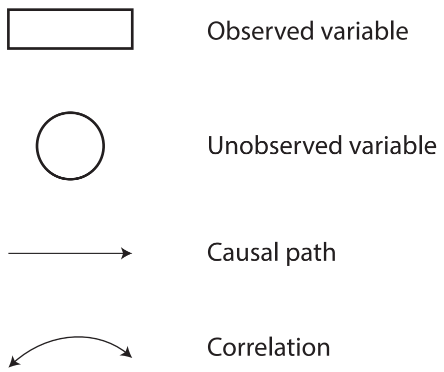

Figure 6.7: SEM model: Conventions in notation (Molin, 2017c)

6.3.2. Assessing a model fit

When a model is created, the model fit has to be assessed before the results can be interpreted. This can be done using the χ^2 value and the p-value of a model (Molin, 2017b). The χ^2 is calculated using formula 6.4.

$$\chi^2 = (N-1)|(S-\Sigma(\delta))| \tag{6.4}$$

Where:

χ^2 = Chi-squared distribution based on degrees of freedom
N = number of cases
S = Observed covariance matrix
$\Sigma(\delta)$ = the reproduced covariance matrix from model

(Molin, 2017b)

This test compares the covariance matrix of the individual relations to the relations modelled. The null hypothesis is that the model fits the data. Therefore, a model fit is indicated by a p-value > 0.05. A lower χ^2 indicates a higher model fit. As can be seen from looking at this equation, a higher number of cases N actually decreases the model fit. This is important to take into account, because this means that using the data of less respondents would increase the model fit, which does not seem logical.

The χ^2 is a useful indicator. However, for large and complex data-sets, it becomes difficult to satisfy the model fit assessed by this indicator (Kenny, 2015). Therefore, assessment based on other indicators might be necessary. This can also help to compare models. These indicators include measures of fit and measures of parsimony. Parsimony is considered, because a good model should not be overly complex. It should only include variables that make a significant difference. Below, a list of commonly used indicators and their use are explained:

- χ^2/df: Is suggested as a better test for goodness of fit for large models. However, it is unclear what ratio indicates a good fit (Arbuckle, 2010). Some researchers suggest that an adequate fit is a value lower than five. Others recommend using 2 or 3 as a boundary value (Arbuckle, 2010).

- GFi: The goodness-of-fit index measures the amount of variance and covariance in the observed covariance matrix that is predicted by the reproduced covariance matrix (Bian, 2012). Kenny (2015) suggests that this value should be larger than 0.9.

- CFI: The comparative fit index, compares the model to the null model (no model) (Arbuckle, 2010). Gaskin (2011) suggests that it should be larger than 0.9.

- PRATIO: the parsimony ratio penalises for lack of parsimony. The number of constraints in the model is divided by the number of constraints in the null model (Arbuckle, 2010). A lower PRATIO is better.
- PCFI. The PCFI is the result of applying the parsimony adjustment (PRATIO) to the CFI (Arbuckle, 2010). Gaskin (2011) suggest that this indicator should be larger than 0.8.
- RMSEA: The root mean square error of approximation divides the fit indicator by the degrees of freedom, therefore penalising model complexity (Arbuckle, 2010). Browne and Cudeck (1993) suggest that a model should not be implemented if the RMSEA is greater than 0.1.
- PCLOSE is the p-value for testing the null hypothesis that RMSEA is no greater than 0.05 (Arbuckle, 2010). According to Browne and Cudeck (1993), a PCLOSE value higher than 0.05 indicates a close fit.
- AIC: AIC stands for Akaike information criterion. For model comparison, the lower AIC reflects the better-fitting model. Also, the AIC gives a higher score to complex models, so it favours a parsimonious model. AIC is useful in combination with the maximum likelihood method (Arbuckle, 2010).
- BCC: The Browne-Cudeck criterion imposes a slightly greater penalty for model complexity (lack of parsimony) than AIC (Arbuckle, 2010). BCC should be close to 0.9 to consider good fit (Bian,2012).
- BIC: BIC is the Bayesian Information Criterion. It penalises for sample size and model complexity. It is recommended when sample size is large or the number of parameters in the model is small (Bian, 2012). In AMOS, it is only reported when means and intercepts are not explicit model parameters (Arbuckle, 2010).
- CAIC: Consistent AIC is comparable to BIC, but less strict. The lower the CAIC measure, the better the fit (Arbuckle, 2010).

From these indicators, the ones listed in Table 6.3 will be used, because they are directly available in the results that AMOS produces. Moreover, they have been used by experts in the field of SEM modelling before, so the boundary conditions are clear and together they give a reliable indication of model fit (Kenny, 2015). Furthermore, using more than one indicator ensures that a model is not over-fitted to satisfy one condition.

Table 6.3: SEM model fit: chosen boundary conditions for a good model fit

Indicator	**Chi-square**	**p-value**	χ^2/df	**GFI**	**CFI**	**PCFI**	**RMSEA**	**PCLOSE**
Boundary condition	As low as possible	>0.05	<2	>0.9	>0.9	>0.8	<0.1	>0.05

If the initially built model does not fit the data, one might first reconsider the theoretical explanation. Furthermore, the modification indices (MI) might be consulted. These indices are given for any possible relation between two variables. It indicates to what extent the χ^2 improves if that path is added to the model. As a rule of thumb, a MI>4 will significantly improve the model fit if added. However, this should only be done if it makes sense theoretically (Molin, 2017c).

If the model fits, it might still be possible to improve some relations and get a higher model fit. This is because the model is theory-based, not data driven, therefore it is uncertain whether an optimal χ^2 value is found. This is one of the difficulties of using Structural Equation modelling. The researcher has to consider whether it is more important that the model fits the theory well, or that the model fit is higher.

To see what might be possible to improve the model fit, one can look at the Critical ratios (C.R.) and p-values of the regression weights. The critical ratio is comparable to a t-value. It is calculated by dividing the ratio of the estimate by its standard error. The Critical ratio indicates how much larger the estimate is compared to its uncertainty. The larger this value, the more certain the estimate is (Kroesen, 2017a). If there are C.R. beneath 1.96, one can consider leaving out this path.

6.3.3. SEM model building

The models will be constructed using the following steps, inspired on the model building steps from Molin (2017c):

1. All perception variables are modelled according to the hypotheses in Chapter 3. This includes factor models if the results from the exploratory factor analysis suggest this.

2. The model is tested on its model fit. All paths should be significant and the model fit is determined by looking at the p-value of the Chi-square test. The p-value should be higher than 0.05.

3. When the perception part is modelled correctly, all personal, trip and event factors that were found significant in the bi-variate analysis are included as predictors, based on the theoretical framework (Chapter 3). Correlations are applied when they can be explained theoretically.

4. When the model does not fit, the p-values and critical ratios of the individual paths will be checked. Variables that do not have any significant relations ($p > 0.05$) to other variables will be removed.

5. Next, one by one, the most insignificant paths will be removed, each time running the model again to check if other relations are influenced.

6. When only significant relations are left, but the model fit based on the six indicator from Table 6.3 is not yet sufficient or when the researcher thinks the model could still be improved, the modification indices are consulted. Suggested paths with modification indices higher than 4 will be modelled and tested one by one to see the effects on the rest of the model.

7. Lastly, variables that were not significant according to the bi-variate analysis, but were theoretically expected to be related to perception, can be added to the model. One variable at a time can be added, based on the relations that were hypothesised.

8. The model is finished when all the steps have been performed, the six indicators show a sufficient model fit and the researcher thinks the relations are explained as good as possible with this data.

9. The results that will be discussed are the total explained variance (R^2) of the perception variables and the direct, indirect and total effects of the predictors. These can be used to interpret the results and evaluate the hypotheses.

Two events are researched, both possibly having other explanatory variables. Consequently, one model will not be able to capture all meaningful results. Therefore, a multitude of models shall be created. Since there are two events, it seems logical to make a best fitting model for both of these. However, creating a model that only applies to one event in one certain year is not useful to increase understanding of perceived crowdedness in general. Hence, another model shall be created that applies to both events. Also, a model that was initially created for the first event will also be tested and improved on data of the second event and vice versa. Concluding, five models will be created, with different goals and starting points. This can be used for future reference to try to predict the perception and experience of pedestrians at mass events.

Table 6.4: SEM model building: 5 model types

5 models				
Perfect model TT	**Starting model TT**	**Starting mix model**	**Starting model RLD**	**Perfect model RLD**
Uses all significant factors/correlations from the statistical analysis TT	Uses all significant factors/correlations that are present in RLD data as well	Uses all significant factors/correlations found in both cases	Uses all significant factors/correlations that are present in TT data as well	Uses all significant factors/correlations from the statistical analysis RLD

6.3.4. SEM model results

The results that will be interpreted are the total explained variance (R^2) of the perception variables and the direct, indirect and total effects of the predictors. These can be used to interpret the results and evaluate the hypotheses.

6.3.5. Conclusion

In conclusion, Structural Equation modelling will be used to analyse the data. It can be used to find the complex relations between all the factors included. Five models will be created, where two are event specific and the other three are applicable to both events. This way, it is possible to give a specific explanation for each event as well as to increase knowledge on pedestrians' perception at events in general. An initial model will be built, based on the theoretical framework. Then, insignificant paths and factors are removed one by one and paths that improve the model fit are added. With this modelling method, it is ensured that all relevant relations will be included in the final model. The models can be interpreted by looking at the direct, indirect and total effects of explanatory factors on the perception variables. This will show to what extent the personal, trip and event factors influence the perception.

6.3.6. Sidenote: Missing data

In all research, it is probable that a dataset is not fully complete. Missing data can be structural or random. This can be caused by malfunctioning sensors or non mandatory survey questions for example. There are three methods that are often applied in order to deal with missing data.

Listwise deletion is removing any record where one variable is missing. This is an easy method, but is has a major downside; A large part of the data will have to be removed. Therefore, a better method is *Pairwise deletion*. In this case, if a regression is tested between two variables, only the missing cases of one of them are excluded. A third approach is *data imputation*. Here a guess is made based on the data that is available. For example, the mean of the variable can be calculated. This value can then be placed at the missing data points (Arbuckle, 2010).

The software package AMOS, which will be used for estimating the model, can accept missing data when the estimation criterion Maximum Likelihood is used. In the AMOS user guide, Arbuckle (2010) gives an example of a model estimated with a complete dataset and another, exactly the same dataset, where a few random values have been excluded. The χ^2 value is slightly higher for the complete dataset, but both model estimates are significant.

In this research, there is missing data for one of the event locations. It is chosen to make use of the method that the software package AMOS provides. Listwise deletion was not a possibility, because then no data acquired at that event location could have been used.

III

Results & Conclusions

7

Results

In this chapter, the results of the analysis as described in Chapter 5 and Chapter 6 are presented. First, the correlations between the perception variables and the variables that were chosen to measure Crowdedness are given (Section 7.1). Second, the results of the Exploratory factor analysis (Section 7.2) are presented. The exploratory factor analysis is used to determine how the perception variables are related and consequently how they will be modelled in a SEM. Third, the results of the bi-variate analysis (Section 7.3) are discussed. Finally, the Structural equation models are elaborated upon in Section 7.5. These models provide insights in the pure effects of the explanatory factors and provide the base for the final interpretation and conclusions.

7.1. Quantification of Crowdedness

In this section, the variables that are chosen to quantify Crowdedness (Chapter 5) are tested. Not all of them can be included in the SEM model, because this would result in multicollinearity (Molin, 2018e). Therefore, only a limited number of measured crowdedness variables will be included in the final SEM model. Which of the variables are included is decided using the test results from the bi-variate analysis. The crowdedness variables that have the highest correlation to perception will be included. In Section 7.1.1, the results for the TT Festival are given and in Section 7.1.2, the results for the Red light district are elaborated upon.

7.1.1. TT festival

In Table 7.1, the correlations between variables that are used to describe Crowdedness and the perception variables are presented.

7.1.1.1 Density indicators

For the Wi-Fi counts, 3, 15, 30 and 60-minute moving averages are tested for local measurements. The table shows that the variable *'local 15-minute Wi-Fi counts'* has the strongest correlation with perceived Crowdedness (τ = .293). A reason for this could be that pedestrians use their memories of the past 15 minutes to assess the level of Crowdedness. For perceived Safety, there is a weak negative correlation with the Wi-Fi counts, which is strongest for the 60-minute time window ($\tau = -.098$). This indicates the people feel a bit less safe when a place is more crowded. Furthermore, Attractiveness and Atmosphere are positively correlated with the Wi-Fi counts. Attractiveness is correlated the strongest with the Wi-Fi counts with a 3-minute moving average (τ = .135), while Atmosphere has the strongest correlation with the Wi-Fi counts with a 60-minute moving average (τ = .141). This could be interpreted as follows: Attractiveness of a location is assessed at the moment, while Atmosphere is experienced over a longer time period. However, the differences in correlations between the time windows are small. Therefore, this interpretation cannot be concluded with certainty. Overall, the findings suggest that the number of people present influences the perception of Attractiveness of the environment and Atmosphere. Regarding perceived Comfort, no correlation was found with local Wi-Fi counts.

Besides the local Wi-Fi counts, the global Wi-Fi counts with a time window of 60 minutes were found to be correlated with the perception variables. Here, a correlation with perceived Crowdedness is found (τ = .185), but it is weaker than the local measurement. Contrary, the correlation with perceived Safety is stronger

Table 7.1: TT Festival: Correlations Perception - Quantified Crowdedness

		P. Crowded.	P. Safety	P. Comfort	P. Attractiveness	P. Atmosphere
WifiC3	Corr.	.198**	-0.041	-0.043	.135**	.112*
	Sig.	0.000	0.213	0.194	0.003	0.013
WifiC15	Corr.	.293**	-.094*	-0.041	.115**	.136**
	Sig.	0.000	0.031	0.207	0.009	0.004
WifiC30	Corr.	.289**	-.098*	-0.042	.120**	.141**
	Sig.	0.000	0.026	0.201	0.007	0.003
WifiC60	Corr.	.275**	-.098*	-0.043	.130**	.130**
	Sig.	0.000	0.027	0.195	0.004	0.005
allWifiC60	Corr.	.185**	-.139**	-.094*	0.037	.117**
	Sig.	0.000	0.003	0.030	0.225	0.010
ped/area15	Corr.	.192**	-0.018	0.013	-0.078	0.016
	Sig.	0.000	0.358	0.395	0.055	0.375
ped/area3	Corr.	.143**	0.011	-0.006	-0.060	0.007
	Sig.	0.002	0.415	0.455	0.110	0.442
vol/cap15	Corr.	.181**	-0.006	0.013	-.081*	0.014
	Sig.	0.000	0.456	0.395	0.049	0.389
vol/cap3	Corr.	.122**	-0.001	-0.024	-.095*	-0.014
	Sig.	0.006	0.496	0.318	0.027	0.394
camcount 3	Corr.	.247**	-.246**	-.178**	-0.026	.122*
	Sig.	0.000	0.000	0.002	0.330	0.024
camcount15	Corr.	.300**	-.271**	-.191**	-0.001	.124*
	Sig.	0.000	0.000	0.001	0.495	0.022
cam flow 15	Corr.	.248**	-.250**	-.149**	0.039	.115*
	Sig.	0.000	0.000	0.007	0.257	0.031
cam flow 3	Corr.	.263**	-.232**	-.155**	0.066	.108*
	Sig.	0.000	0.000	0.006	0.136	0.040
in/out15	Corr.	0.038	-0.036	-0.069	0.080	-0.051
	Sig.	0.259	0.283	0.129	0.091	0.205
in/out3	Corr.	.109*	-0.031	-0.046	0.092	-0.003
	Sig.	0.034	0.307	0.225	0.064	0.478

($\tau = -.139$). Moreover, it is correlated with perceived Comfort as well ($\tau = -.094$). On the other side, it is not correlated with Attractiveness. It was hypothesised that the correlations for global Wi-Fi counts would be lower for all perceptions, since the survey questions address the local perception (e.g. *"How would you rate the level of crowdedness at this location?"*).

Next, the correlation between density (ped/m^2) and number of pedestrians compared to the maximum number of pedestrians ($ped(t)/max(ped(t))$) and the perception variables are tested. There is a correlation between these variables and perceived Crowdedness. However, the correlation is less strong compared to the pure Wi-Fi counts. Furthermore, a weak negative correlation between Perceived Attractiveness and $ped(t)/max(ped(t))$ is found, which might indicate that areas nearly filled to capacity are found less attractive.

Since the variable *'15-minute local Wi-Fi counts'* has to strongest relation with perceived Crowdedness is and also strongly correlated with the other perception variables, this variable will be included as a density indicator in the Structural equation model.

7.1.1.2 Flow indicators

For the camera counts, a 3 and 15-minute moving average are tested. The 15-minute counts have the strongest correlation with all the perception variables. Perceived Crowdedness is correlated stronger with the 15-minute camera counts ($\tau = .300$) than with the 15-minute Wi-Fi counts, although the difference is small . Therefore, the Wi-Fi counts and camera counts are equally strongly correlated to perceived Crowdedness.

For perceived Safety, the correlation is stronger as well ($\tau = -.250$). A moderately strong relation with perceived Comfort is found as well ($\tau = -.155$), which indicates that the amount of movement of a crowd is negatively correlated with the perception of Safety & Comfort. The flow ($ped/min/m$) has the same correlations as the pure camera counts, but the correlations are all slightly weaker. Lastly, a only weak correlation between the proportion of in- and outflow and perceived Crowdedness is found. To conclude, *'15-minute local camera counts'* will be used in the SEM model, because this variable has the strongest correlations with the perception variables.

7.1.1.3 Scatter and simple regression
A simple regression is performed for the for the *'15-minute local Wi-Fi counts'* and the *'15-minute local camera counts'*, with perceived Crowdedness as the dependent variable. Figure 7.1 shows that the 15-minute Wi-Fi counts accounts for 18% of the variance in perceived Crowdedness ($R^2 = .180$). Figure 7.2 illustrates that the 15-minute camera counts account for 12% of the variance of perceived Crowdedness. This suggests that Wi-Fi counts are the better predictor for perceived Crowdedness, while the correlation was higher for the camera counts. This could have multiple reasons. First, the correlation is calculated using Kendall's rank correlation coefficient (Appendix D), while a simple regression seeks a linear relationship (Chapter 6). This means that the relation between the two variables is tested in a different way. Other than that, it is known that the same level of flow is possible at different levels of density (Chapter 2). Consequently, a low flow can correspond to a very deserted area or a very crowded area. Therefore, the relation between flow and perceived Crowdedness is less clear as well.

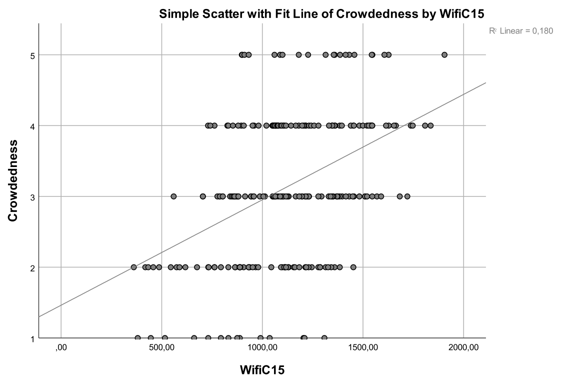

Figure 7.1: TT Festival: Regression 15-minute local Wi-Fi counts - P. Crowdedness

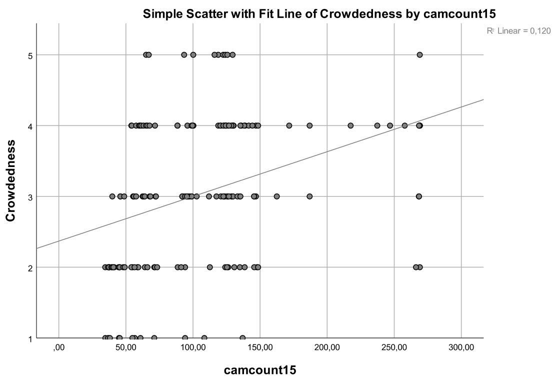

Figure 7.2: TT Festival: Regression 15-minute local camera counts - P. Crowdedness

In Figure 7.3, Wi-Fi counts and perceived Crowdedness are plotted over time. This figure shows that the perception seems to be different for the different locations (every jump in time corresponds to another location). Therefore, it is important to take location into account in the SEM. More scatter plots and regression lines can be found in Appendix B. There, the Wi-Fi counts and perceived crowdedness are plotted split per day and location.

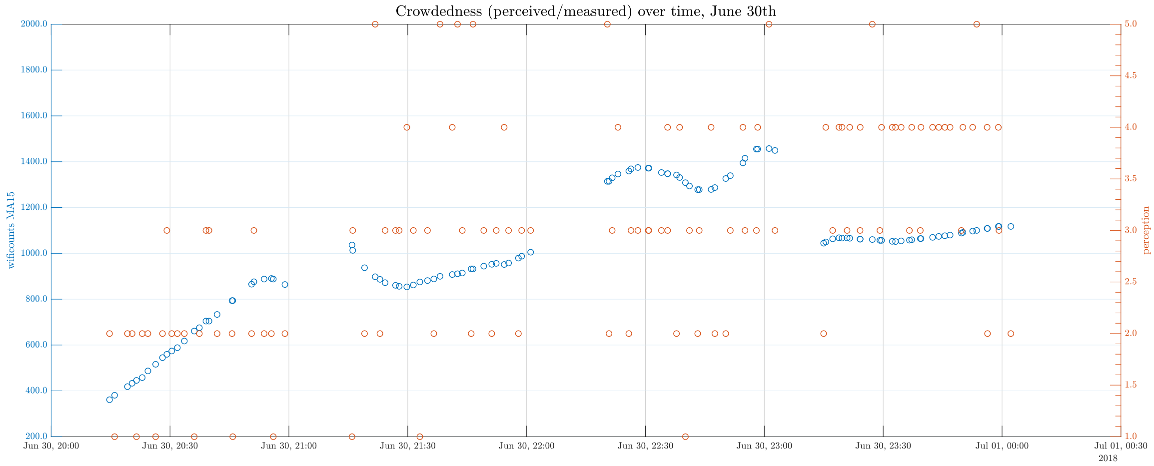

Figure 7.3: TT Festival: Scatter 15-minute Wi-Fi counts and P. Crowdedness over time, three locations, 20:00-21:00 Koopmansplein, 21:00 - 22:00 Kermis, 22:00 - 23:00 Markt, 23:00 - 00:00 Koopmansplein. June 30, 2018.

7.1.2. Red light district

Table 7.2 depicts the correlations between quantified crowdedness and perception on Crowdedness and other crowd related perceptions. Here, it is noticeable that mainly perceived Crowdedness is correlated with the quantified crowdedness variables, while in the case study of the TT Festival correlations were found between quantified crowdedness and the other perception variables as well.

Table 7.2: Red light district: Correlations Perception - Quantified Crowdedness

		P. Crowded.	P. Safety	P. Comfort	P. Attract.	P. Atmos.	Exp. Crowded.
WifiC3	Corr.	.205**	0.002	-0.046	-0.025	0.010	-0.066
	Sig.	0.000	0.488	0.207	0.328	0.427	0.118
WifiC15	Corr.	.215**	0.023	0.003	-0.012	0.022	-0.073
	Sig.	0.000	0.345	0.481	0.416	0.345	0.095
WifiC30	Corr.	.224**	0.008	-0.017	-0.034	-0.002	-0.070
	Sig.	0.000	0.442	0.383	0.271	0.486	0.105
WifiC60	Corr.	.226**	0.000	-0.019	-0.046	-0.024	-0.055
	Sig.	0.000	0.497	0.369	0.204	0.333	0.161
allWifiC60	Corr.	.292**	-0.011	0.008	-0.025	0.002	-0.053
	Sig.	0.000	0.422	0.445	0.328	0.487	0.171
vol/cap15	Corr.	.265**	-0.039	-0.054	-0.053	-0.010	-.118*
	Sig.	0.000	0.248	0.167	0.171	0.431	0.017
vol/cap3	Corr.	.224**	-0.024	-0.063	-0.039	0.006	-0.081
	Sig.	0.000	0.341	0.130	0.246	0.461	0.074
camcount 3	Corr.	.140**	0.039	0.036	-0.041	-0.036	-0.013
	Sig.	0.007	0.252	0.261	0.236	0.261	0.409
camcount15	Corr.	.162**	0.041	0.066	0.009	0.036	-0.015
	Sig.	0.002	0.239	0.120	0.437	0.264	0.398
cam flow 15	Corr.	.127*	0.062	0.050	0.010	-0.008	0.000
	Sig.	0.013	0.139	0.185	0.430	0.442	0.500
cam flow 3	Corr.	.097*	0.044	0.055	-0.032	-0.034	-0.018
	Sig.	0.045	0.225	0.163	0.286	0.276	0.375

7.1.2.1 Density indicators

For the local measurements, the correlation between the 60-minute Wi-Fi data and the perceived Crowdedness is the strongest (τ = .226). Furthermore, the correlation between the global 60-minute Wi-Fi data and perceived Crowdedness is even stronger ($\tau = .292$). This suggests that the Wi-Fi counts of the whole Red light district are a better indicator for perceived Crowdedness than the local crowdedness. This seems quite logical, since the event area is smaller and people are predominantly walking around, which means that they have been at various locations recently and they experience the area as one whole. The number of pedestrians compared to the maximum number of pedestrians measured in that area ($ped(t)/max(ped(t))$) has a slightly lower correlation with perceived Crowdedness compared to the global Wi-Fi counts ($\tau = .265$). A small negative correlation with Experienced Crowdedness is found as well ($\tau = -.118$). The density ($ped./m^2$) is not calculated for the Red light district, because determining the area that a Wi-Fi sensor measures is more difficult for the small alleyways.

In the final model, *15-minute local Wi-Fi counts* can be used, in order to compare the TT and RLD model better. Otherwise, *global 60-minute Wi-Fi counts* or $ped(t)/max(ped(t))$ would be a good option. In the end, *global 60-minute Wi-Fi counts* is chosen to be used in the model, because the correlation of this variable with perceived Crowdedness is the strongest.

7.1.2.2 Flow indicators

For the flow indicators, pure camera counts and the flow (ped/m) are compared with a moving average of 3 or 15 minutes. The 15 min camera counts are correlated with perceived Crowdedness the strongest ($\tau = .162$). The flow variables have a lower correlation. The proportion in and outflow is not calculated for the Red light district, because it did not yield many results in the TT case. Therefore, *15-minute camera counts* will be used in the model, just as in the TT model.

7.1.2.3 Scatter and simple regression

In Figure 7.4 and Figure 7.5, the chosen density and flow indicator are used as a predictor for perceived Crowdedness. The global 60 min Wi-Fi data accounts for 12.5% of the variance in perceived Crowdedness ($R^2 = .125$). 15 min camera counts account for 4.5% of the variance of perceived Crowdedness ($R^2 = .045$). The latter value is very low, which indicates describing the relation between perceived Crowdedness and "flow" linearly does not provide much insight.

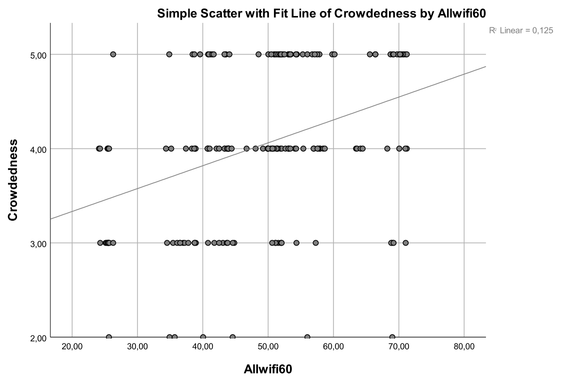

Figure 7.4: Red light district: Regression global 60-minute Wi-Fi counts - P. Crowdedness

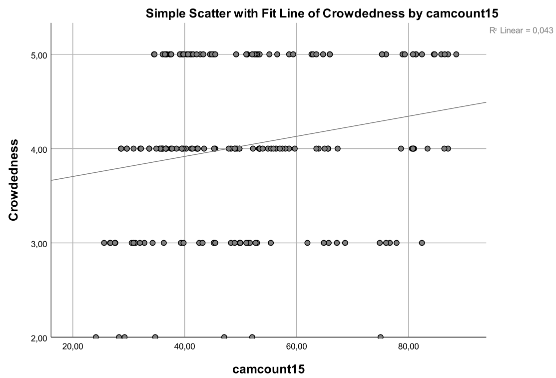

Figure 7.5: Red light district: Regression 15-minute camera counts - P. Crowdedness

Figure 7.6, the perceived Crowdedness and 15-minute Wi-Fi data of one evening are plotted over time. Three locations were researched that evening, respectively GAWW-06 *Oudezijds Achterburgwal*, GAWW-07 *Stormsteeg* and GAWW-02 *Oude kennissteeg*. The small breaks at 20:00 and 21:00 indicate a switch of location. It can be seen that the differences in perceived Crowdedness per location are less pronounced than at the TT Festival. Furthermore, it shows that there is quite some fluctuation in the measured Crowdedness. The perceived Crowdedness does not correspond well to the Wi-Fi counts at the end of the evening. However, when looking at the 1-minute data, there was a drop in the Wi-Fi counts around that time (B.15). More scatterplots can be found in Appendix B. There, the Wi-Fi counts and perceived crowdedness are plotted split per day and location.

For the SEM model, it is expected that Wi-Fi counts will be more closely related to the perceived crowdedness than the camera counts, but both variables will be tested.

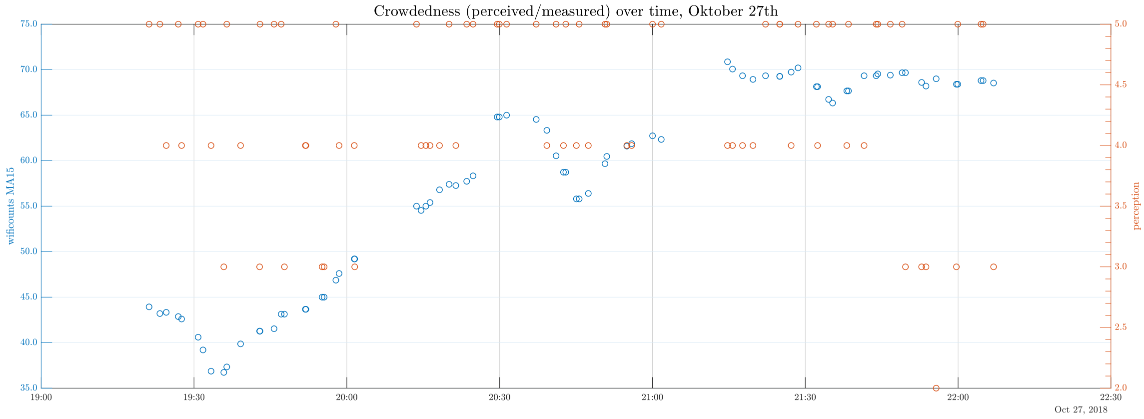

Figure 7.6: Red light district: Scatter 15-minute Wi-Fi counts and P. Crowdedness over time. 19:00 - 20:00 Oude Kennissteeg, 20:00 - 21:00 Stormsteeg, 21:00 - 22:15 Oudezuids Achterburgwal. October 27, 2018.

7.2. Exploratory factor analysis

In this analysis, exploratory factor analysis is used to see whether the six questions related to crowd perception and experience are in fact indicators of one or more factors. This is important to know how the relations between the perception variables can best be modelled. The full analysis can be found in Appendix E. In this section, the most important results are discussed.

The following boundary conditions have to be met in order to use variables as indicators for a latent variable:

- A latent variable should have at least two indicators, preferable three or more (Section 6.1.2)
- Factor loadings should be above 0.5. This indicates that the overlap of the indicators is sufficient (Section 6.1.2).
- Each indicator should only load on one factor. If there is a cross loading, the difference should be at least 0.2 (Appendix E).
- The total variance explained by the factors is preferable above 50%. (Appendix E)

The results are presented and discussed in this section.

7.2.1. TT Festival exploratory factor analysis

At the TT Festival, five questions related to perception were posed.

Table 7.3: TT Exploratory factor analysis: 5 perceptions included

Rotated factor matrix		
	Factor 1	Factor 2
P. Crowdedness	0.355	
P. Safety		0.576
P. Comfort		0.662
P. Attractiveness	0.627	
P. Atmosphere	0.750	
Variance explained	38.568%	

In Table 7.3, the results of an exploratory factor analysis with these five perception variables are shown. Table 7.3 indicates that the factor loading of Perceived Crowdedness is too low and the total variance explained by the factors (38.6%) is also low. Therefore, another exploratory factor analysis is performed, excluding the variable perceived Crowdedness.

Table 7.4: TT Exploratory factor analysis: 4 perceptions included, P. Crowdedness excluded

Rotated factor matrix		
	Factor 1	Factor 2
P. Safety		0.571
P. Comfort		0.657
P. Attractiveness	0.721	
P. Atmosphere	0.675	
Variance explained	44.457%	

In Table 7.4, the results of a second exploratory factor analysis is shown, in which the perception variables Safety, Comfort, Attractiveness of the environment and Atmosphere are included. Two factors, one consisting of the indicators Safety and Comfort and one of Attractiveness and Atmosphere, can explain 44,5% of the total variance. All factor loadings are above 0.5. Together, this indicates that perceived Safety & Comfort can be modelled as one factor, and perceived Attractiveness and Atmosphere can be seen as indicators for one factor.

7.2.2. Red light district exploratory factor analysis

For the RLD case, the same analysis is performed, only one extra variable was included in the survey; the experience of Crowdedness. This additional variable is included in this analysis as well. Table 7.5 shows the results of the initial test. In this case, not all factor loadings are higher than 0.5. Furthermore, there are cross loadings present for experienced Crowdedness. Since Crowdedness seems to have the least connection to the rest, another exploratory factor analysis is performed, excluding this variable. Furthermore, experienced Crowdedness was excluded, after another test showed that the loadings of Experienced Crowdedness are too low on all factors to be included as an indicator for a latent variable.

Table 7.5: RLD Exploratory factor analysis: 5 perceptions and 1 experience included

Rotated factor matrix			
	Factor 1	Factor 2	Factor 3
P. Crowdedness			-0.371
P. Safety		0.574	
P. Comfort	0.308	0.867	
P. Attractiveness	0.722		
P. Atmosphere	0.842	0.350	
Exp. Crowdedness	0.378		0.371
Variance explained	52.724%		

Table 7.6: RLD Exploratory factor analysis: 4 perceptions included

Rotated factor matrix		
	Factor 1	Factor 2
P. Safety		0.663
P. Comfort		0.780
P. Attractiveness	0.738	
P. Atmosphere	0.828	0.357
Variance explained	64.522%	

Table 7.6 illustrates that two factors explain 64.5% of the variance. Perceived Safety and Comfort both load high only on factor 2. Perceived Attractiveness and Atmosphere both load high on factor 1. Perceived Atmosphere also loads on factor 2, but this loading is very low and the difference in loading on the two factors is quite high. Therefore, it is chosen to use the same construct as the TT Festival case.

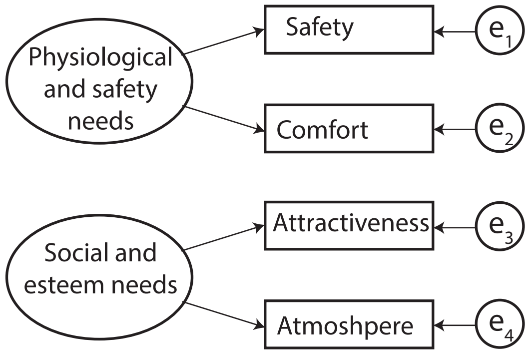

Figure 7.7: Exploratory factor analysis: resulting factor construct

7.2.3. Discussion

This analysis shows that perceived Crowdedness is different from the other perceptions in both case studies. This is important, because it learns us that the other perceptions are influenced in other ways by the explanatory factors.

Both in the TT Festival case and the RLD case, two latent factors can be extracted. This can be interpreted in the following way: Factor 2 connects perceived Safety and perceived Comfort. Both of these variables concern a person's physical experience of a crowd. In Maslow's pyramid (McLeod, 2007), they correspond to a person's most basic needs: Physiological and Safety needs. Factor 1 connects perceived Atmosphere and perceived Attractiveness. Both of these perceptions give an indication of how a person perceives an event and the crowd present. This corresponds to the higher levels of the pyramid: Social and esteem needs.

In the SEM model, the latent variables will be constructed as presented in Figure 7.7.

7.3. Bi-variate analysis results: Correlations and z-scores

The complete bi-variate analyses can be found in Appendix H and K. Here, an overview of the correlations and z-scores found in this analysis are presented in a Table 7.7 and 7.8 and Figure 7.9 and 7.10. Only significant correlations are included in the tables. In this section, the resulting correlations are interpreted. Please note, one-on-one correlations might not always show the pure effect of a variable. Additionally, this section determines which factors will be used in the models, based on the outcomes of this analysis.

7.3.1. TT Festival bi-variate results

The correlations presented in Table 7.7 are discussed per category in this section.

7.3.1.1 Correlations between perception variables

Table 7.7 indicates that several of the perception variables are correlated. However, perceived Crowdedness is not significantly correlated with Safety and Comfort. This could mean that Safety and Comfort are less related to perceived Crowdedness than expected or that the crowdedness was never that high that Safety and Comfort were negatively effected. Or, the survey question formulation was not specific enough. Perceived Crowdedness and perceived Attractiveness and Atmosphere are positively correlated, which confirms the hypothesis. Perceived Safety and Comfort are strongly correlated, as well as perceived Attractiveness and Atmosphere. This corresponds with the findings in Section 7.2.

7.3.1.2 Correlations with socio-demographics

In the category socio-demographics, the hypothesis that woman perceive Safety lower than men is confirmed by the bi-variate analysis. This could be explained by the difference in physical height between men and women, or by the different experience of social safety. Other than that, no significant differences between gender was found. For age, no correlations were found. This was unexpected, since it was hypothesised that younger people would have a more positive perception. The fact that the TT Festival is an event for all ages, where many groups consisted of people from different age categories could explain why no difference is found. Additionally, no relation between urbanisation level and perception was found. Based on this result, the hypothesis that a higher urbanisation level of a person's place of residence leads to a higher perception of

Table 7.7: Correlations and z-scores: TT Festival. Positive correlations in bold font

	P. Crowdedness	**P. Safety**	**P. Comfort**	**P. Attractiveness**	**P. Atmosphere**
P. Crowdedness				**τ = 0.150** **p = 0.003**	**τ = 0.201** **p = 0.000**
P. Safety			**τ = 0.342** **p = 0.000**		
P. Comfort		**τ = 0.342** **p = 0.000**		**τ = 0.190** **p = 0.000**	**τ = 0.136** **p = 0.009**
P. Attractiveness	**τ = 0.150** **p = 0.003**		**τ = 0.190** **p = 0.000**		**τ = 0.460** **p = 0.000**
P. Atmosphere	**τ = 0.201** **p = 0.000**		**τ = 0.136** **p = 0.009**	**τ = 0.460** **p = 0.000**	
Male		**z = 2.339** **p = 0.019**			
Age					
Urbanisation level residence					
Foreign		**z = 2.961** **p = 0.003**	**z = 2.163** **p = 0.032**		
Visit Assen					
Visit Event	τ = -0.182 p = 0.001				
Purpose: Leaving	**z = 3.283** **p = 0.000**		z = -2.084 p = 0.021		
Group size	**τ = 0.167** **p = 0.002**		τ = -0.104 p = 0.037		**τ = 0.113** **p = 0.027**
Group type					
Group composition: male vs female		**z = 2.642** **p = 0.025**			
Pleased					
Activated			**z = 2.340** **p = 0.009**		
Substances					
Time spent	**τ = 0.100** **p = 0.030**				
Time of day	**τ = 0.352** **p = 0.000**	τ = -0.184 p = 0.001	τ = -0.163 p = 0.003		**τ = 0.115** **p = 0.040**
Time of week	H(2)= 6.157 p = 0.046				
Location: Markt vs Kermis				**z = 3.419** **p = 0.002**	
Light intensity	τ = -0.349 p = 0.000			τ = -0.111 p = 0.043	τ = -0.164 p = 0.004
Sound intensity	**τ = 0.194** **p = 0.000**				
Music type: headliner vs background		z = -2.004 p = 0.043			
Temperature	τ = -0.319 p = 0.000	**τ = 0.173** **p = 0.002**	**τ = 0.122** **p = 0.022**		τ = -0.162 p = 0.003
Weather type: Sunny vs clear	z = -4.849 p = 0.000	**z = 2.445** **p = 0.007**	**z = 2.146** **p = 0.016**		z = -2.093 p = 0.019

Crowdedness and a lower perception of Safety and Comfort cannot be confirmed. A reason for this result can be that perception of event crowdedness and urban crowdedness are based on separate habituation for event crowdedness and urban crowdedness. However, another reason for this result can be that the method of determining the urbanisation level is not sufficient, which will be further discussed in Chapter 8. Foreigners perceive Safety and Comfort higher, while the other perceptions are not significantly influenced by country of residence. This result could be explained by the fact the foreign people perceive Dutch events well-organised.

7.3.1.3 Correlations with personal state & trip factors

In the category Personal state & trip factors several correlations were found. The factor *Visit Event* correlates negatively with perceived Crowdedness. The factor *Visit Assen* is uncorrelated to the perception variables. This seems to indicate that people compare the level of Crowdedness to previous events or the previous day, but not to the normal Crowdedness in the city when there is no event. An urgent purpose, which included going home or going to the train station, has a positive correlation with perceived Crowdedness and a negative relation with Comfort. *Group size* correlates positively with perceived Crowdedness and perceived Atmosphere, but negatively with perceived Comfort. This differs from the hypothesis, but it can possibly be explained as follows: With a larger group, it is more difficult to stay together, because of the level of crowdedness. Therefore, Crowdedness is perceived to be higher and level of Comfort is lower. *Group type* did not yield any significant relations. *Group composition* did show a significant difference between groups of only men and only women. Groups of men perceive Comfort higher than groups of women. The answers regarding emotional state are split up in two binary variables; *Pleased* (yes/no) and *Activated* (yes/no). A relation between being activated and perceived Comfort was found. This results fits the hypothesis, however, it is surprising that this is the only correlation found. Substance usage (such as alcohol) is not significantly correlated with any of the perception variables. *Time spent* has a weak positive correlation with perceived Crowdedness. This is probably caused by the actual crowdedness that is higher later in the evening. Unexpectedly, *Time Spent* is not significantly correlated with Comfort.

7.1.3.4 Correlations with Event & Environment factors

In the category Event & Environment factors, *Time of day* has a strong positive correlation with Crowdedness, a moderate positive correlation with perceived Atmosphere and a moderate negative relation with perceived Safety & Comfort. For Crowdedness, this is assumed to be caused by the actual level of crowdedness. For Safety and Comfort, it fits the hypothesis that these are perceived lower at night. The variable *Time of week* distinguishes the three evenings that are researched. The result shows that Thursday was perceived to be the most crowded, Friday was perceived to be a bit less crowded and Saturday was perceived to be the least crowded. This could be explained by two things. One, since the layout of the event was different Thursday, the actual crowdedness per location was different. On Thursday, there were only five stages, while on Friday and Saturday, there were ten. The number of visitors might have been higher on Friday and Saturday, but the visitors were spread over a larger area. The second explanation is that most people seem to visit the event every evening and consequently get used to the crowdedness.

For the three locations where the survey was conducted, there was a significant difference for the perceived Attractiveness of the environment between the *Markt* and the *Kermis* location, where the location *Markt* was perceived more positively. As the *Markt* location had a very attractive view of a lighted Ferris wheel and also was a nicely decorated residing area, this is a logical result. Accordingly, the variable *Location* needs to be included in the SEM.

Furthermore, light and sound data was gathered. *Light intensity* correlates negatively with perceived Crowdedness. Furthermore, light intensity has a negative correlation with perceived Attractiveness & Atmosphere. This is all assumed to be caused by the effect of sunlight. The light measurements after nightfall gave no accurate measurements. Therefore, light intensity will not be taken into account in the model. *Sound intensity* and perceived Crowdedness are positively correlated, which corresponds to the hypothesis that noises increase the perceived Crowdedness. However, the correlation could also be explained by *time of day*. The music may have been louder in the evening. *Music type* was tested as well. A distinction between background music and headliners was made. Headliner music has a negative relation with perceived Safety. A reason for this could be because there is more movement towards the stage when a headliner is playing. It is chosen to take only sound intensity account in the SEM, because this correlation is strong and has a logical explanation.

Finally, the weather related variables are discussed. *Temperature* relates to perceived Crowdedness and Atmosphere negatively. This can be explained by the actual level of crowdedness. *Temperature* correlates positively with perceived Safety and Comfort, which is probably because of the difference between daytime and nighttime. Thus, temperature itself probably does not have much influence in this research. Finally the variable *Weather type* is reviewed. Since the weather during the whole event was constantly sunny, the variable *Weather type* only distinguishes two categories: sunny (day) and clear (night). Daytime correlates positively with Safety & Comfort, which confirms that the difference between day- and nighttime relates to the perception of Safety & Comfort. Hence, the factor *Weather type* will be included in the model.

To conclude, the results of the bi-variate analysis for the TT Festival justify that the following factors will be taken into account in the SEM model: Male, Foreign, Visit Event, Purpose, Group size, Group composition, Activated, Time spent, Sound intensity and Weather type. These factors have a significant and logical relation to the perception variables.

7.3.2. Red light district bi-variate results

The correlations presented in Table 7.8 are discussed per category below.

7.3.2.1 Correlations between perception variables

The correlations between the perception variables show that perceived Crowdedness is only correlated with the Experience of Crowdedness. This correlation is negative, which seems logical, as higher levels of Crowdedness lead to a less pleasant experience of the Crowdedness. It is quite unexpected that there are no other correlations with perceived Crowdedness. This could indicate that people, in the case of the Red light district, do not relate Safety, Comfort, Attractiveness of the environment and Atmosphere to the number of people present. It could also be caused by the survey question formulation, which will be further discussed in Chapter 8. Other than that, all perception variables are strongly positively correlated with each other. Safety & Comfort and Attractiveness & Atmosphere have the highest correlations, which is in line with the results from Section 7.2.

7.3.2.2 Correlations with Socio-demographics

In the category socio-demographics, several correlations are established. First of all, being a male correlates positively with perceived Safety and perceived Attractiveness. This could both be explained by the difference in physical height. Furthermore, women might also feel less safe overall as the environment of the Red light district is aimed at men. *Age* correlates positively with perceived Crowdedness and negatively with perceived Attractiveness and Atmosphere. This fits with the hypothesis identified in Section 3.2. Foreigners perceive a lower level of Crowdedness, but do perceive Safety, Comfort, Attractiveness and Atmosphere higher. It was expected that tourists would have a more positive perception. However, it was also expected that they would perceive the Crowdedness of the Red light district as higher, because they are unfamiliar with the Red light district. Amsterdammers, perceive a lower Atmosphere and experience a more unpleasant the level of crowding, compared to other Dutch citizens. This is logical, because other Dutch citizens probably have a recreational purpose, while Amsterdammers often have an urgent purpose. For the SEM, it is useful to include both the distinction between foreigners and Dutch citizens and the distinction between Amsterdammers and Dutch citizens, to capture the differences between these groups best.

7.3.2.3 Correlations with Personal state & Trip factors

For the personal state and trip factors, many significant correlations are found. To begin, visiting Amsterdam more often correlates negatively with all perception variables and Experience of Crowdedness. This corresponds to the hypothesis that unfamiliar people think Crowdedness is higher, but still perceive the other crowdedness related perceptions more positive. The variable *Visit Wallen* correlates negatively with perceived Attractiveness & Atmosphere. Since *Visit Amsterdam* affects more of the perception variables, this variable will be included in the model.

Next, the variable *Purpose* is discussed. Having an urgent purpose (train station, home/hotel, work) correlates negatively with all perception variables other than perceived Crowdedness. It is logical that a person experiences the crowd as more unpleasant. However, is was expected that this would also influence the perceived Crowdedness. Furthermore, there was no hypothesis concerning trip purpose and perceived Safety and Comfort. It seems as though people with a specific purpose tend to be more negative overall.

Table 7.8: Correlations and z-scores: Red light district. Positive correlations in bold font

	P. Crowded.	P. Safety	P. Comfort	P. Attractiveness	P. Atmosphere	Exp. Crowded.
P. Crowdedness						τ = -0.144 p = 0.012
P. Safety			**τ = 0.499 p = 0.000**	**τ = 0.203 p = 0.001**	**τ = 0.254 p = 0.000**	**τ = 0.245 p = 0.000**
P. Comfort		**τ = 0.499 p = 0.000**		**τ = 0.310 p = 0.000**	**τ = 0.446 p = 0.000**	**τ = 0.360 p = 0.000**
P. Attractiveness		**τ = 0.203 p = 0.001**	**τ = 0.310 p = 0.000**		**τ = 0.575 p = 0.000**	**τ = 0.317 p = 0.000**
P. Atmosphere		**τ = 0.245 p = 0.000**	**τ = 0.446 p = 0.000**	**τ = 0.575 p = 0.000**		**τ = 0.377 p = 0.000**
Exp. Crowdedness	τ = -0.144 p = 0.012	**τ = 0.254 p = 0.000**	**τ = 0.360 p = 0.000**	**τ = 0.317 p = 0.000**	**τ = 0.377 p = 0.000**	
Male		**z = 1.978 p = 0.025**		**z = 1.853 p = 0.032**		
Age	**τ = 0.115 p = 0.038**			τ = -0.186 p = 0.002	τ = -0.116 p = 0.035	
Foreign	z = -1.753 p = 0.042	**z = 2.787 p = 0.005**	**z = 3.795 p = 0.000**	**z = 2.328 p = 0.010**	**z = 2.311 p = 0.010**	
Amsterdammer					z = -1.977 p = 0.026	z = -2.160 p = =.016
Visit Amsterdam	τ = -0.136 p = 0.019	τ = -0.128 p = 0.026	τ = -0.129 p = 0.022	τ = -0.152 p = 0.009	τ = -0.157 p = 0.008	τ = -0.169 p = 0.004
Visit Wallen				τ = -0.113 p = 0.043	τ = -0.144 p = 0.015	
Purpose		z = -2.080 p = 0.019	z = -1.688 p = 0.046	z = -2.528 p = 0.006	z = -1.977 p = 0.024	z = -3.147 p = 0.001
Group size			τ = -0.165 p = 0.006			
Group type: Colleagues vs Friends	z = -3.534 p = 0.006					
Group type: Colleagues vs Couple	z = -3.604 p = 0.005					
Group composition						
Pleased		**z = 2.477 p = 0.013**	**z = 3.428 p = 0.001**	**z = 2.469 p = 0.014**	**z = 2.959 p = 0.003**	
Activated				**z = 2.086 p = 0.037**		
Substances: Marijuana		**z = 2.342 p = 0.019**	**z = 2.435 p = 0.015**	**z = 3.489 p = 0.000**	**z = 2.961 p = 0.003**	
Time of day	**τ = 0.174 p = 0.007**					
Date	**H(2)= 26.580 p = 0.000**					
Location						
Sound intensity			**τ = 0.149 p = 0.006**	**τ = 0.119 p = 0.022**		
Temperature	τ = -0.300 p = 0.000					
Weather type: Clear vs rainy	z = -4.387 p = 0.000					

Group size only has a negative relation to perceived Comfort. This is contradicting the hypothesis, but is agreeing with the results of the TT Festival. For *Group type*, it seems like a group of Colleagues perceive Crowdedness significantly lower than a group of friends or a couple. This could be because a group of Colleagues have another (recreational) trip purpose or because they are more familiar to the crowdedness.

The emotional state *Pleased* relates positively to perceived Safety, Comfort, Attractiveness and Atmosphere. This fits the hypothesis that positive emotions relate to a positive perception of crowd related variables. Since it affects many perception variables, it will be included in the model. Being *Activated* only correlates with perceived Attractiveness. This might be a causal relation where the perception of the environment causes a higher level of activation. Therefore, this variable will not be included as a predictor in the SEM.

Again, no relation between alcohol usage and the perception variables is found, which is unexpected. This confirms the suspicion that the survey question formulation might not have been sufficient. However, for Marijuana usage, a significant relation was found for Safety, Comfort, Attractiveness and Atmosphere. Marijuana users have a more positive perception, probably because they have a recreational purpose.

7.3.2.4 Correlations with Event & Environment factors

For the Red light district case, *Time of day* is only correlated with perceived Crowdedness. This seems quite logical for this data, since Section 7.1 illustrated that perceived Crowdedness was the only perception that was correlated with measured crowdedness. For the time of day during which the research was performed (between 19:00-22:30), most other Event & Environment factors did not change drastically. For the three different evenings, the 27th of October was the most crowded, followed by October 19th. For perceived Crowdedness, the distinction between the dates is in the same order of actual crowdedness. Therefore, this variable is explained away by actual crowdedness and does not have to be included in the model.

No results for the variable *Location* were found, meaning that the three locations researched were not perceived differently. This can be explained by the fact that the locations are quite close to each other and are all walking areas rather than residing areas.

Sound intensity correlates positively with perceived Comfort and Attractiveness. This will not be included in the SEM model, because it is not in line with the hypothesis. Furthermore, the measurement method was not trustworthy, which will be further discussed in chapter 8.

Temperature correlates negatively with perceived Crowdedness, which is again explained away by the measured Crowdedness. For weather type, a strong negative relation between rainy weather and perceived Crowdedness is found. This will be included in the model as a control factor for measured crowdedness, since it only rained on one day and this day was noticeably less crowded.

To conclude, the factors Gender, Age, Foreign, Amsterdammer, Visit Amsterdam, Purpose, Group size, Group type, Pleased, Activated, Marijuana and Rain have significant and understandable relations to the perception variables. Therefore, they will be used in the SEM model.

7.4. Discussion preliminary analysis

For the measured crowdedness, the variables that have the strongest correlation with perceived Crowdedness are the local Wi-Fi counts with a 15-minute moving average for the TT Festival, the global Wi-Fi counts with a 60-minute moving average for the Red light district and the camera counts with a 15-minute moving average for both events. A 15-minute moving average seems to capture the perception of pedestrians well overall, which indicates that this is a good time window to adopt for measuring crowdedness.

From the exploratory factor analysis, it can be concluded that in both cases, Perceived Safety & Comfort can be seen as indicator of one latent factor, which corresponds to physiological and safety needs. Perceived Attractiveness & Atmosphere can combined into one latent factor as well, corresponding to a person's social and esteem needs.

Based on the theoretical framework 3.2, hypotheses were tested with bi-variate data analysis techniques (Appendix D). These preliminary results give an indication of the relations that will be found in a model. All the variables included in the hypotheses that were confirmed by the bi-variate analysis will be added to the SEM model. When a significant relation was found that was not hypothesised, but can be logically interpreted, it is included as well. Data which seems unreliable, such as the light intensity data, is not included.

In Figure 7.9 and 7.10, the significant and relevant relations found in the bi-variate analysis for respectively the TT Festival and de Red Light District are shown. On one line, all the predictors for one perception variable are stated. For example, in Figure 7.9, *Group size*, Wi-Fi counts and Camera counts are significantly correlated with perceived Atmosphere.

A comparison between the events shows that although many of the same predictors are significantly related to one of the perception variables, the relations are not the same. For example, *Group size* is significantly correlated with perceived Crowdedness, Atmosphere and Comfort for the TT Festival, while at the Red light district, it is only correlated with Perceived Comfort. Moreover, in the Red light district case, perceived Crowdedness is less connected to the other perception variables and quantified crowdedness is only related to perceived Crowdedness. This could be caused by contradicting answers of tourists and residents, as illustrated in Table 7.9. The data indicates that tourists give similar answers to all the perception variables (mode 4/5 for all), while Amsterdammers think it is more crowded and less pleasant in every way. However, the number of respondents who lived in Amsterdam was too low to give a representative view of their perception.

Table 7.9: RLD: Most given answer perception, comparison Amsterdammer (yes/no)

Variable	Other N =171	Amsterdammers N=11
P. Crowdedness	4 Crowded	5 Very Crowded
P. Safety	4 Safe	4 Safe
P. Comfort	4 Comfortable	1 Very uncomfortable
P. Attractiveness	4 Attractive	3 Neutral
P. Atmosphere	4 Good Atmosphere	2 Bad Atmosphere
Exp. Crowdedness	4 Pleasant	3 Neutral

Figure 7.8 shows the mean of Experience of Crowdedness for every rank of Crowdedness. The means are split for foreigners and Dutch citizens. The figure shows that for foreigners, the relation between Perceived and Experienced Crowdedness is less pronounced. The mean experience of Crowdedness is the highest for an average perceived Crowdedness (3/5). This seems to fit the hypothesis that people think an event should be crowded, but not too much so. For Dutch citizens, the Experience of Crowdedness increases as the perceived Crowdedness decreases.

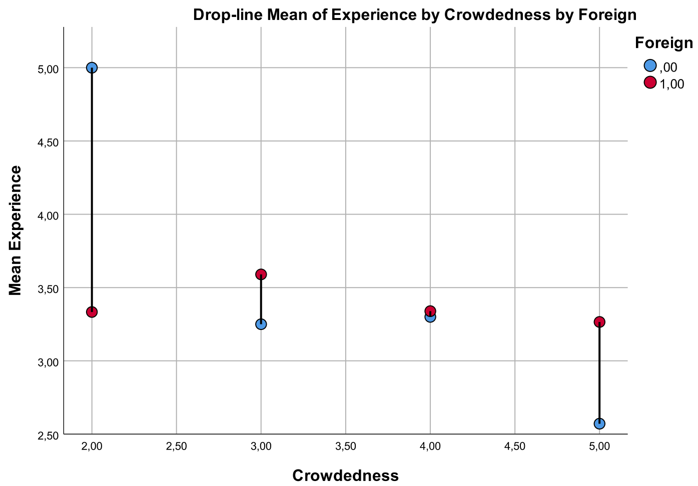

Figure 7.8: RLD: Mean Experienced Crowdedness by Crowdedness, split for Foreign (yes/no)

The missing connection between perceived Crowdedness and the other perceptions might lead to complications while building a combined model. However, in Chapter 6 it was explained that some relations might not be found with bi-variate analysis, but can be found with indirect effects in a SEM.

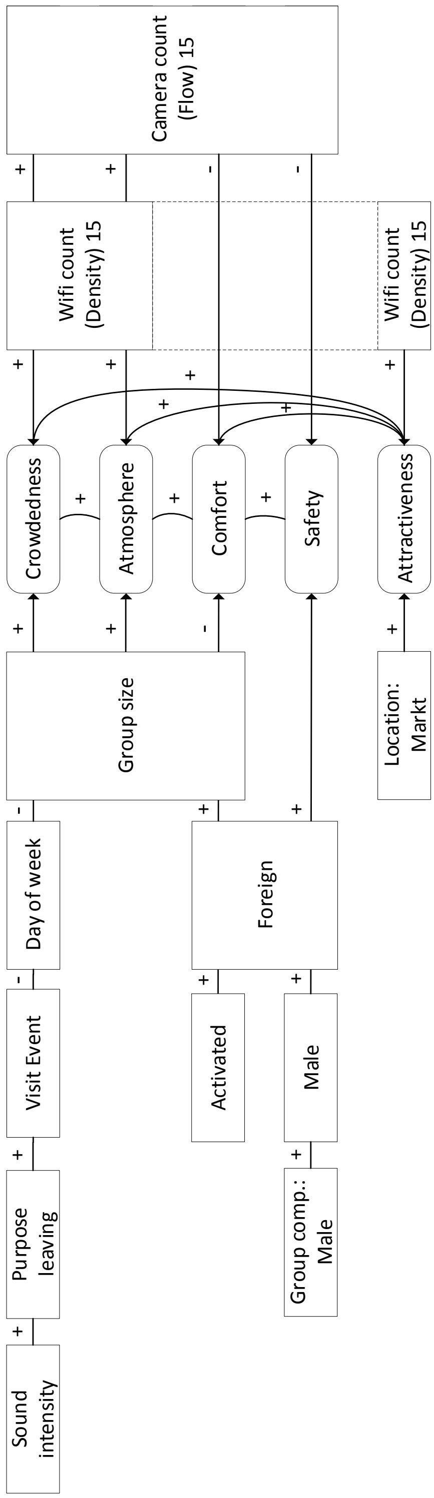

Figure 7.9: TT Festival: significant and relevant correlations

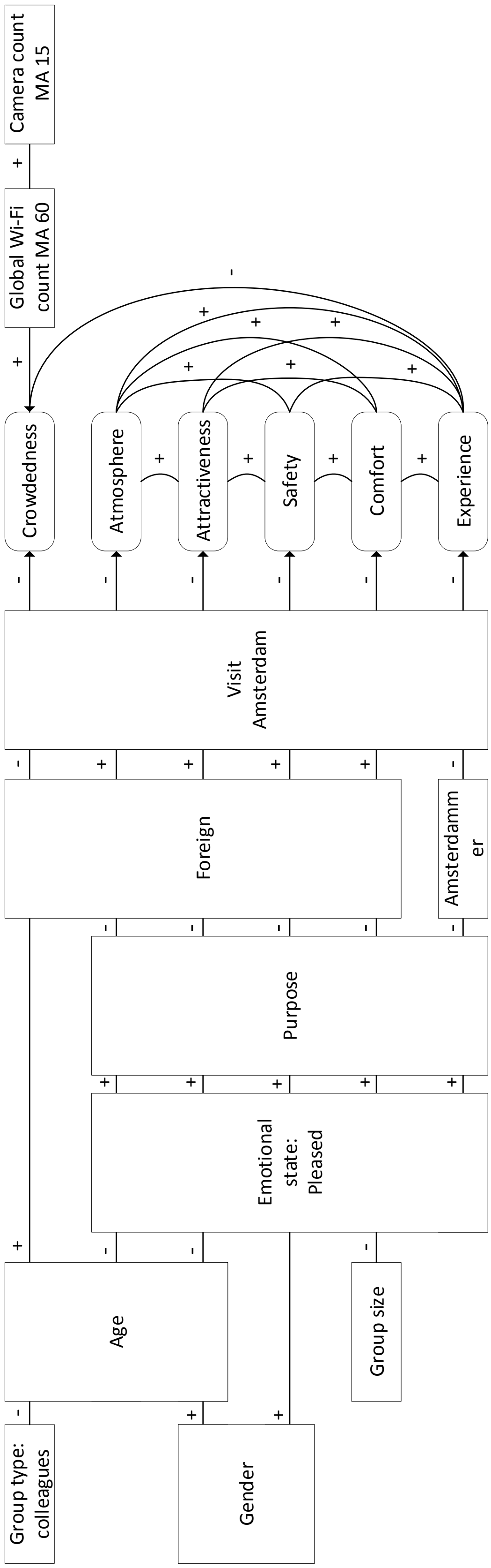

Figure 7.10: Red light district: significant and relevant correlations

7.5. Structural Equation Models

In this section, the Structural equation models for both events are presented. The modelling steps from Chapter 6 were followed to come to these models. The intermediate models can be found in Appendix C.

7.5.1. TT Festival best fit

In Figure 7.11, the final model for the TT case is presented. This is a visualisation of the SEM model that has been edited to be more easily interpreted. The AMOS visualisation can be found in Appendix C.

As can be seen, not all of the significant correlations from Figure 7.9 are included in this final model. They have been tested in a SEM, as can be seen in Appendix C. However, the relations between these predictors and the perception variables was not significant, controlled for the other factors that are included in the model. For example, *Time spent* did not have a direct relation to the perception variables. *Gender*, *Group size* and *Sound intensity* were insignificant compared to the other variables. The variable *Isdaytime* had some problems with multicollinearity.

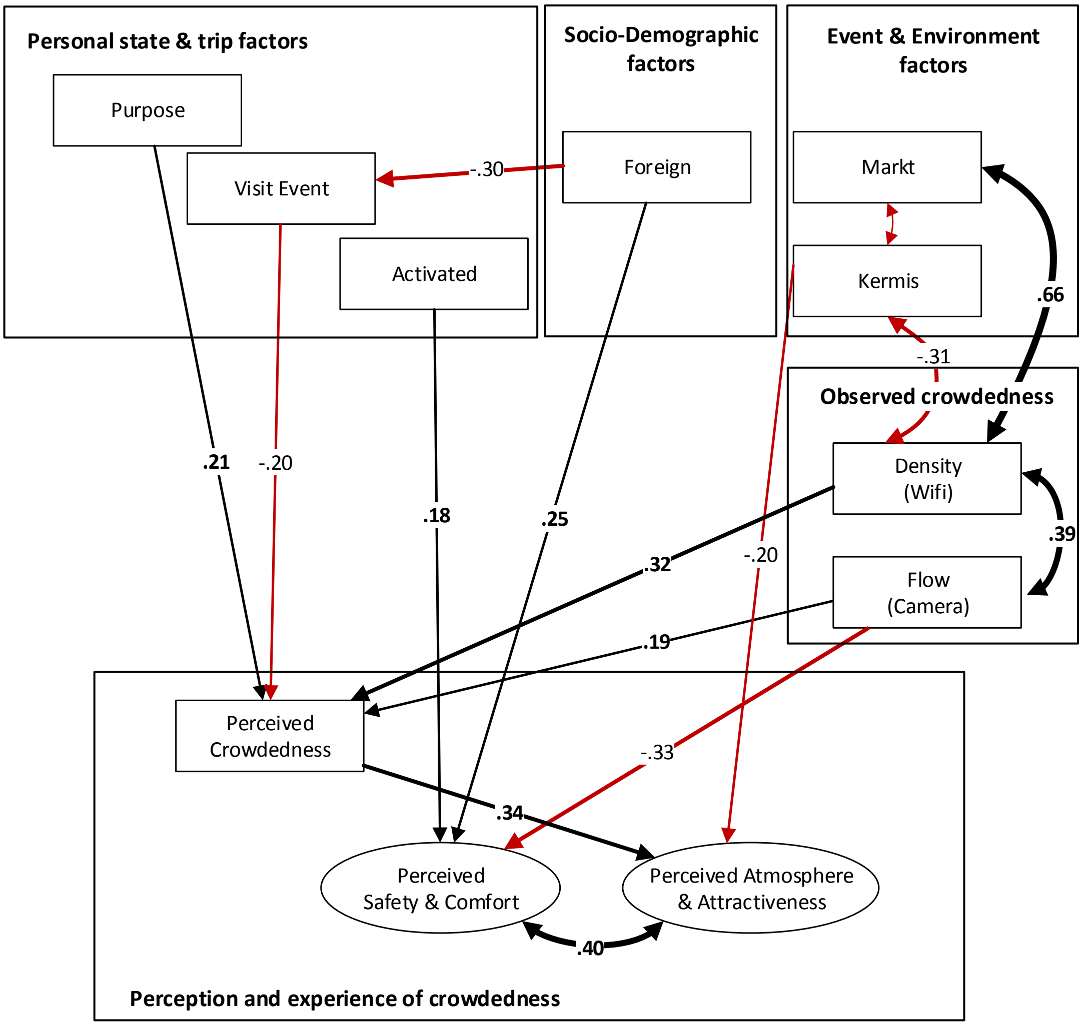

Figure 7.11: TT final model: Visual representation. Line thickness represents strength of the relation. A straight line with one arrow is a causal path, a curved line with two arrows is a correlation. A red line stands for a negative relation, a black line for a positive one. Oval shapes are latent variables.

Model fit

All the paths presented in Figure 7.11 are significant. Table 7.10 provides the model fit indicators hat were chosen in Chapter 6. As can be seen, most indicators are sufficient. The p-value is far above 0.05, which confirms the null hypothesis is that the SEM model fits the covariance matrix of the individual relations. Only the PCFI is not sufficient, which indicates that the model could be more parsimonious, for example by eliminating more variables or paths. However, in the view of the researcher, the model is sufficiently parsimonious. Eliminating more paths or variables would lead to a loss of information.

Table 7.10: TT model: Model fit indicators

Indicator	N	χ^2	**p-value**	**df**	χ^2/df	**GFI**	**CFI**	**PCFI**	**RMSEA**	**PCLOSE**
Boundary condition	-	low	>0.05	-	<2	>0.9	>0.9	>0.8	<0.1	>0.05
Model TT	194	72.394	0.113	59	1.227	-	.966	.626	.034	.840

Looking at Table 7.11, it can be concluded that 27% of the variance of the perceived Crowdedness is explained. In Section 7.1, we saw that Wi-Fi counts alone could explain 18% of the variance of perceived Crowdedness. Including more variables has improved the understanding of perceived Crowdedness substantially. Furthermore, Table 7.11 gives an overview of the total standardised effects of the predictor variables on the perception variables. These are the different causal paths that can be followed from one variable to the other. In this table, the latent variables are split up again.

Table 7.11: TT model: Total standardised effects

	Dependent				
Independent	Crowdedness	Safety	Comfort	Attractiveness	Atmosphere
Foreign	0.060	0.181	0.139	0.014	0.014
Camera count MA 15	0.191	-0.240	-0.185	0.045	0.044
Wi-Fi count MA 15	0.322			0.075	0.074
Visit_event	-0.199			-0.046	-0.046
Purpose	0.206			0.048	0.048
Activated		0.130	0.100		
Kermis				-0.135	-0.134
Crowdedness				0.233	0.231
P. Safety & Comfort		0.721	0.555		
P. Attractiveness & Atmosphere				0.691	0.686
Explained variance %	27%	51.9%	30.8%	47.7%	47.1%

In the visualisation (Figure 7.11), causal paths, indirect relations and correlations are visible. These will be explained per category.

Perception variables

As can be seen in Figure 7.11, perceived Safety & Comfort and Perceived Atmosphere & Attractiveness are included in the model as latent variables. These two variables have to strong correlation with each other ($\beta = .40$). Perceived Crowdedness has a causal relation to perceived Atmosphere & Attractiveness ($\beta = .34$). This relation is modelled as causal, because this increased the model fit. Hence, a this causal relation shows that pedestrians that visit an event first form their perception of crowdedness. Based on this perception, perceived Attractiveness and Atmosphere are assessed. There is no direct relation between perceived Crowdedness and perceived Safety & Comfort in this model. However, through the path of perceived Attractiveness and Atmosphere, there is a correlation ($I = 0.40 \cdot 0.34 = .136$). This correlation is positive, because higher Crowdedness lead to a higher perceived Atmosphere and a high perceived Atmosphere is correlated with a high perceived Safety & Comfort. Based on this model, it cannot be concluded that perception of Crowdedness influences perception of Safety & Comfort. It is found that they are correlated in the SEM model, which was not found in the bi-variate analysis.

Quantified crowdedness
To represent crowdedness, 15-minute Wi-Fi counts and 15-minute camera counts are included in the model. They correspond to the macroscopic flow variables *Density* and *Flow*. The camera counts have a large chunk of missing data, because there was no counting camera at the *Markt* location. Therefore, the model was tested without this variable as well. However, including the camera counts leads to a higher percentage of explained variance as well as a higher model fit.

Wi-Fi counts and camera counts are strongly correlated ($\beta = 0.39$), which is the relation that can be illustrated in a fundamental diagram. For perceived Crowdedness, the strongest predictor is the Wi-Fi counts ($\beta = 0.322$). However, the camera counts provide a significant contribution to explaining perceived Crowdedness as well, controlled for the Wi-Fi counts. This means that these variables both explain an aspect of perceived Crowdedness. The Wi-Fi counts explain the number of people that is perceived in proximity. The camera counts explain the perceived Crowdedness related to the movements of the crowd and the ease of movement. Analysing them together increases the percentage of explained variance. Perceived Comfort & Safety are influenced strongly by the camera counts ($\beta = -.33$). This shows that more movement around an individual lowers their perceived Safety & Comfort. Perceived Atmosphere & Attractiveness is indirectly influenced by the Wi-Fi counts ($I = .108$) and camera counts ($I = .064$) through perceived Crowdedness.

Socio-demographic, personal state & trip factors
Just as was expected from the correlations, purpose influences perceived Crowdedness. The emotional state *Activated* influences the perception of Safety & Comfort. This shows that being in an active, happy state of mind makes a person's perception of Safety & Comfort more positive too. In this model, emotional state does not directly influence perceived Attractiveness & Atmosphere. This is an unexpected result, which is assumed to be caused by the survey question formulating.

Next, familiarity is discussed. As can be seen in the model, being foreign influences perceived Safety & Comfort positively, as was seen in the bi-variate analysis. Also, *Visit Event* influences perceived Crowdedness negatively, which was concluded from the bi-variate analysis as well. However, there is also an indirect path from *Foreign* through *Visit Event* to perceived Crowdedness. This shows that foreign people have visited the event on average less often compared to Dutch citizens. Consequently, they perceive Crowdedness slightly higher. *Gender* and *Group size* were eliminated from the SEM, because compared to the other factors, their influence on the perception variables was insignificant.

Event & Environment factors
In the model, the dummies *Markt* and *Kermis* are visible. The third location, *Koopmansplein* is not visible in the model, because with modelling categories, the number of dummies included should always be N-1. The paths from *Markt* and *Kermis* to the perception variables show the strength of the relation relative to the location *Koopmansplein*. The location *Kermis* has a negative impact on perceived Attractiveness & Atmosphere ($\beta = -0.20$) compared to the location *Koopmansplein*. Since there is no path from *Markt* to perceived Attractiveness & Atmosphere, there is no difference in perception between these two locations. The correlation between *Markt* and Wi-Fi counts shows that this location was more crowded compared to *Koopmansplein* and even more crowded compared to the *Kermis*.

Sound intensity was eliminated from the SEM, because compared to the other factors, its influence on the perception variables was not significant. Furthermore, the binary value for day or nighttime had some problematic effects on the model.

7.5.2. Red light district best fit

In Figure 7.12, the final model for the RLD case is presented. This model has been edited to be more easily interpreted, the AMOS visualisation can be found in Appendix C. As can be seen, not all of the significant correlations from Figure 7.9 are included in this model. They have been tested in a SEM, as can be seen in Appendix C, but were not found significant controlled for the other variables. The model seems more complex than the TT model. This is caused, among other things, by the dummies for group type that were included. Moreover, more predictors seem to have an effect on the perception variables in this case. To increase the readability of this model, different parts will be highlighted in this section.

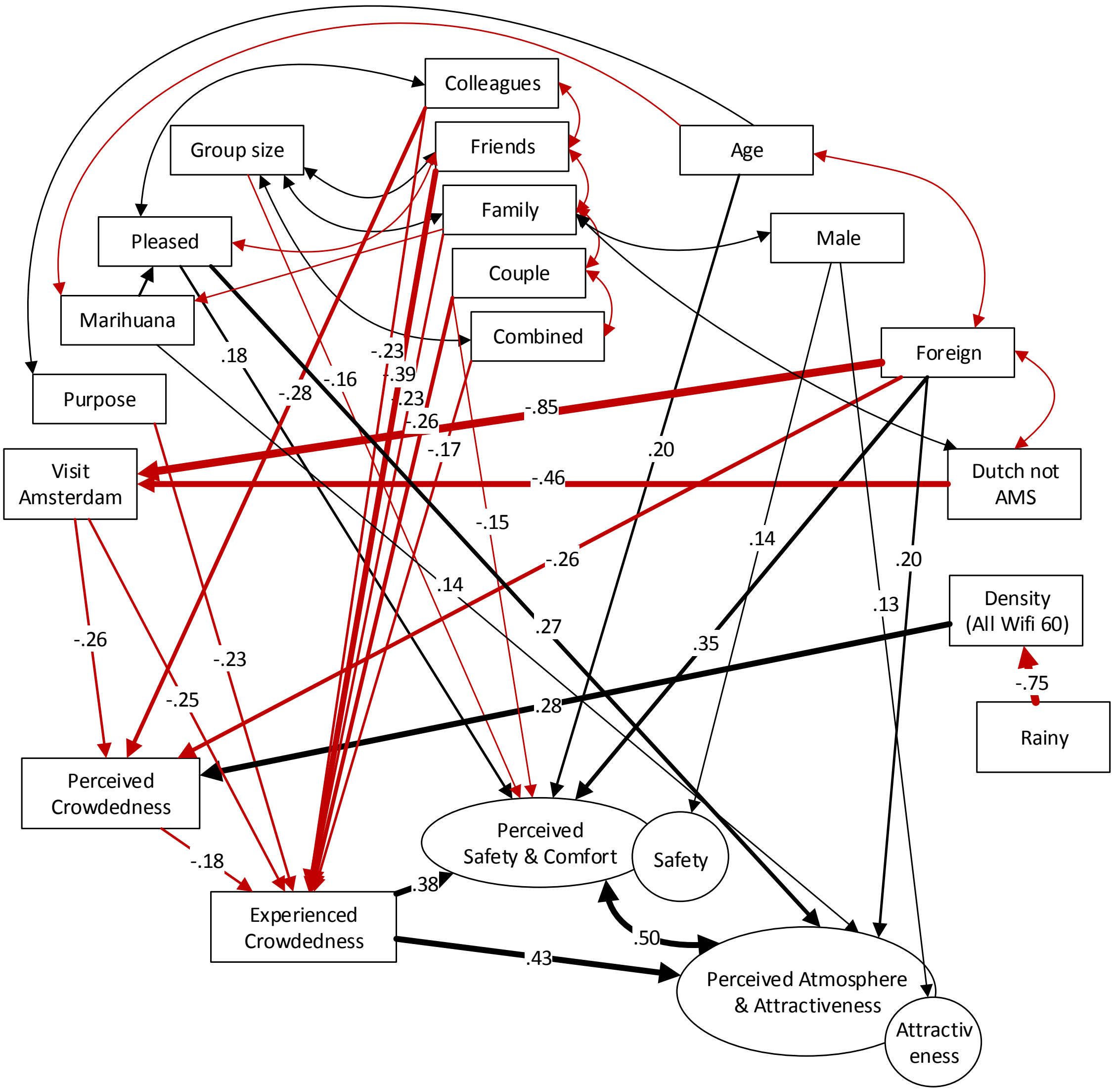

Figure 7.12: RLD final model: A visual representation. Line thickness represents strength of the relation. A straight line with one arrow is a causal path, a curved line with two arrows is a correlation. A red line stands for a negative relation, a black line for a positive one. Oval shapes are latent variables.

Model fit

In Table 7.12, the model fit indicators for the final model are presented. The model fit is very good. The p-value is far above 0.05. However, the Chi-square value is much higher than for the TT Festival. This means that there is more difference between the observed covariance matrix and the reproduced covariance matrix compared to the TT model. The PCFI for this model is higher than that of the TT, while the RLD model certainly does not look more parsimonious. However, since other fit indices have such a high score, the penalty for model complexity apparently does not outweigh the achieved goodness of fit.

Table 7.12: model RLD: model fit indicators

Indicator	N	χ^2	**p-value**	**df**	χ^2/df	**GFI**	**CFI**	**PCFI**	**RMSEA**	**PCLOSE**
Boundary condition	-	low	>0.05	-	<2	>0.9	>0.9	>0.8	<0.1	>0.05
Result	182	192.19	0.221	178	1.08	.918	.988	.761	.021	.997

Looking at Table 7.13, it can be read that 22.3% of the variance of perceived Crowdedness is explained. This is lower than the explained variance in the TT case. This is understandable when looking at Table 7.13. There are only a few variables that influence perceived Crowdedness.

Table 7.13: model RLD: total standardised effects

	Dependent					
Independent	Crowdedness	Experience	Safety	Comfort	Attractiveness	Atmosphere
Foreign	-0.039	0.222	0.275	0.408	0.213	0.276
Dutch_not_AMS	0.117	0.095	0.022	0.033	0.029	0.038
Age		-0.042	0.103	0.152	-0.043	-0.056
Gender			0.140		0.132	
WifiC15	0.246	-0.044	-0.010	-0.015	-0.013	-0.017
Visit_Amsterdam	-0.256	-0.207	-0.049	-0.073	-0.064	-0.083
Purpose		-0.230	-0.081	-0.119	-0.089	-0.116
Pleased			0.167	0.248	0.115	0.149
Combined		-0.165	-0.039	-0.058	-0.051	-0.067
Couple		-0.263	-0.155	-0.229	-0.082	-0.106
Family		-0.229	-0.058	-0.087	-0.091	-0.117
Friends		-0.392	-0.093	-0.138	-0.122	-0.158
Colleagues	-0.281	-0.183	-0.043	-0.064	-0.057	-0.074
Group_size			-0.098	-0.146		
Marijuana			0.025	0.036	0.116	0.150
Crowdedness		-0.176	-0.042	-0.062	-0.055	-0.071
Experience			0.238	0.352	0.311	0.402
PS & PCom			0.629	0.931		
PA & PAE					0.719	0.929
Explained variance %	22.3%	18.4%	41.6%	86.7%	53.7%	86.3%

Perception variables
As can be seen in the model, the construct of the perception variables is different than for the TT case. The main difference is the Experience of Crowdedness that is added to the model. Figure 7.13 shows that without this variable, it would not have been possible to connect Perceived Crowdedness to the other perception variables. What we see, it that there is a moderate negative relation between how crowded people think the district is and how pleasant they experience that level of Crowdedness. The reason this relation is not stronger is because many visitors still perceive the number of people as pleasant. The relation in reality is expected to be stronger, but it is not linear. The relation between experienced Crowdedness and the other perception variables is very strong, meaning that the more pleasant the Crowdedness is perceived, the higher levels of Safety e.g. are perceived. Through experienced Crowdedness, the effect of perceived Crowdedness on perceived Safety & Comfort is $I = -0.18 \cdot 0.38 = -0.068$ and the effect on perceived Attractiveness & Atmosphere is $I = -0.18 \cdot 0.43 = -0.077$.

Quantified Crowdedness
For measured crowdedness, only the global Wi-Fi counts are included in the model. In intermediate versions of the model, camera counts were included as well, but these did not have a significant relation to any of the perception variables, compared to the Wi-Fi counts. The reason for this is that the Wi-Fi counts and the

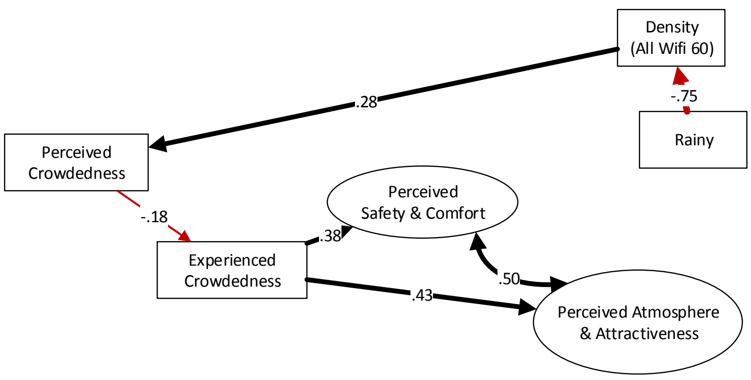

Figure 7.13: Final model RLD: Relations between perceptions and measured crowdedness

camera counts are very highly correlated ($\beta = 0.72$). A model using only camera counts would have been applicable as well, but the correlation with perceived Crowdedness would be slightly lower. This tells us that pedestrians' perception of Crowdedness is more related to Density (people nearby) than to Flow (people moving around). Also, the strongest relation with a time window of 60 minutes tells us that pedestrians' perception of Crowdedness is based on memory of a longer time period. The relation between the Wi-Fi counts and perceived Crowdedness is quite strong ($\beta = .28$), which means that people have a decent idea of the actual crowdedness.

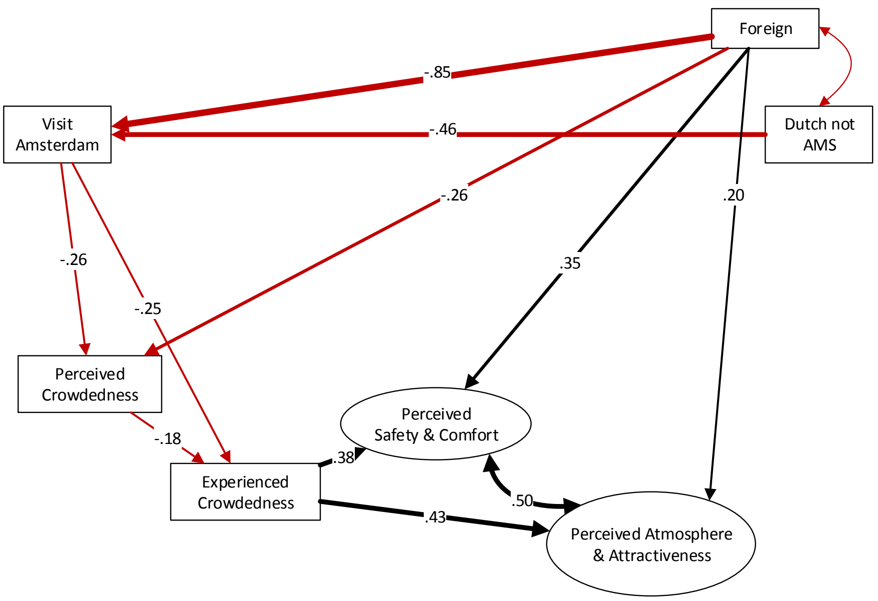

Figure 7.14: Final model RLD: Relations between perceptions and familiarity

Familiarity

In Figure 7.14, the predictor variables concerning familiarity are highlighted. We see that perceived Crowdedness is negatively influenced by the number of times a person has visited Amsterdam ($\beta = -0.26$). This means that familiarity with Amsterdam makes a person perceive Crowdedness lower. The effect of being foreign on perceived Crowdedness is modelled through two paths. The direct path shows that foreigners perceive Crowdedness lower ($\beta = -0.26$). However, since foreigners have visited Amsterdam less often, this effect is diminished. In Table 7.13, the total effect of the variable Foreign can be checked. This total effect is very small ($T = -0.039$). Being foreign does influence all perception variables directly or indirectly.

Furthermore, there is a variable present that represents Dutch citizens who do not live in Amsterdam. Since they have visited Amsterdam less often than people who live there, they perceive the Crowdedness higher ($I = 0.117$).

Concluding, familiarity has two effects. Crowdedness is perceived lower, because of familiarity with the number of people that are normally in the Red light district. Second, familiarity influences experience of Crowdedness and other perception variables negatively.

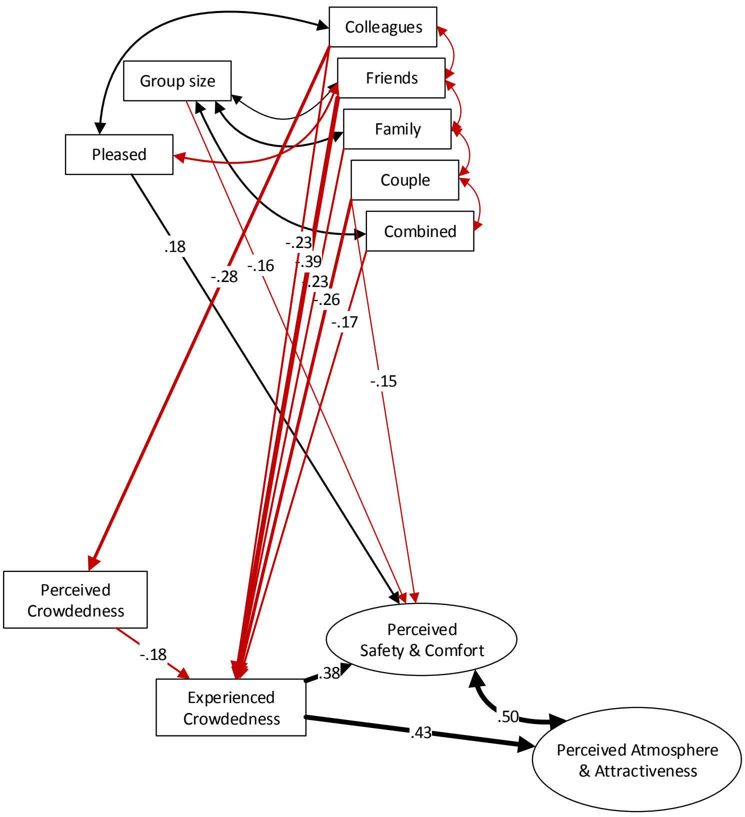

Figure 7.15: Final model RLD: Relations between perceptions and Group type

Group type

In Figure 7.15, the effects of *Group type* on perception are highlighted. Five group types are distinguished, which are compared to the control group *Alone*. One can see that groups have a more negative experience of Crowdedness compared to individual pedestrians. Also, *Group size* has a negative relation to perceived Safety & Comfort. This means that groups experience Crowdedness more negatively, because they fear they might lose group member and have to try hard to keep together. A group of colleagues perceive the Crowdedness lower than someone who is alone ($\beta = -0.28$). Additionally, Colleagues are the most pleased group. This can be interpreted by the goal of their visit, recreation. Remarkably, groups of friends seem to be the least pleased and also experience Crowdedness the most negatively. Finally, *Couples* perceive Safety & Comfort lower. This could be because a they do not know what to make of the red light windows.

Other Socio-demographic factors

For age, a moderate positive influence on perceived Safety & Comfort (β = .20) is found. This is a different finding than the result from the bi-variate analysis. There, a positive correlation with Crowdedness and a negative correlation with Atmosphere & Attractiveness was found. Apparently, these correlations can be explained away by the relation the variable *Age* has to other variables in the model. For example, *Age* is found to correlate negatively with being foreign and using marijuana, while it correlates with having an urgent purpose positively. In Table 7.13, the total effect of *Age* through various paths can be found. Indeed, a small negative effect on Experience, Attractiveness and Atmosphere is found.

An exception in the modelling rules is made, to connect *gender* to perceived Safety and perceived Attractiveness instead of connecting the variable *gender* to the latent variables perceived Safety & Comfort and perceived Atmosphere & Attractiveness. The reason for this modelling choice, it that it can be explained theoretically very well. In an area such as the red light district, it is logical that men would perceive the environment as more attractive. Furthermore, physical height plays a role in the difference in perception between men and women. Originally, the variable gender was connected to the latent variables, but in this case, the relation was not significant. As can be seen, the relation between gender and perception is not that strong, so it also could have been excluded without much loss of knowledge.

Other Personal state & trip factors

Other Personal state & trip factors that have not been discussed yet are the *Emotional state*, *Substance usage* and *Purpose*. The emotional state *Pleased* improves the perception of Perceived Safety & Comfort and Perceived Attractiveness and Atmosphere. The effect of alcohol was not found, but the effect of marijuana is positive on the variable *Pleased* and the perception of Atmosphere & Attractiveness. Marijuana is used for recreation, therefore these findings are quite logical. However, it would not have been unexpected to find a negative relation, because of paranoia. Both for emotional state and marijuana, it can be discussed whether they cause a positive perception, as is modelled, or simple correlate with this.

Trip purpose has a negative effect on experience of Crowdedness ($\beta = -0.23$). No direct effect on perceived Crowdedness is found, which means that pedestrians in this case to not overestimate the number of people, because they experience the number of people as unpleasant. A reason this relation was not found could be because everyone's perception of Crowdedness was quite high.

Event & Environment factors

Lastly, the event and environment factors will be discussed. Only *Rain* is included in the model, as a control factor for the measured crowdedness. This shows that rainy weather greatly lowers the number of people in the Red light district. No difference between the measurement locations was found. It is expected that the event settings actually have a large influence on perception, but these are not quantified and could only be found when compared to other event settings.

7.5.3. TT base, RLD base and mixed base

It has been attempted to create a model that would fit both events. However, these attempts have not been successful. The first attempt was started with a TT base using only the variables that were measured in both events, as was described in Chapter 6. For example, 15 min Wi-Fi data was used. Subsequently, the RLD data was loaded and tested. Step by step, non-significant paths were removed. After a few iterations, it became clear that some essential connections would not become significant, such as the relation between perceived Crowdedness and the other perception variables. Therefore, this model building process was terminated. For the RLD base, it was expected that the same problem would occur. In the TT survey, the question regarding the experience of Crowdedness was not yet included, therefore, the connection between perceived Crowdedness and the the perception variables cannot be made.

As an attempt to overcome this problem, a third option was tried, which was testing a combined data set, meaning that the data of the TT and the RLD were added together. With this combined dataset, was is possible to include variables such as experienced Crowdedness. Various combinations of models have been tried on this dataset. However, it was still not possible to come to a final model with a good model fit.

Even though the attempts to create a model applicable to both events have not been successful, lessons are learned from this fact. The way in which crowdedness is measured and quantified is very important. As can be seen by comparing these events, in one case a shorter time window on a local level relates best to perception of Crowdedness, in the other case a longer time window using global measurements is most applicable. This implicates that pedestrians' perception of Crowdedness is influenced by different underlying variables. It could be caused by the event size, the distance between locations or by the behaviour of the pedestrians (walking or standing still), but this cannot be concluded from the models.

8 Conclusions and recommendations

In this chapter, the conclusion of this research is given (Section 8.1). This answers the main research question. Next, in Section 8.2, the possible shortcomings of this research are discussed. Finally, in Section 8.3 recommendations for future research and recommendations for future practice are given.

8.1. Conclusions

The objective of this research was to gain a better understanding of pedestrians' perception of Crowdedness. The research question that will be answered in this section is:

"To what extent is a pedestrian's perception & experience of crowdedness influenced by personal, event and trip characteristics?"

This research based on two case studies shows how perception & experience of Crowdedness are influenced by personal, event and trip characteristics. Four main conclusions are drawn by comparing these case studies.

About the relation between perception of Crowdedness and the other perceptions and experiences that relate to Crowdedness, the following can be said: For both events, it was found that perception of Safety and comfort are so similar, that they can be seen as indicators for one latent variable. Likewise, Perceived Attractiveness of the environment and Atmosphere form one latent variable. The effect of perceived Crowdedness on the other perceptions is different for both cases. In the TT model, higher perceived Crowdedness leads to higher perceived Attractiveness & Atmosphere, meaning that Crowdedness has a positive effect on the perceived Attractiveness & Atmosphere. No effect of perceived Crowdedness on perceived Safety & comfort was found. In the RLD model, there is an indirect negative influence of perceived Crowdedness on perceived Safety, comfort, Attractiveness and Atmosphere. Furthermore, the experience of Crowdedness is negatively influenced by the perception of Crowdedness, meaning that a person who thinks it is more crowded also finds the number of people less pleasant.

Concerning the relation between quantified crowdedness and perceived Crowdedness, the following conclusions can be drawn: There is a relation between measured crowdedness and perceived Crowdedness. In the TT case, this relation is best brought forward by using 15-minute local Wi-Fi counts and 15-minute camera counts. For the Red light district, a strong influence of 60-minute global Wi-Fi counts on perceived Crowdedness was found. For both cases, Wi-Fi counts are more closely related to perceived Crowdedness than camera counts. This result is logical, since crowdedness is often quantified using the variable density ($ped./m^2$), which in this case the Wi-Fi counts represent. In the TT case, a strong negative connection between camera counts and perceived Safety & Comfort was found. This can be interpreted as follows: The more movement there is around a person, the less comfortable and safe they feel. Other ways to quantify crowdedness where less related to perception variables than pure Wi-Fi and camera counts in this research.

Another interesting finding from this research shows the different ways in which familiarity influences the perception and experience of Crowdedness. In both case studies, familiarity with the event (TT) or the city (RLD) made people perceive the level of Crowdedness lower, but also caused a more negative perception of Atmosphere & Attractiveness. This shows that expectations concerning an event influence a person's perception. Interestingly, the RLD model also shows that foreigners perceive a lower level of Crowdedness. However, since foreigners are on average less familiar with the city/event, the total effect of being foreign on the perception of Crowdedness is very small. In both cases, foreigners have a more positive perception of Comfort & Safety. At the Red light district, the overall experience of Crowdedness of foreigners is much more positive.

Finally, an important finding is made by comparing the events and event locations researched. At the TT Festival, three locations were researched; one location was mainly a passageway, one location was a passageway near the main stage and one location was a relaxed residing area with many stationary pedestrians. The TT model shows that controlled for the Crowdedness indicators, the perception of Atmosphere & Attractiveness of these locations is different. At the Red light district, three locations were researched as well, namely a very narrow alley, a street along the canal and an alley that is an exit/entrance of the Red light district. However, no difference in perception was found between these locations. This learns us that the function of a location is important with relation to the perceived Attractiveness & Atmosphere, while other location characteristics, such as width of the passageway did not yield significant differences in this research. Furthermore, for the Red light district global Wi-Fi counts are the best predictor of perceived Crowdedness, while for the TT Festival, local Wi-Fi counts are the best predictor. This indicates that it is important to think about the area for which Crowdedness needs to be captured. This depends on the size of the event, the location types, the behaviour of the people (walking around or standing still), the distribution of Crowdedness over the event and the characteristics of the rest of the event.

8.2. Discussion

In this discussion, the limitations of the chosen research method will be discussed. Especially, there will be a focus on how this research can be improved, given the knowledge about the results found. This research had a broad focus, in order to bring physical and psychological research together. The methods applied are perhaps uncommon, since there is no proven method for combining monitoring data with perception data in one model. There are many facets within this research, which could all be performed more thoroughly and could profit from the expertise of someone from that particular research field.

Several aspects of the research will be discussed, namely the theoretical framework chosen, the survey as a data collection method, the design of the survey and the formulation of survey questions, the monitoring data collection and processing, the metadata collection and processing, the limitations of Structural Equation Models and finally other modelling methods that could have been used.

8.2.1. Theoretical framework

Looking back at the theoretical framework it can be concluded that the theorised relations between the categories were identified correctly. For example, from all four categories, factors that explain perception and experience of Crowdedness could be found. Also, the influence of socio-demographics on personal state factors was found. For example, being foreign influences familiarity and older age influences trip purpose and drug usage. Additionally, the effect of Event & Environment factors on measured crowdedness is illustrated in the models by the factors Location and Rain. Despite this, the theoretical model can also be improved. In Figure 8.1, a new proposed theoretical framework is presented.

The new framework has same relations as the original framework, but a few things have been changed. First, perception and experience are more clearly distinguished. In this research, this distinction has not always been clear. In hindsight, also looking at the final models, the perception of Crowdedness is quite different from the other perception variables. The perception of Crowdedness is modelled and interpreted as a perception that is formed subconsciously, but is biased as to a person's background. The other perceptions could also have been named feelings or experiences. They are formed more consciously and contain a value judgement about the Crowdedness perceived. From the survey question regarding perceived Crowdedness, it cannot be determined yet if this perception is a positive or negative judgement. Crowdedness can either be seen as something good or bad. For Safety, Comfort, Attractiveness and Atmosphere, it is clear that a higher score relates to a better experience.

Also, it can be discussed whether emotions are the cause or the result of the Crowdedness experience. Therefore, in this revised model, a clear feedback loop is included from experience of Crowdedness to Per-

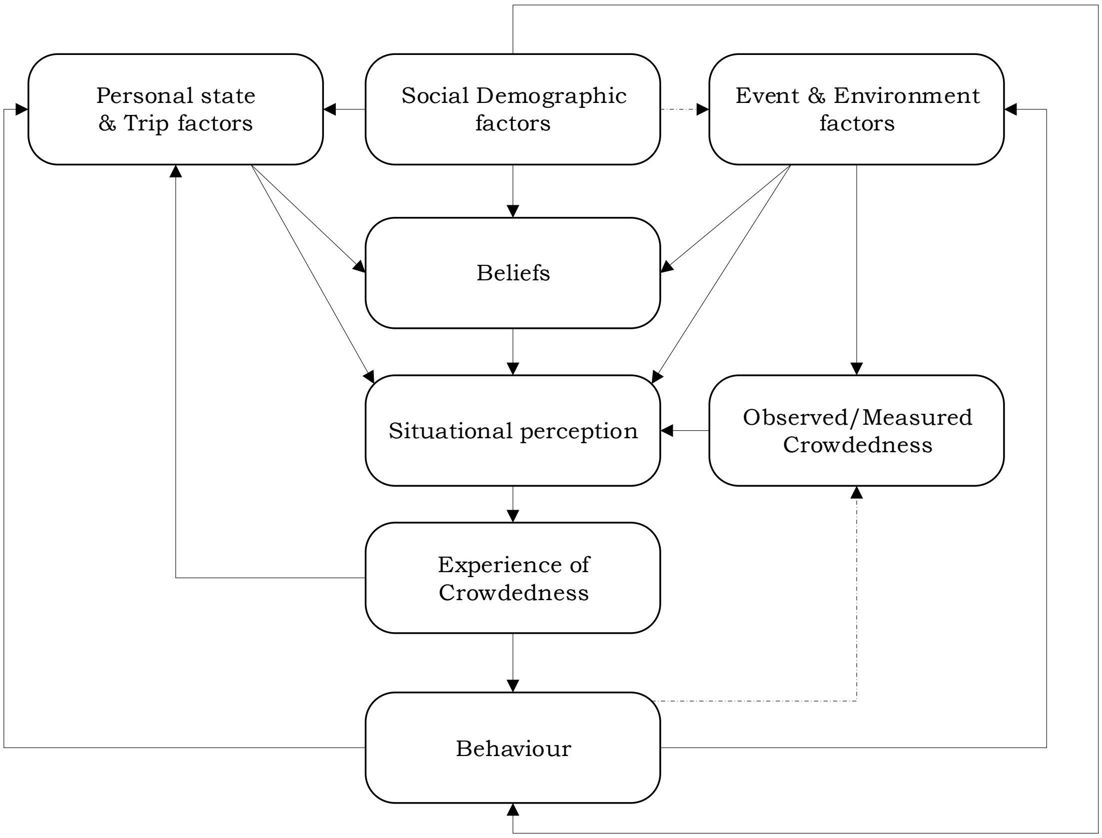

Figure 8.1: Revised theoretical framework. Dotted line is applicable only on crowd level

sonal state & Trip factors. Modelling this in a SEM is possible, but it makes the model non-recursive, thus making the model estimation more complex.

This model concerns the perception and behaviour of an individual, but can also be applied on the crowd level. In this case, the dotted line is relevant as well. The socio-demographics of the crowd, or the crowd composition, could influence the situational perception through the Event & Environment factors. Also, the behaviour of the crowd can change the observed/measured Crowdedness.

Furthermore, the importance or beliefs, or expectations should not be underestimated. This was noticeable while conducting the surveys. Respondents often said something like: "Well, compared to yesterday it is not that crowded." In this revised model, Personal state & Trip factors and Event & Environment factors influence beliefs and expectations, but also influence the situational perception directly. The difference can be illustrated with an example: Loud sounds could directly influence the perception of Crowdedness subconsciously, but the symbolic meaning of a location is interpreted by someone's beliefs. In this research, the scope was limited to perception, beliefs and behaviour were excluded. However, beliefs or expectations are probably an important factor to include in order to understand a person's perception.

8.2.2. Limitations of survey as a data collection method and execution

Although a survey was deemed to be the most effective way to discover personal characteristics and perceptions, the survey method has its shortcomings.

One drawback of conducting surveys on the street is that the surveyor can influence the results. This effect was tried to be minimised by approaching people for the survey as randomly as possible. However, only a certain type of person is likely to respond. On the other hand, this is also a problem for surveys that are filled in at home. In this research, people who are in a bad mood or in a hurry are expected to be less likely to respond, while their perception would be interesting. Furthermore, a bias arises when a respondent asks for an explanation for a certain question. This extra information is not given to all respondents and another surveyor might explain a question differently than the other. This was tried to be prevented by letting people interpret the questions themselves and by discussing beforehand with fellow surveyors which explanation should be given.

By randomly approaching people, another problems arises. In this research, some groups are under represented. For example, in the TT case, there were not enough foreign participants. In the RLD case, there were not enough Dutch citizens and residents of Amsterdam. This made it more difficult to analyse the differences between these groups. When a large dataset was gathered for all groups, it would have been possible to estimate separate models.

The reason why the relation between perceived Safety & Comfort and Crowdedness was not found directly could be because the researched locations were not crowded enough to make it seriously unpleasant and uncomfortable. However, it is impossible for a surveyor to research dangerously crowded situations. Also, it is not possible to conduct surveys close to a stage, since it is difficult to communicate there because of the noise and it is difficult to move around.

8.2.3. Survey design

In a survey, the resulting answers are largely dependent on the survey question formulation. The survey questions regarding Safety and comfort could have been made more specific, to avoid different interpretations. In the evaluation of the case studies, it became clear that the questions regarding Comfort and Safety were formulated in a vague manner. Respondents often pointed out that they felt safe, because they had seen police officers or hosts. Also, some respondents felt safe because there were many people around. For Comfort, separate questions for physical, physiological, facilities, security officers and social aspects could have been included. Now, respondents often asked what was meant with Comfort.

Also, more overlapping questions regarding Safety and Comfort could have been posed. The survey design did not include a real measurement model for latent variables, this construct was only thought of later. Addressing multiple questions to the subject of Safety, such as was illustrated in Chapter 6, could result in a stronger relation with perceived Crowdedness. However, in this case it has to be considered that the survey becomes longer.

Some of the factors that were expected to influence the perceived Crowdedness were not found significant in the analysis. For example, urbanisation level. A reason for this could be that Municipality, which was asked, is not the best way to determine this. For every Dutch municipality, the CBS urbanisation level was connected to the survey data. However, municipalities can have a large variation in urbanisation level locally, which is not accounted for in this way. The question could have been posed differently. For example, respondents could have been asked to give a grade to the level of urbanisation to their own residence. Or, they could have been asked if they live in a big, medium or small city. Then, urbanisation could also have been determined for foreigners.

Besides that, the effect of alcohol usage was not found. This was unexpected, because in previous studies, this effect was found. A possible explanation would be that the question is not precise enough. Instead of only addressing which stimulants are used, the amount could have been questioned. Many respondents who had drunk one beer during their dinner where now categorised with people who had trouble having a conversation because of their intoxication.

The question regarding emotional state could have been posed differently. People were not always able to select the emotion that they actually felt. For example, some people said they felt confused or hungry, which is not accounted for. Also, it seems as though foreigners chose the emotion *Happy* most, because this was a word that they recognised, while other words might be difficult to understand in a person's second language. However, the division of emotional states in *Pleased* and *Activated* seems to be effective in the RLD case. Still, it could be considered to leave out some similar emotions, like *Happy* and *Glad*.

In the TT case, the survey question regarding emotional state was still a multiple answer question, which made analysing the answer set more difficult. Therefore, this was changed for the RLD case. The same goes for the Group type. It is expected that no results were found for this factor at the TT, because it was a multiple answer question which was difficult to analyse.

8.2.4. Limitations of using Wi-Fi sensors and counting cameras

The monitoring data used had some drawbacks. First, there was some missing data which had to be corrected. No ground truth was used to validate the counts, which makes the research more unreliable. Many steps had to be taken in order to come to the variables that were chosen to describe Crowdedness. It is expected that a stronger relation could have been found when these steps where undertaken with more precise filtering methods. However, in this research, there was limited time available for data processing.

Furthermore, the filtering of the data was done in different ways for both events, which makes it more difficult to compare the results. For the TT case, the Wi-Fi counts were determined for overlapping time windows of three and fifteen minutes, while at the Red light district, they were collected every minute. Also, for the TT case, a conversion rate was calculated by the researcher, while for the RLD case, the conversion was already done, but it is uncertain how it has been done. For the RLD case, the monitoring data is less connected to the perception variables. If other filtering steps have been applied, these results might have been different.

The reason why the counts, and not the actual macroscopic flow variables (Density/Flow) are related to the perceived Crowdedness is unknown. It is assumed that this is because these variables are the least altered. Attempts to calculate density and flow were less successful, because of uncertainty in determining the area that a Wi-Fi sensor covers and the effective width of passageways.

8.2.5. Metadata collection and processing

The light and sound data had a few problems. First, the measurement device (a mobile phone) was not accurate enough to measure light intensity at nighttime. The flashing lights of the stages were not detected with this measurement method. As could be seen from two measurements taken only two minutes after each other, the values can be vary greatly every minute. Therefore, measurements at intervals of 30 minutes are not sufficient to capture the variance in light and sound intensity during an event. Also, the orientation of the measurement device was very important, for example, pointing a device towards a stage or the other way, which was not taken into account.

8.2.6. Limitations of Structural Equation Modelling

It was determined that to answer the research question, a Structural Equation Model had to be applied. However, Structural Equation Models are based on certain assumptions and rules.

For Structural Equation Models, it might be discussed that it is difficult to determine whether a model has reached a sufficient level of fit. In literature, many model fit indicators are provided, but there is no consensus amongst researchers on the boundary values for these indicators. Therefore, to ensure a good model fit, multiple model fit indicators were collected. In this way, it is ensured that the model satisfies the goodness of fit and is not overly complex. Furthermore, the modelling steps were determined beforehand and followed. However, with a SEM, no optimisation takes place, therefore it is never sure whether the best model for the data is found. On the other hand, this has the benefit that a model is not over-fitted to one dataset, because it should always be based on theory.

One important assumption in the model is that perceived Crowdedness causally influences the other perceptions. This effects the results significantly, because all factors that influence perceived Crowdedness now influence the other perceptions as well. Furthermore, the chosen construct with latent variables can be discussed. This construct was chosen to make the measurements of the perceptions more reliable, to make the connections stronger and to simplify the model. However, the perception of Safety & Comfort and the perception of Attractiveness & Atmosphere are not always influenced by all the factors in the same way. For example, in the RLD case, an exception was made for the effect of gender. In any case, it would have been better to think about latent constructs for perception variables before creating a survey.

Other than that, the modelling programme used, AMOS, can only find linear relations. For this reason, the negative relation between a *very crowded* perceived location and perceived Safety and Comfort might not be found. Also, AMOS only treats the data as either interval/ratio or binary data. The perception data was Ordinal, for which separate statistical methods are needed. However, in the field of psychological research, this type of Ordinal data is often used in Structural Equation models. The reason this is allowed, is because perceptions are in reality a value on a continuous scale, only the measurement method is ordinal. To include non-linear relations and use ordinal data, the software package Mplus could have been used.

In case of the TT event, there was missing data for the camera counts of one location. The effect this has on the model is unsure. It makes the relation of camera counts to perception more uncertain, since it is tested for a smaller sample.

8.2.7. Other models

To find the relations presented in the theoretical framework, another model could have applied as well, namely a Hybrid choice model. This model could have included behaviour or perceptions as an outcome of the other factors. The reason why a SEM was chosen, was because it was necessary to first increase knowledge about perception of Crowdedness and the factors that influence it, before a predicting model can be created. With the knowledge of this research, it becomes easier to make a selection of factors and perceptions that need to be included in such a model.

8.3. Recommendations

Finally, recommendations for future research and practice are given in this section. These are based on the conclusion and discussion provided in this chapter.

8.3.1. Recommendations for research

Data collection & processing

- In a follow up research, a survey should be designed to include measurement models for each of the perception variables, meaning that multiple questions that address different aspects of a perception such as Safety are included. For Safety, questions could be split up in social Safety, physical Safety and Safety by (police) control. By In this way, the effect of Crowdedness on Safety can better be distinguished.
- It is recommended to further research the effect of light and sound on perceived Crowdedness. In the TT case, some promising results were found. If light and sound data are chosen to take into account, accurate sensors on fixed locations and with fixed or predetermined orientations performing continuous measurements are required. For both light and sound, intensity can be measured, as well as fluctuations in intensities.
- To be able to compare different groups better, a larger dataset needs to be gathered. As a guideline, around N=100 respondents per social group are required. Then, it is possible to create separate models for different social groups. For example, in the RLD case, this would be necessary to understand the difference in experience between foreigners and Dutch citizens better.
- The question regarding substance usage has to include amounts for alcohol consumption. For example an answer set with ranks can be used (None, 1-3 drinks, 4-6 drinks, more than 6 drinks). This proved to work quite well for age. Also, to the knowledge of the researcher, none of the respondents chose not to answer the question about substance usage. Therefore, it seems to be not as sensitive a subject as was expected.
- When there is more time available, the processing of the monitoring data should be performed more thoroughly. Validating the data by comparing camera counts to manual counts would be appropriate. Methods for flow and density estimation such as described by Yuan et al. (2016) can be used. For this, the raw data including the MAC addresses is required. By using an algorithm that can pair MAC addresses between two Wi-Fi sensors, the number of devices between these sensors is determined. Then, a counting camera has to be used to find a penetration rate of the combined Wi-Fi sensors.
- Determining the width of the passageway more accurately can be done by simply bringing a tapemeasure along during the research. The width has to be measured on a few points in the neighbourhood of the counting camera, since it may vary due to obstacles. Determining the area of a Wi-Fi sensor is more complex, since it varies with the number of devices measured.
- It is also useful to include in the survey whether a person was standing still or walking. If a person is walking, the direction of the movement has to be registered as well.
- To research areas that are not suitable for conducting surveys, a mobile phone application might be used.

Analysis

- More different types of events can be researched to gain a better understanding of the factors that play a role in different settings. In this case, location characteristics should be quantified consistently. For example, location function, location size, the proportion of people moving/standing still, the activities offered and the atmosphere should be noted.

- A hybrid choice model could be developed when a more concrete tool to predict perceived and experienced Crowdedness is desired. The factors density (Wi-Fi counts), flow (camera counts), country of origin, familiarity, trip purpose, group, emotions and location characteristics should be considered. Furthermore, a model that includes expectations and/or choice behaviour with relation to perception of Crowdedness can also be created based on the revised theoretical framework.

- To develop a new Level of Service system, piecewise linear regression can be used (Papadimitriou et al., 2010) to distinguish categories of Crowdedness that are perceived. This is a form of regression where breakpoints are allowed in a straight line to better fit the data. Papadimitriou et al. (2010) found that car drivers only perceived three categories of Crowdedness, while the LOS system had six categories.

8.3.2. Recommendations for practice

For both events, other results are found. Recommendations to increase pedestrians experience are given in this section. Furthermore, some recommendations for research can be considered to be executed by the event organisers, crowd managers and municipalities.

In both cases, it would be a good idea to develop a perception based LoS system. If Wi-Fi counts or camera counts are available these can be used to give an indication of the perceived and experienced Crowdedness. Additionally, knowledge about the location function and the crowd composition present can be used to further specify whether the density and flow at this location are on a desirable level. For example at the TT festival, a location such as *Markt* can have high levels of Density without decreasing the positive experience of Crowdedness, thus a high level of service. However, a high level of flow at this location might decrease positive experience of Crowdedness and thus the user based Level of Service. For the RLD case, a high flow might be an indicator of a more positive experienced Crowdedness, because it is possible to move and the pedestrians are not impeded. This all needs to be researched further. This research was exploratory and therefore does not yet provide concrete answers. Still, recommendations for developing a concrete system can be given.

Location function: Identify and separately assess the Crowdedness at different locations based on the function of that location. Separate walking areas, standstill areas and combined areas. Also identify the activities that are present at these locations.

Crowd composition: At every location or event, different groups of people are present. These different groups (people with recreational purpose vs people with an urgent purpose, familiar vs unfamiliar people, pleased vs unpleased people, large or small groups) have different perceptions of Crowdedness. Therefore, knowing who is present and in what proportion is very important. If this is known, user based Level of Service can be determined looking at the relations found in this research.

Other than developing a system that uses monitoring data, it can be useful in both cases to develop a mobile application for real-time research and crowd management. Such an app, that can also provide (real-time) information from the crowd managers to the people, can be used as follows: A person an occasion receives notifications, asking them one or two questions about their experience. Furthermore, a person can choose to give a notification when they do not feel comfortable or pleasant at a location. This notification system should be as simple as a few clicks and has to be anonymous, but does need to include location. It is not necessarily meant for real danger, because in this case, the police should be directly alerted. However, if many notification come in from one location, it can become clear that the atmosphere there is not optimal and action might be taken to improve this and to prevent anything from happening.

TT Festival

Overall, people perceived the Crowdedness at the event quite positively. The results of this research can be used to estimate perceived Crowdedness, Safety and comfort from monitoring data in future years. The best indicators to estimate perception and experience of Crowdedness from monitoring data are Wi-Fi counts over 15 minutes and camera counts with a 15 minute moving average. Together, they give insight in perceived Crowdedness, Safety and comfort. A next time, areas that are more troublesome could be researched, like Doevenkamp, using the mobile phone application method described above. Doevenkamp was a stage area that attracted younger people, because of the artists that performed here. During the event, this location was the main concern of the crowd management. This location was at times very crowded, which could be troublesome. Furthermore, there was speculation on social media about a fight that was planned at that location.

Red light district

Overall, the perception of the Red light district was positive. However, it is important to keep in mind that there is a major difference between Amsterdammers, Dutch citizens and foreigners.

The experience of pedestrians can be improved if the Crowdedness becomes lower. This can be achieved by effective crowd management. The efforts of the hosts seem to be effective in keeping people in line and improving the flow in the crowd, although this is rather a personal observation than a result of this research. In future research, the effects on perceived Crowdedness when hosts are present or not could be specifically researched.

A recommendation regarding the monitoring system is to gain more insight in the filtering steps that are applied to the counts, because they seem to influence the results that are found. Furthermore, it is recommended to gather Wi-Fi data for time window of three and fifteen minutes. In this way, the Wi-Fi counts are less similar to the camera counts and can provide some other insights. To understand pedestrians' perception and experience of Crowdedness now, the best indicator from the monitoring data gathered are the global Wi-Fi counts with a 60 minute moving average applied.

A final recommendation for the Red light district is to think about the division of functions over the various streets and alleyways. Based on this research, it cannot be concluded how these functions should be divided (activities/entertainment placement, one or two-directional passages), although this research does show that Amsterdammers perceive the Crowdedness higher than foreigners and this lowers their experience. For them, passageways with lower Crowdedness are desired.

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A

Travel behaviour models

In this Section, possible modelling paradigms and their accessory conceptual and measurement models are discussed. To describe travel behaviour, Kroesen (2017b) distinguishes six paradigms: Econometric, Psychological, Marketing, Geographical, Biographical and Sociological. In travel behaviour research, the Econometric paradigm is often used, because it lends itself well to choice modelling. It assumes a participant is completely informed and makes a rational decision. In Figure A.1, an example of a conceptual model is shown. In previous researches, this type of model was applied to develop a route/activity choice model for pedestrians (Galama, 2016) (Ton, 2014). Psychological attitudes can be taken into account, but are often neglected. The weights of the alternatives can be found out using a stated preference method, where participants are asked to choose between a number of alternatives which have different attribute values. Other than that, revealed preference can be used. In this case, the researcher has to give values to the attributes that are taken into account.

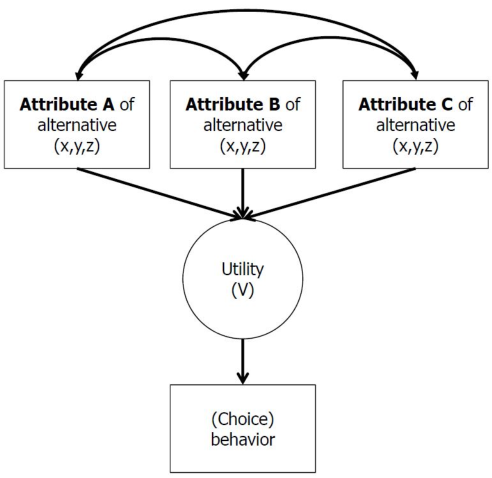

Figure A.1: Econometric conceptual model

Another paradigm that could be applied for this research is the psychological one. This focuses on the reason behind decisions, and therefore has a high explanatory power. However, the conceptual models are more complex and do not often lead to surprising insights. Compared to a discrete choice model, the causality between factors is less clear. Some famous psychological models are the Theory of Planned Behaviour, the Theory of Reasoned Action Fishbein and Ajzen (2011) and Social Learning Theory (Bandura, 1971). The theory of reasoned action takes behavioural factors, social norms, habit and perceived control into account. Social learning theory focuses on cognitive, environmental and behavioural factors. Psychological models can be structured using Structural Equation Modelling, as shown in A.2. This method was used by Hoon Kim et al. (2010) for their study at a festival to test the relations between perceived value, satisfaction and intention to revisit.

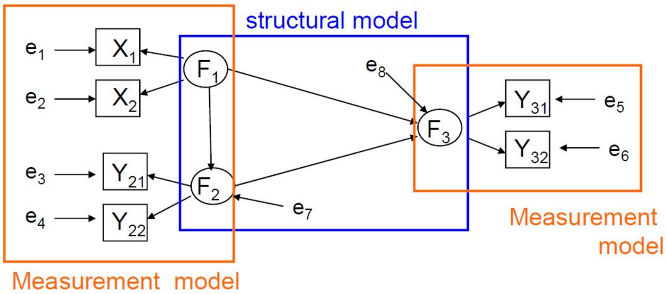

Figure A.2: Structural Equation Model

Choosing between these paradigms will have a very large influence on the outcomes of this research. However, since this research aims to identify the perception of the pedestrians, this seems to fit a psychological model better. However, if choice behaviour is to be modelled, an econometric approach is needed. Therefore, a combined model should also be considered. In Figure A.3, a conceptual model is shown that uses both choice modelling and structural equation modelling. The utility of a choice is determined through observed behaviour and the latent variables, such as perceptions are measured using Likert scale questions. According to Chorus and Kroesen (2014), the most popular type of Hybrid choice model, the integrated latent variable discrete choice model, is useful to gain a better understanding of the behaviour, but is not useful to determine policies. For example, a policy can try to change people's perception on comfort of public transport, but the relation between perception and behaviour goes both ways. People tend to have a biased view on the transportation mode that they already use. For this thesis project, it would be possible to apply a hybrid choice model, since the objective is to gain more insight in the perceived LoS of pedestrians at mass events and not to determine policies.

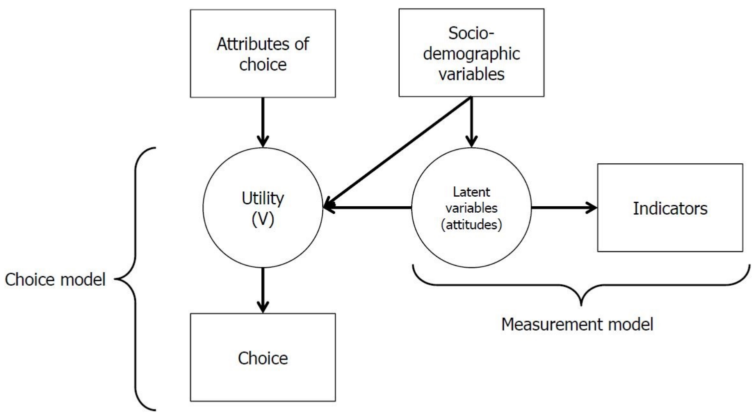

Figure A.3: Combined econometric and psychological model

In conclusion, the psychological paradigm seems most suited to apply for this research, since this paradigm can best capture perception. In econometric models, utility is not dependent on what information input a person receives, because it is assumed that a person bases his/her decision on complete and objective information. Therefore, a Structural Equation Model will be applied in this thesis project.

A.1. Psychological theoretical frameworks

In order to shape a theoretical framework, a few behavioural theories are elaborated in Appendix A. It is chosen to find a framework in the Psychological paradigm (see also Appendix A, since this offers the most options to include all factors mentioned in Section 2.6. The following renowned theories are discussed: The theory of Reasoned Action (Fishbein & Azjen, 1980), the theory of Planned Behaviour (Azjen, 1985), Social Learning theory (Bandura, 1977) and Habit (2006, Verplanken). The theory of Planned Behaviour will be applied for this research, for which a brief explanation isfound in the following section.

Theory of reasoned action

The theory of reasoned action was introduced by Fishbein and Azjen in 1980. It includes beliefs, attitudes, intention and behaviour as consecutive factors in a process to choose behaviour (see Fig A.4). Beliefs are divided into behavioural beliefs, which are the cost and benefits a certain type of behaviour could have according to the beliefs of the person. Together with evaluation the outcome, this forms a attitude towards this behaviour. Attitude is defined by Thurstone (1931) as: “the affect for or against a psychological object”.

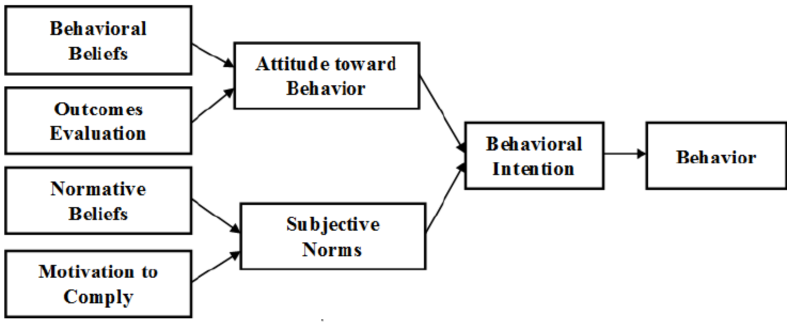

Figure A.4: The theory of Reasoned Action

Normative beliefs are the social norms that the person perceives. Together with the motivation to comply, this forms the subjective norms of this person. The intention, the behaviour that the person in question plans to do, is determined by the attitude towards behaviour and the subjective norms. Which of those two is more important depends per person. Furthermore, the intention will not always lead to the actual behaviour. However, in this theoretical framework, this cannot be seen clearly, because there seem to be no other factors involved.

Theory of planned behaviour

In order to take the earlier mentioned factors into account, the theory of planned behaviour was created as an elaboration on the theory of reasoned action. It has a new factor build into the framework, namely control beliefs and perceived behavioural control (see Figure A.5). The importance of this factor in behaviour is deemed very influencing, but has been described with various definitions that are not completely the same. Self-efficacy, helplessness, powerless, choice, decision freedom, locus of control and autonomy are some examples. The meaning of control beliefs according to Fishbein and Ajzen (2011) is the belief of a person that they have control over the things that happen in their lives. In other words, perceived behavioural control describes "a general sense of personal competence or perceived ability to influence events (e.g., Burger, 1989; Rodin, 1990)”

Perceived behavioural control influences the intention, but also the difference between intention and behaviour. Actual control is added as well. Background factors are shown to have influence on behavioural, normative and control beliefs. Additional factors that could be added are mentioned as well. Triandis (1977) adds habit and emotion to the framework. Fisher and Fisher (1992) add knowledge and Bagozzi and Warshaw (1990) add motivation and goal pursuit.

The term Affect is used to describe general mood and emotion state. It is different than attitude, which is an evaluation of a psychological object in terms of pleasant/unpleasant or like/dislike. Affect can influ-

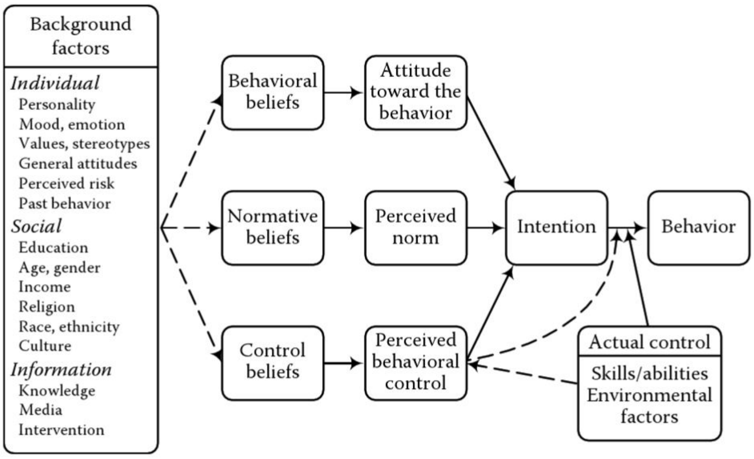

Figure A.5: Theory of planned behaviour

ence attitude, but it is assumed to be an indirect influence. Moods can be distinguished between pleasant and unpleasant and activation and deactivation (see Figure A.6. For example, feeling tired is an unpleasant, deactivated emotional state. When affect is included in a model, it should be included with the background factors. The same is true for including knowledge, habit and goal pursuit.

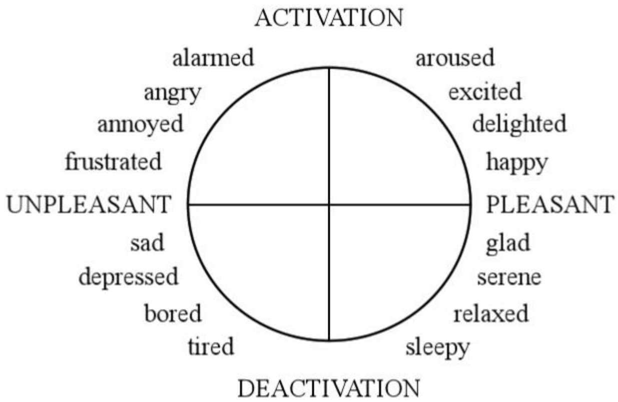

Figure A.6: Affect: Emotional states

Social learning
In 1971, Bandura introduced Social Learning theory. This theory explains behaviour as the outcome of a cognitive process, where learning is an important aspect. According to Bandura, behaviour can be learned by direct experience, observation of behaviour and by vicarious reinforcement. Vicarious reinforcement is a learning method where good behaviour is rewarded and/or undesired behaviour is punished. The information that is extracted from an observation depends on the cognitive processes at work. *Attention* is the first step in the learning process and is influenced by the perception and assumed importance of a subject. *Retention* is the ability to remember certain behaviour. *Reproduction* captures the cognitive and sensimotor abilities to implement the remembered behaviour. Finally, *Motivation* is determined by environmental and social factors and the expected outcome of the behaviour. This theory seems less applicable to this study, since the learning process is not a focus point, and only the motivation part includes those factors that are of interest.

Habit
In previous researches, the theory of Planned Behaviour proved to not be fully able to explain the difference

between intention and actual behaviour. Therefore, Aarts et al. (1998) added the missing link: Habit. Habit formation involves the creation of associations in memory between actions and stable features of the context in which they are performed. Habits may be triggered by environmental cues, such as time of day or location, by internal states, such as particular moods and by the presence of typical interaction partners (Verplanken and Wood, 2006). Lastly, habits develop by the systematic experience of rewarding consequences. In other words, habits have a function in achieving a certain goal, that have been proven to work in the eyes of a persons that performs these habits (Aarts et al., 1998). Habit could be an important factor to take into account, since the factors that trigger habits are all present at an event (environment, location, personal state, group of friends). It could also influence a person on all three levels of decision making. On a strategic level, the decision to go the an event can be made because an individual goes to the event every year. On the tactical level, Srinivasan and Mahmassani (2000) show that people would rather use routes that are familiar with. The same is assumed to be probable for typical festival activities, such as visiting a certain stage multiple times. When possible, it would be useful to take habit into account in a theoretical framework.

From this short analysis, the theory of planned behaviour seems most applicable to this research. It has a clear structure that can take into account the environment, social demographics and personal state to determine perception. The social learning theory focuses on the cognitive process and the ways of learning, which would be interesting to know. However, it will require much knowledge of an individual and is therefore not realistic to achieve. Habit can be taken into account additionally, as it can explain part of the behaviour that individuals exhibits at an event.

B

Regression and scatter plots

B.1. TT Festival

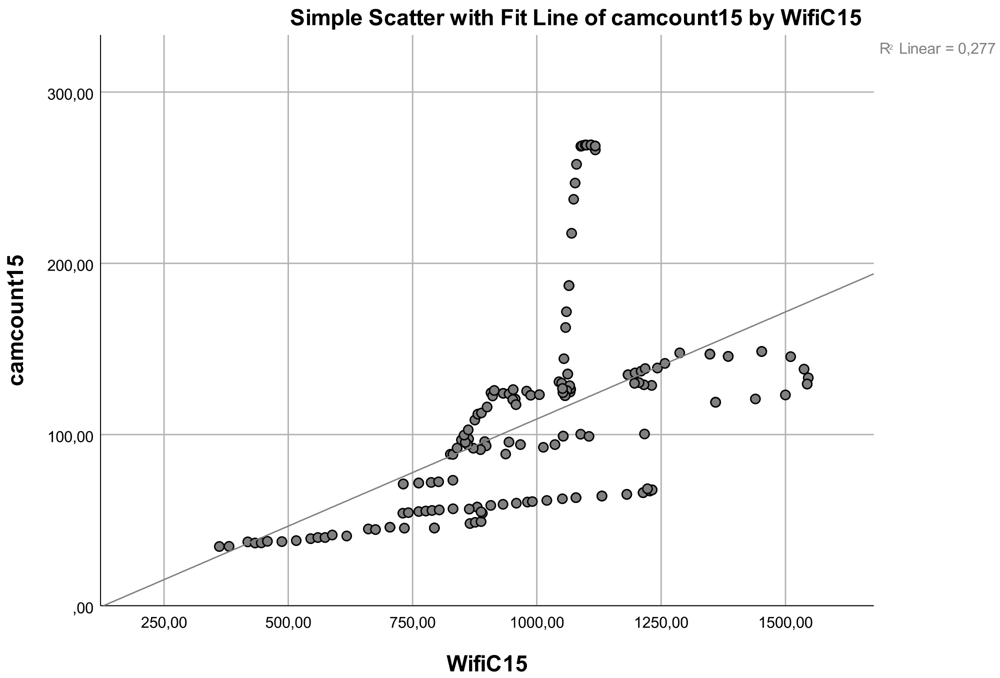

Figure B.1: TT: Wi-Fi counts - camera counts

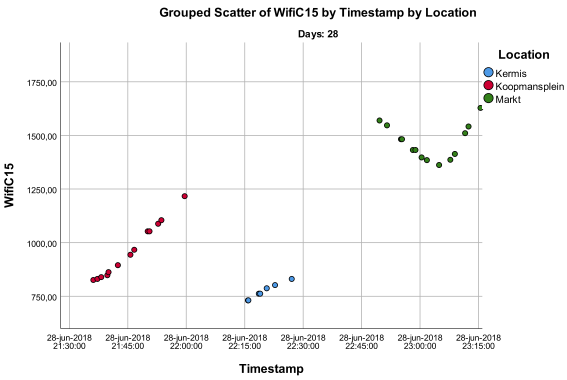

Figure B.2: TT: June 28, 2018. Wi-Fi counts - Time per location

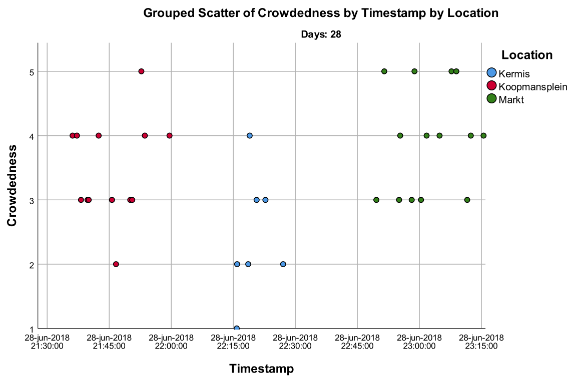

Figure B.3: TT: June 28, 2018. Perceived Crowdedness - Time per location

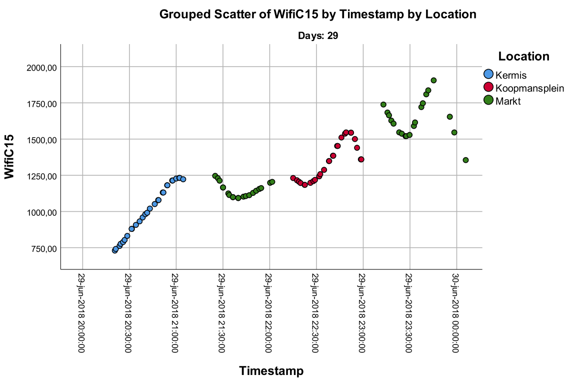

Figure B.4: TT: June 29, 2018. Wi-Fi counts - Time per location

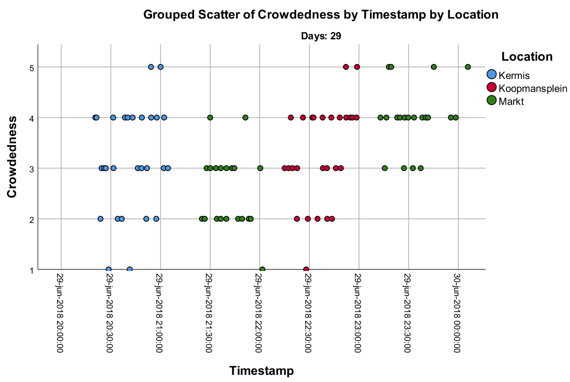

Figure B.5: TT: June 29, 2018. Perceived Crowdedness - Time per location

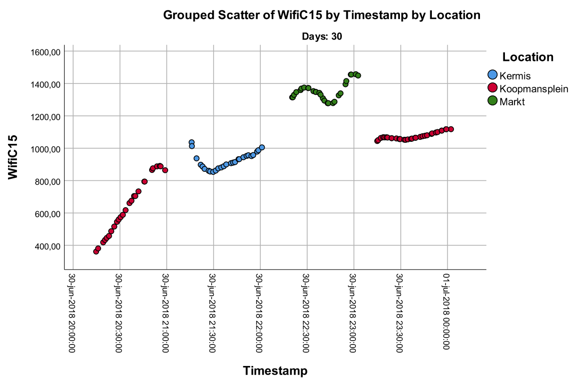

Figure B.6: TT: June 30, 2018. Wi-Fi counts - Time per location

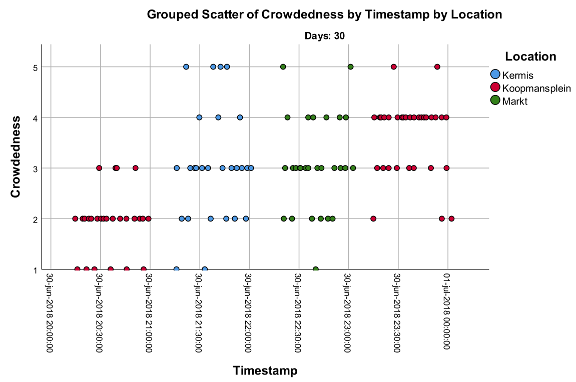

Figure B.7: TT: June 30, 2018. Perceived Crowdedness - Time per location

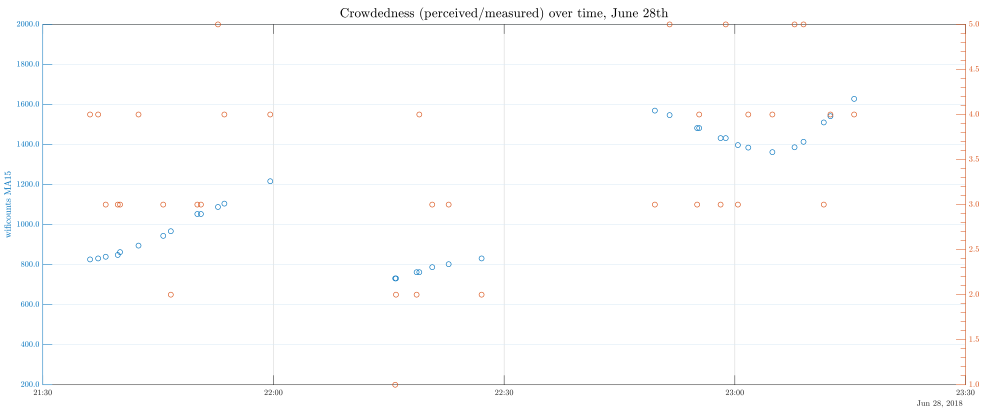

Figure B.8: TT: June 28, 2018. Wi-Fi & Perceived Crowdedness over time

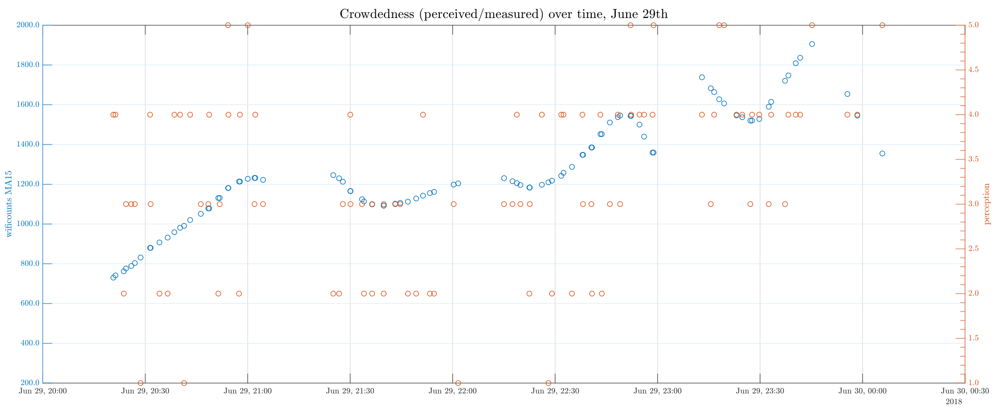

Figure B.9: TT: June 29, 2018. Wi-Fi & Perceived Crowdedness over time

B.2. Red light district

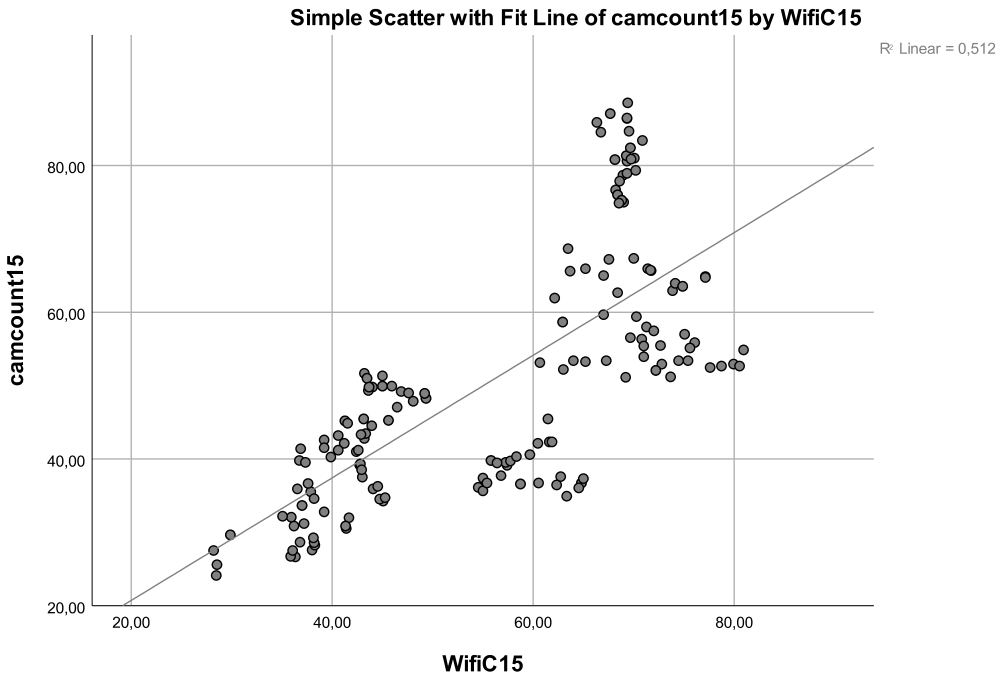

Figure B.10: RLD: Wi-Fi counts - camera counts

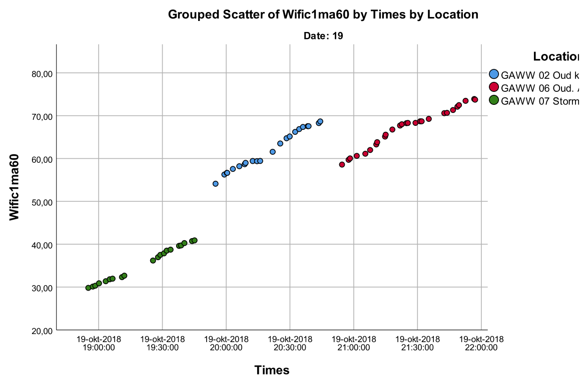

Figure B.11: RLD: October 19, 2018. Wi-Fi counts - Time per location

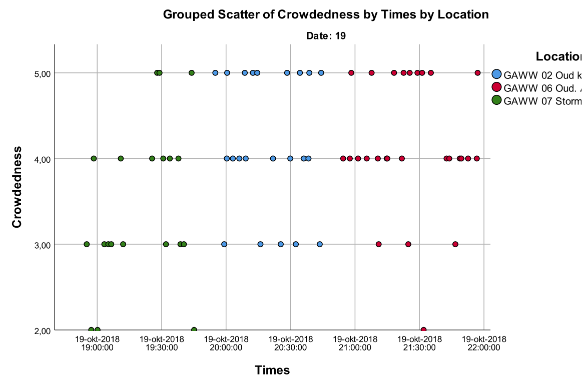

Figure B.12: RLD: October 19, 2018. Perceived Crowdedness - Time per location

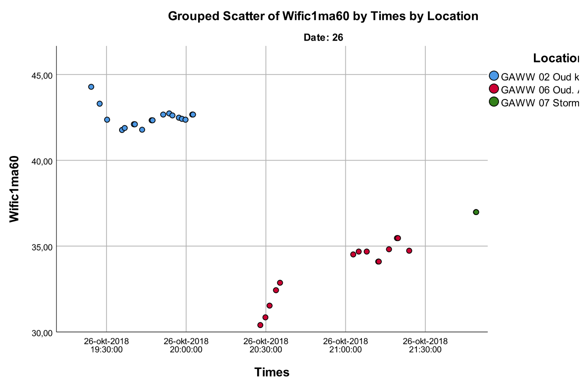

Figure B.13: RLD: October 26, 2018. Wi-Fi counts - Time per location

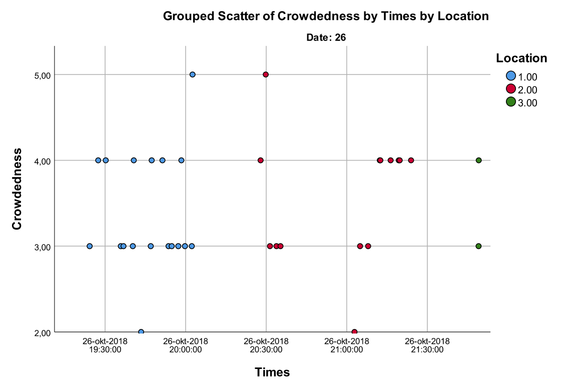

Figure B.14: RLD: October 26, 2018. Perceived Crowdedness - Time per location

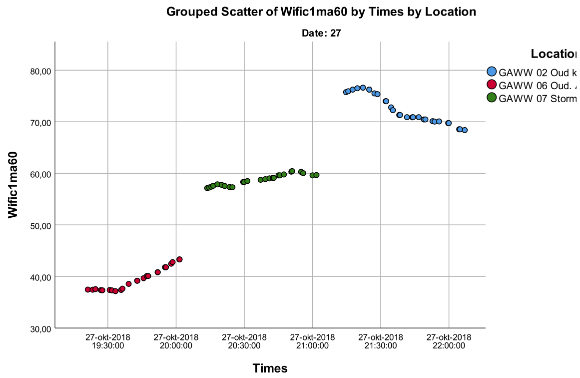

Figure B.15: RLD: October 27, 2018. Wi-Fi counts - Time per location

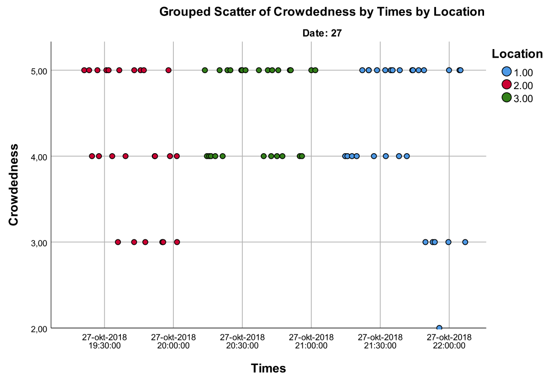

Figure B.16: RLD: October 27, 2018. Perceived Crowdedness - Time per location

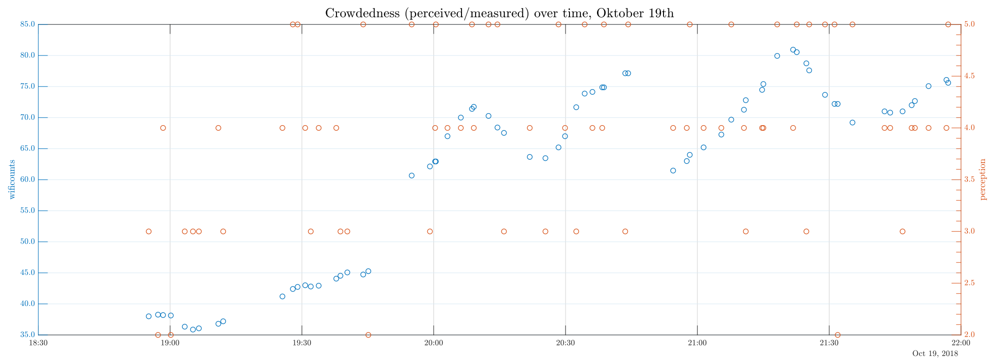

Figure B.17: RLD: October 19, 2018. Wi-Fi & Perceived crowdedness over time

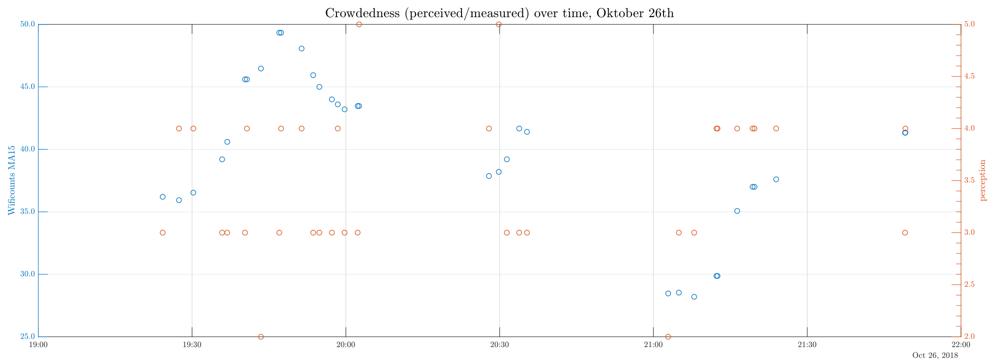

Figure B.18: RLD: October 26, 2018. Wi-Fi & Perceived crowdedness over time

C

Intermediate models

C.1. TT intermediate models

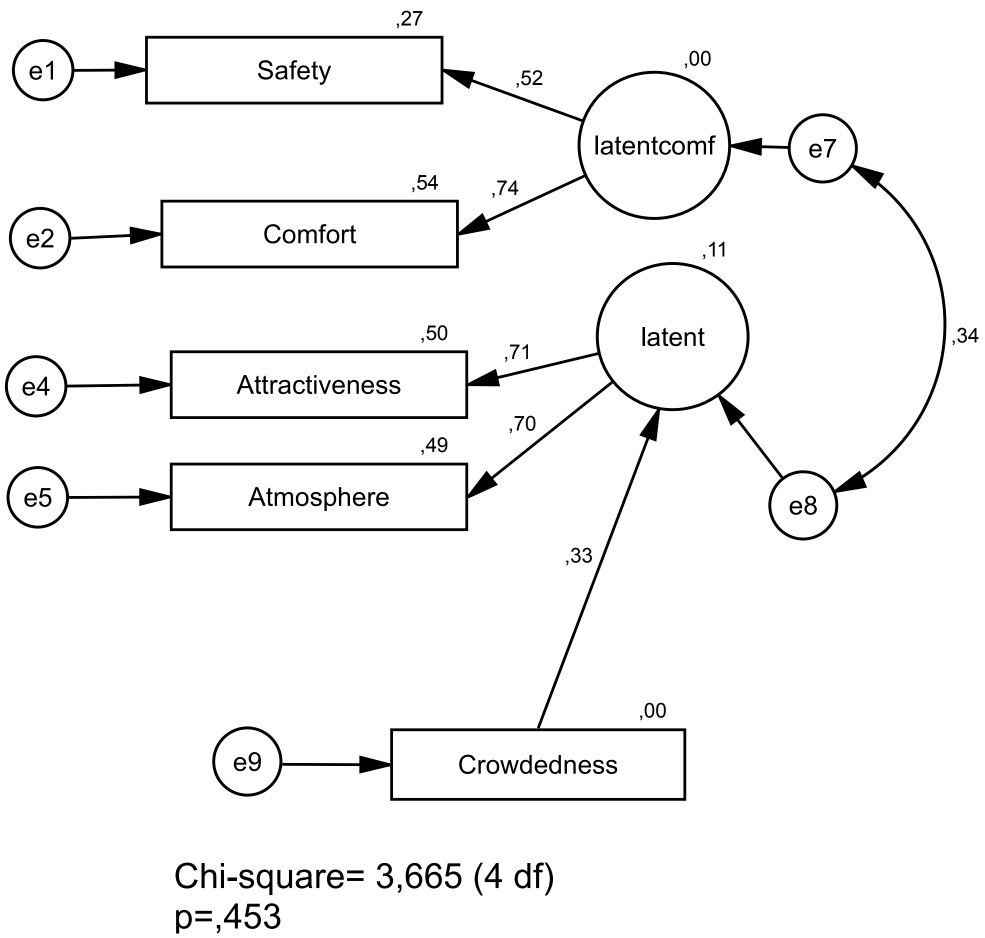

Figure C.1: TT Model 1: Perception variables in measurement model, significant

Figure C.1 shows the first model that is made, using only the perception variables. The latent construct was determined from the exploratory factor analysis. The figure shows that the loadings the the latent factors are sufficient. Furthermore, perceived crowdedness is directly related to the latent factor combining Attractiveness and Atmosphere.

Figure C.2 shows the first try for a full model, based on the hypotheses and the bi-variate analysis. As can be seen, it does not fit and there are some weak correlations. These will be removed in steps.

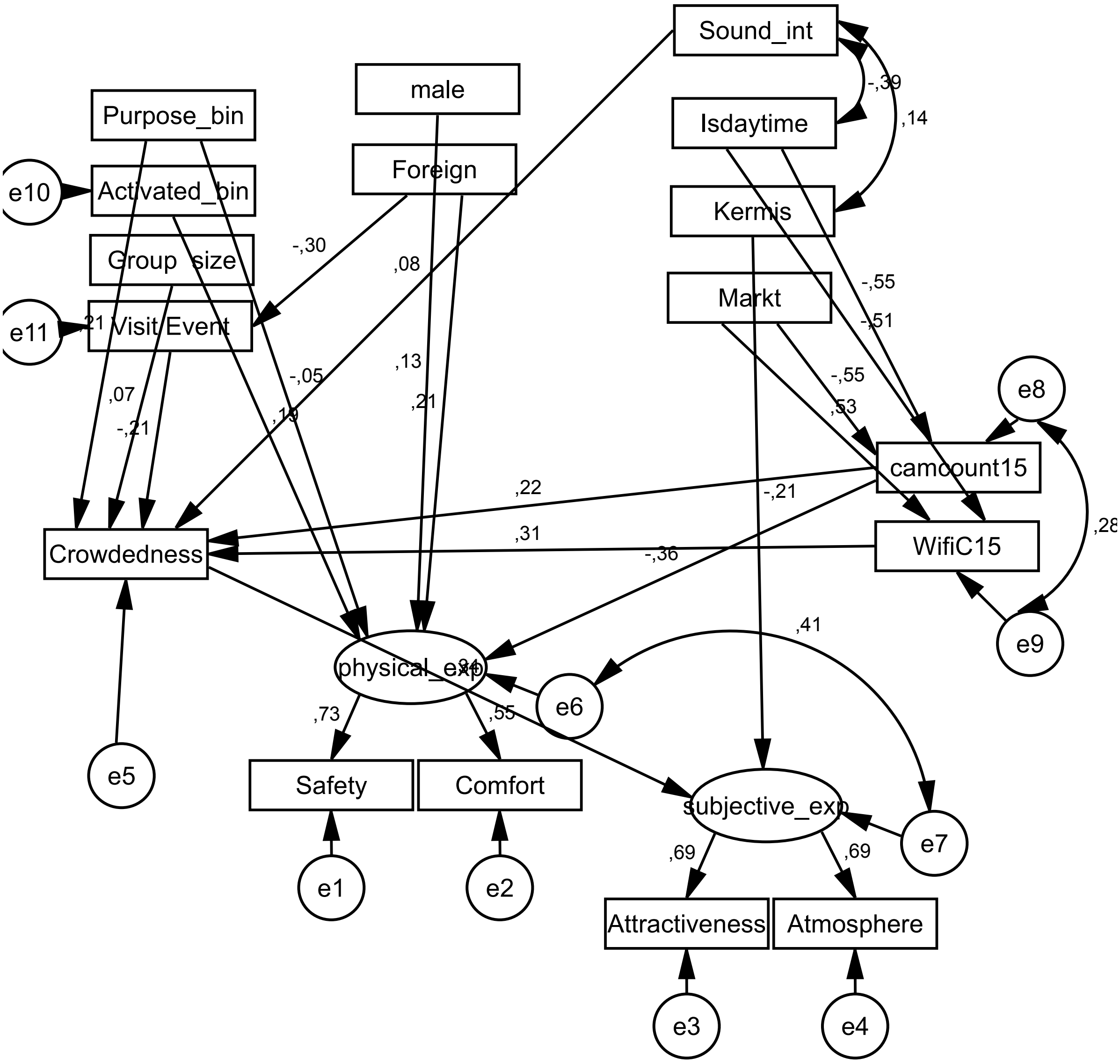

Figure C.2: TT Model 2: Full model based on theory, not significant

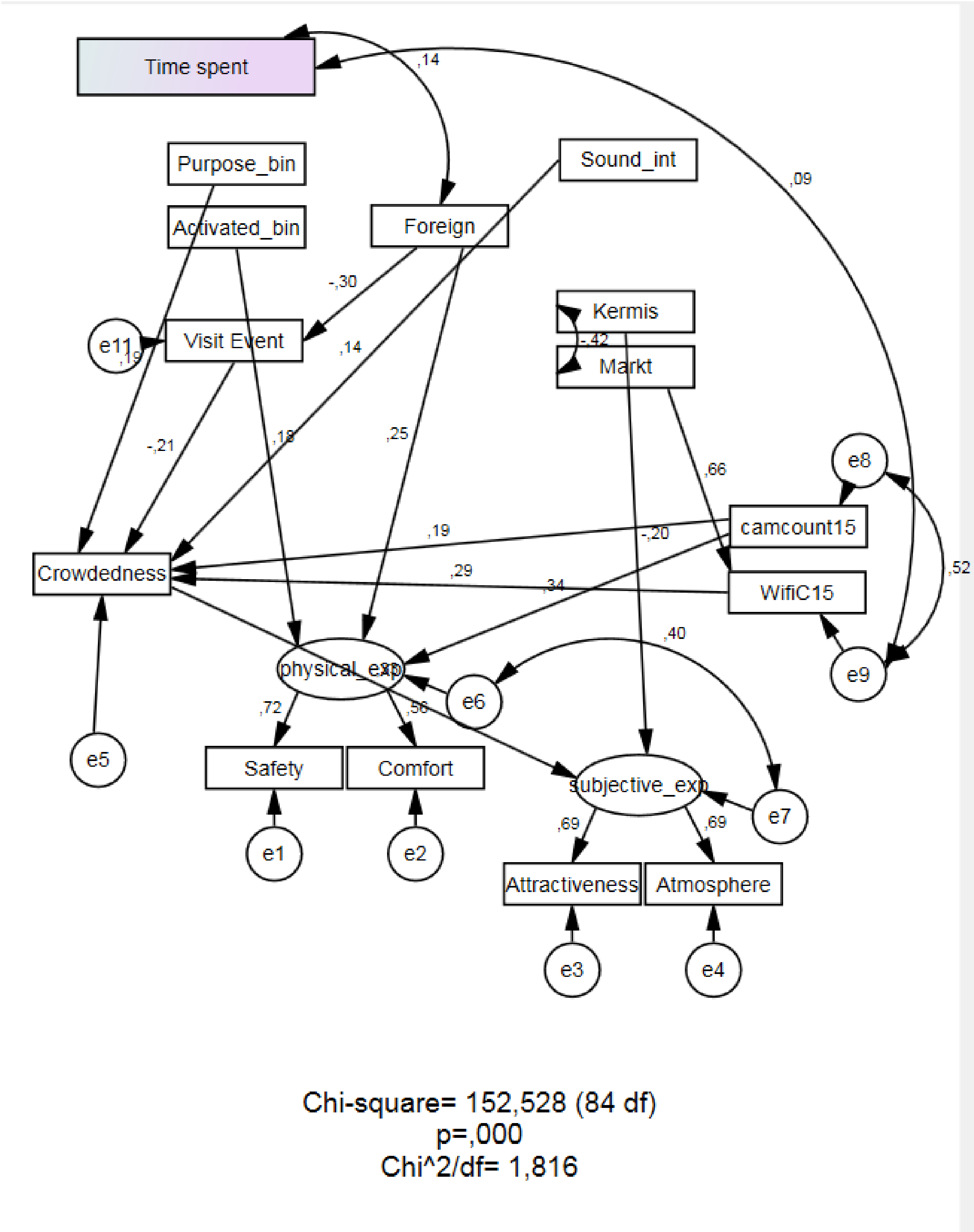

Figure C.3: TT Model 3: Intermediate model with time spent, not significant.

This model is not fitting according to the probability level, but looking at other indicators, it does. For example χ^2/df is below 2. All relations drawn are significant.

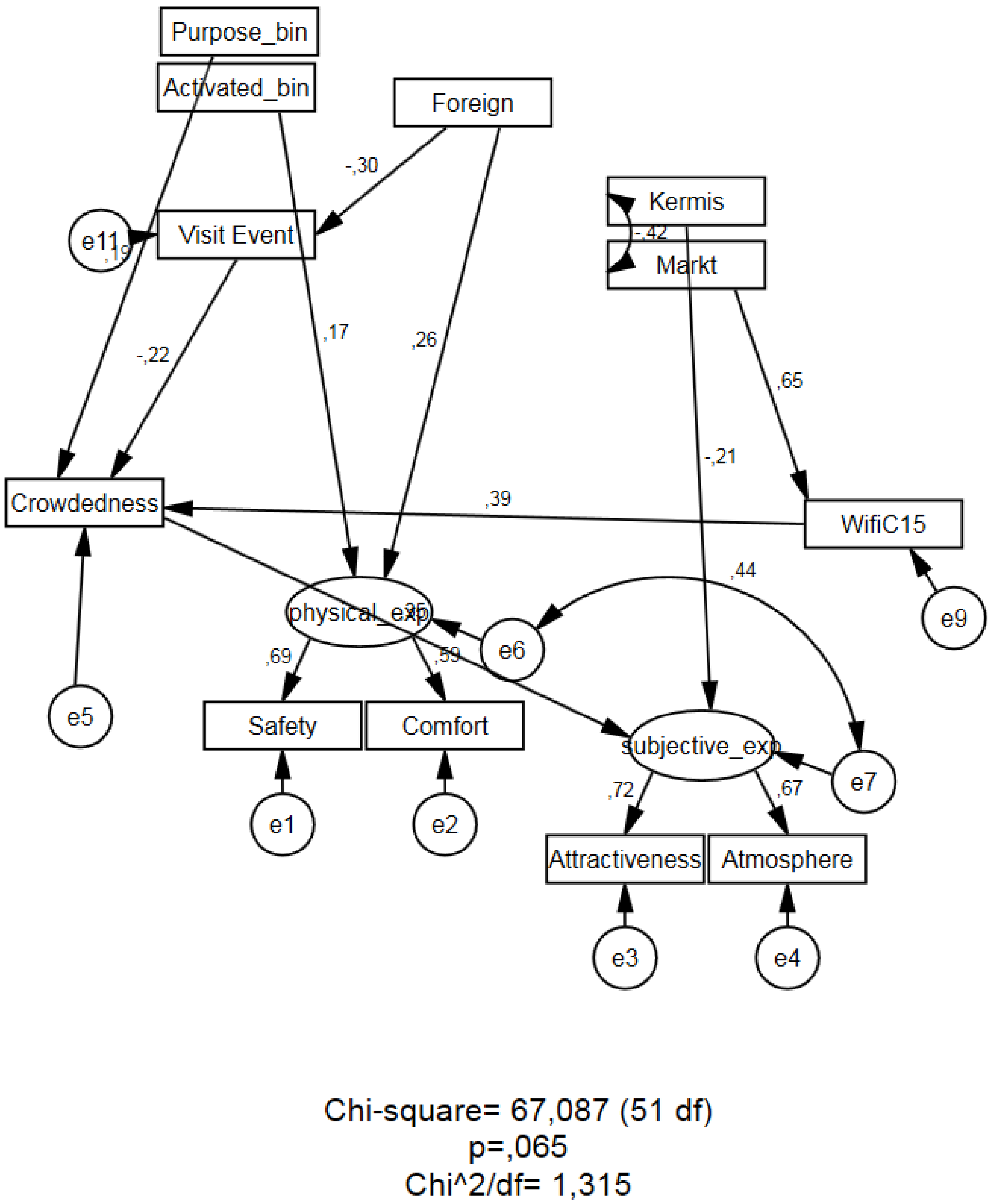

Figure C.4: TT Model 4: Intermediate model without camera counts, significant.

Here, a model is found that fits and only has significant relations. However, it is missing an the indicator flow.

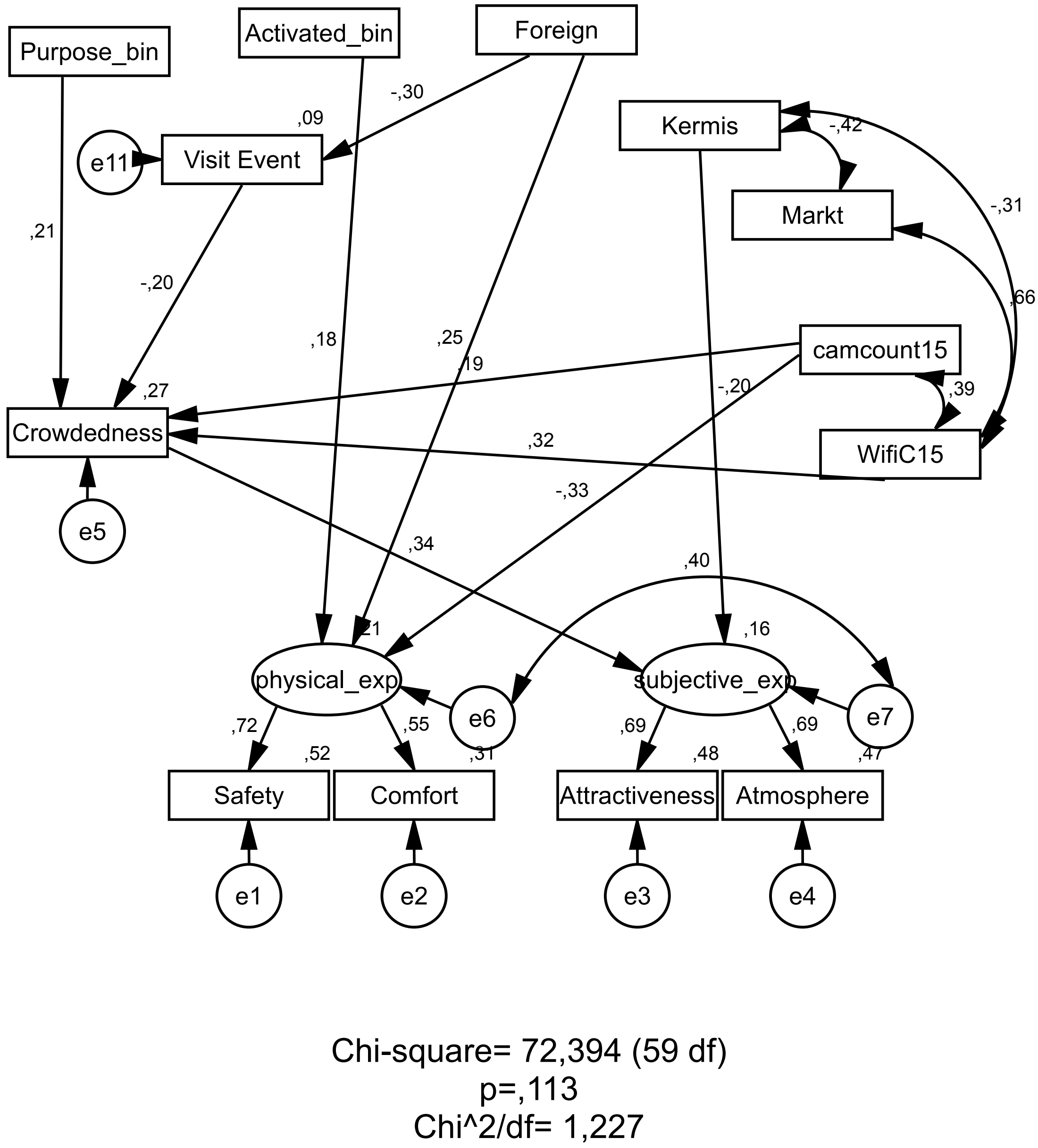

Figure C.5: TT Model 5: Final model

Figure C.5 represents the final model for the TT Festival.

C.2. RLD intermediate models

For the RLD case, a comparison between including the perception variables as separate entities and including them as latent variables is shown in Figure C.6 and Figure C.7. In Table C.1, their model fit indicators are compared.

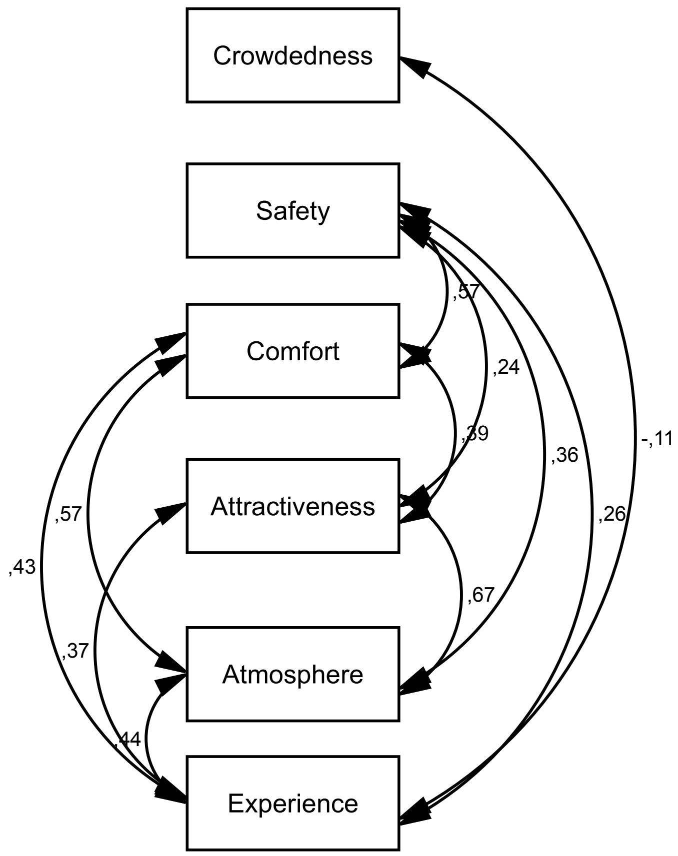

Figure C.6: RLD Model 0: Perception variables as correlations, significant

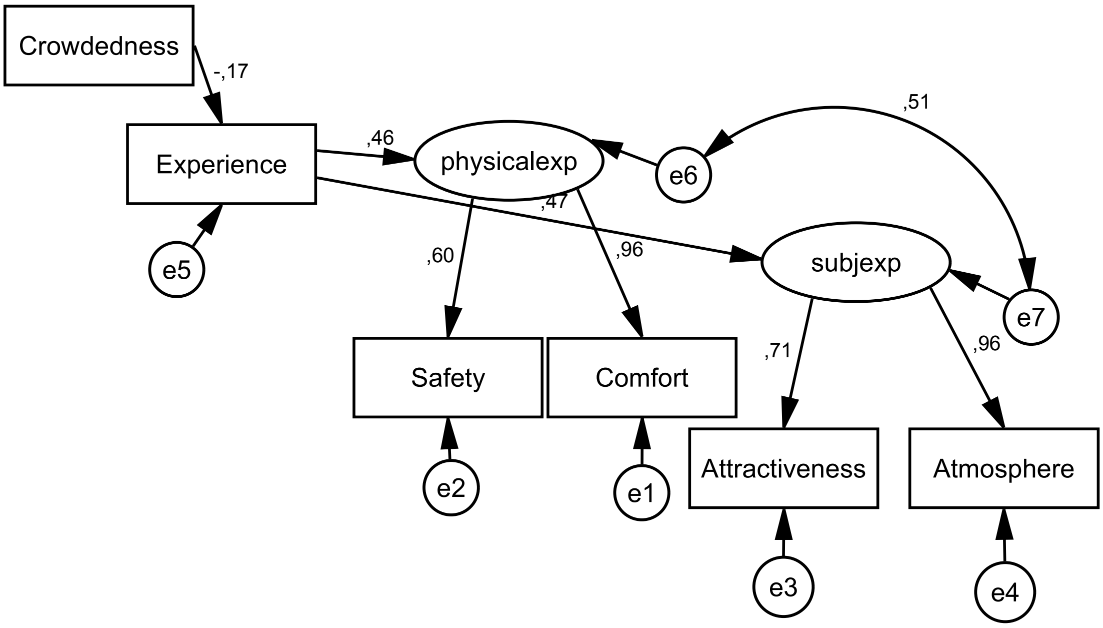

Figure C.7: RLD Model 1: Perception variables in measurement model, significant

Table C.1: SEM chosen boundary conditions for a good model fit

Indicator	Chi-square	p-value	df	Chi^2/df	GFI	CFI	PCFI	RMSEA	PCLOSE
Boundary condition	Low	>0.05	<2	>0.9	>0.9	>0.8	<0.1	>0.05	
Model 0	3.258	0.516	4	.814	.994	1.000	.267	.000	.707
Model 1	3.028	0.882	7	.433	.995	1.000	.467	.000	.961

Table C.1 shows that the model with a latent construct performs just as good or better on all indicators. The only indicator that is not satisfied is PCFI.

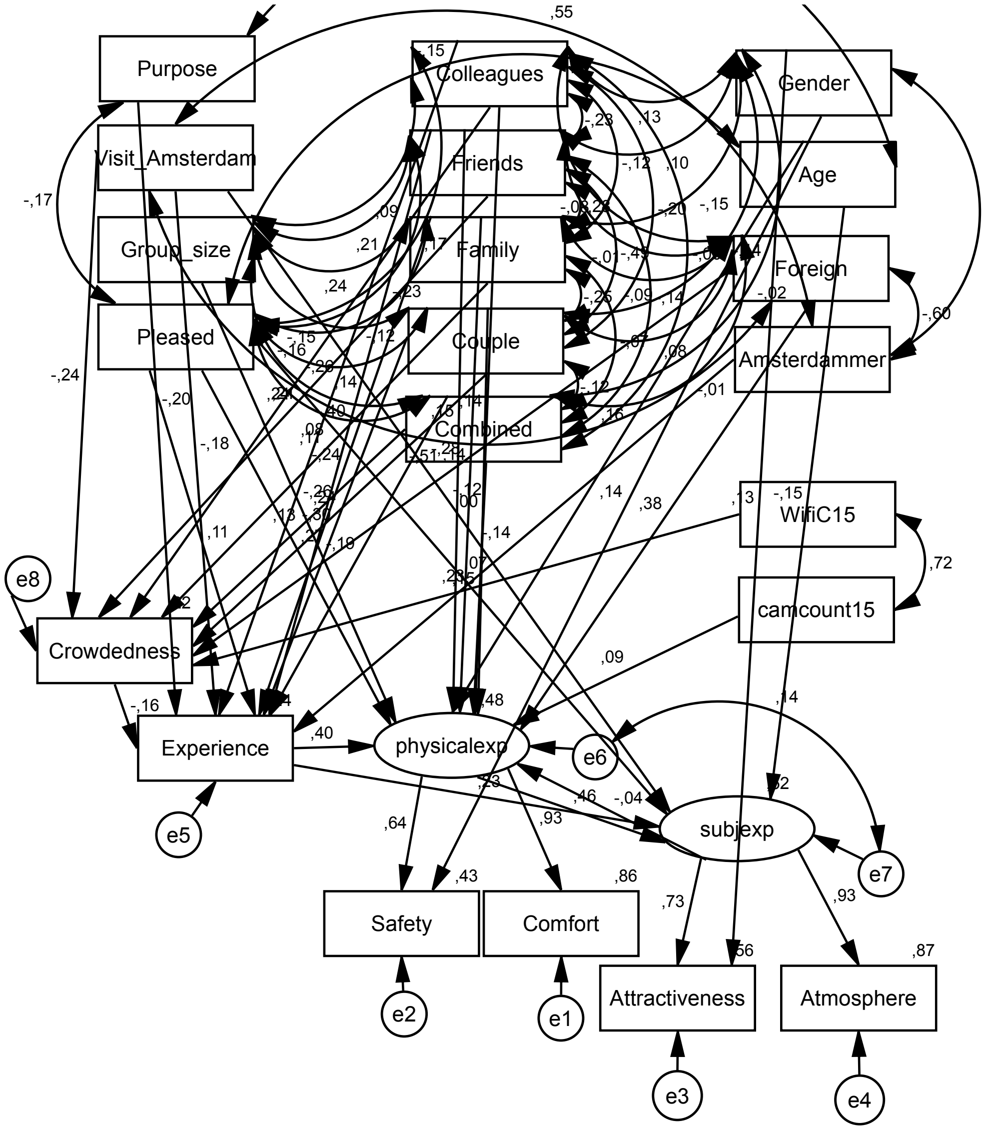

Figure C.8: RLD model 2: Full model based on theory, not significant

The full model based in theory is shown in Figure C.8. Many paths are insignificant and need to be removed.

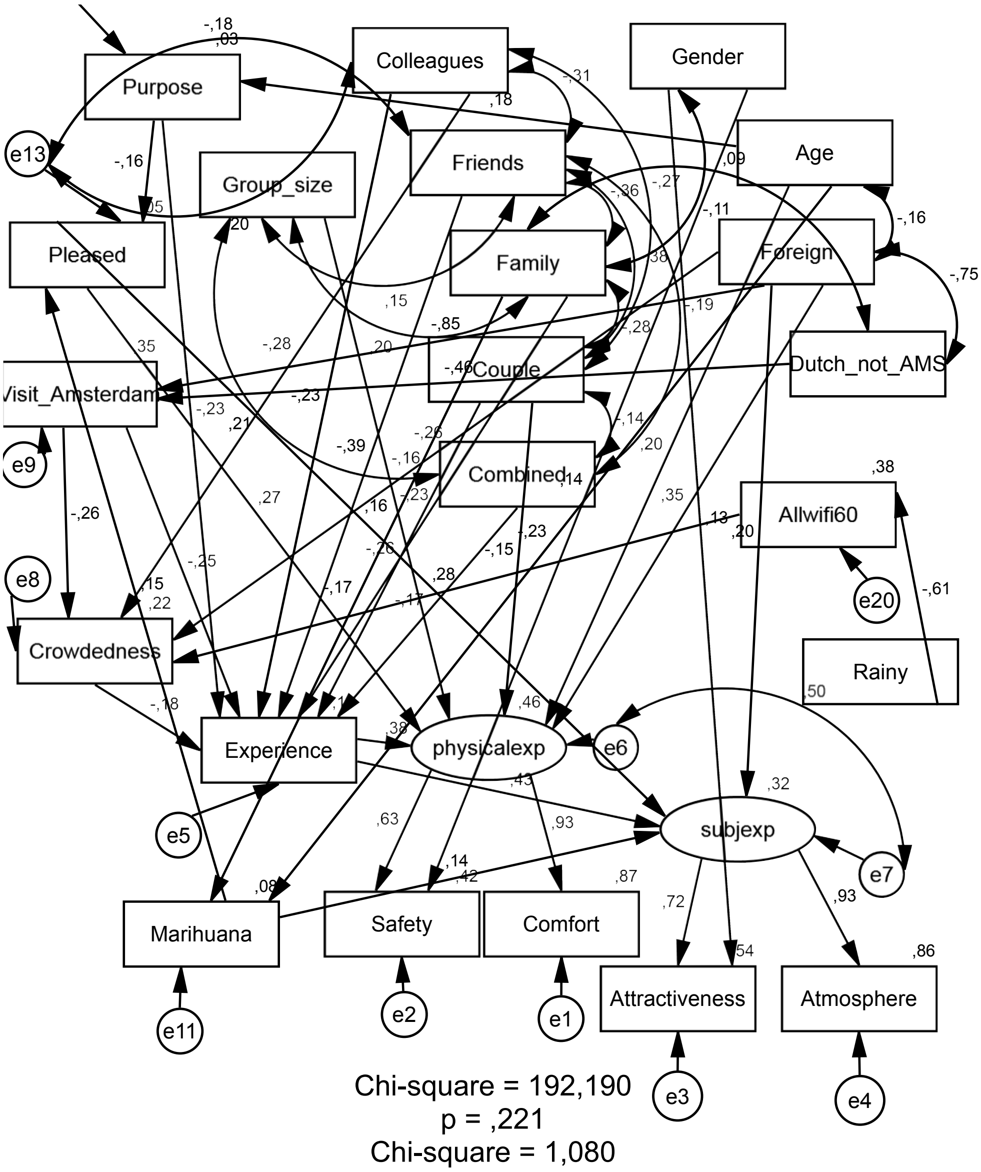

Figure C.9: Model RLD: Final model

Figure C.9 shows the final model for the Red light district.

D

Bi-variate data analysis techniques

For all other Appendices, please contact the author:
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