Crowd management in train and metro stations

Proposing a framework to select and assess effective crowd management measures

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Royal HaskoningDHV
Enhancing Society Together

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by

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Preface

This thesis is the final requirement for me to obtain the degree of Master of Science of the track Transport, Infrastructure and Logistics. Before the start of this thesis six months ago, I was worried that I would miss the company of more project members. However, I soon noticed that coming to this document would be more of a team effort. The extensive advice and feedback coming from both the Delft University of Technology and Royal HaskoningDHV helped to significantly improve the quality of the work and for that I would like to thank the following people.

First of all, I would like to thank my daily supervisors from the TU Delft, Winnie Daamen and Flurin Hänseler. Not the tiniest detail of this thesis has remained unread by both of you and therefore I am quite sure you will even read this. I really appreciate this, as I can only imagine the time this must have taken. I have always really enjoyed the discussions we had and it has definitely helped me a lot to improve the work.

I would like to thank Serge Hoogendoorn for the never ending enthusiasm and the opportunities from the start. Furthermore, thanks to Jan Anne Annema for always keeping me on track and focusing on the most relevant things.

I am also grateful for the opportunity Eelco Thiellier provided me at Royal HaskoningDHV. I would also like to thank Robert Versteeg from RHDHV for showing me the choices consultants make and always asking me the fundamental question “What is your thesis on?”. I have enjoyed working at the office in Utrecht, the help from many people there, the lunches and admire the endless passion for trains and train stations.

Victor Mensink
Delft, June 2017

Summary

Public transportation ridership has grown significantly over the past decades and this growth is expected to continue into the future. Crowding at train and metro stations is therefore experienced more frequently, resulting in safety issues, decreased comfort levels, increased total travel times and modality shifts. On the long term large infrastructural changes can be considered to increase the capacity but for the short term more flexible and cheaper crowd management measures can be applied. Little scientific research has been dedicated to study the effects of crowd management measures or when to apply them.

The aim of this thesis is to design a method to systematically select and assess effective crowd management measures to increase the safety and throughput in train and metro stations.

The five objectives behind crowd management are to improve the safety, increasing the reliability and punctuality, increasing the comfort, decreasing the travel times and increasing shop and ticket revenues. Trough interviews with different stakeholders, it was established that improving the safety is the most important objective. A list of 29 crowd management measures to reach these objectives is composed based on literature, experts or previous applications. All these measures are categorized into four strategies: increase throughput, prevent blockades, distribute traffic and limit inflow. Furthermore, the field of application, characteristics and estimate of the costs of all measures are given. Indicators used in literature to assess the effects of crowd management measures are compared, in which the Level of Service (LOS) is found to be used the most.

If a measure can possibly lead to unsafe situations or is too complex or expensive to test in real life, a model can be used to assess the measure using indicators such as the LOS. Different requirements are needed from a model to accurately model a measure. For each measure, these requirements from a model are determined. No model exists that is able to fulfill all requirements, which shows the necessity for a careful selection of a model to assess a measure.

A framework is developed to provide a means to select crowd management measures to apply at a particular train or metro station. The framework starts with an applicability check to see if crowding problems are expected on a train or metro station, with pedestrians only and whether the objective is one of the five objectives mentioned previously. If one of these questions is not answered positively, the framework should not be applied or the results interpreted carefully. The next step is to see what the time window is in which crowding problems occur, where the bottlenecks are and an estimation of how many people are influenced by the crowding problems. Based on these answers, the field of application of the measures, the specific locations or type of problems occurring and the extent to which dynamic or reactive measure are needed, possible measures from the list of 29 can be selected. If a real life test cannot be performed, it can be checked what is needed from a model to accurately model the selected measure and assess its effects. Using indicators dependent on the objective of crowd management, it can then be assessed if the measure gives the desired results on the objective. If not, a different measure can be selected and otherwise the framework is terminated. The framework can be seen in figure 1.

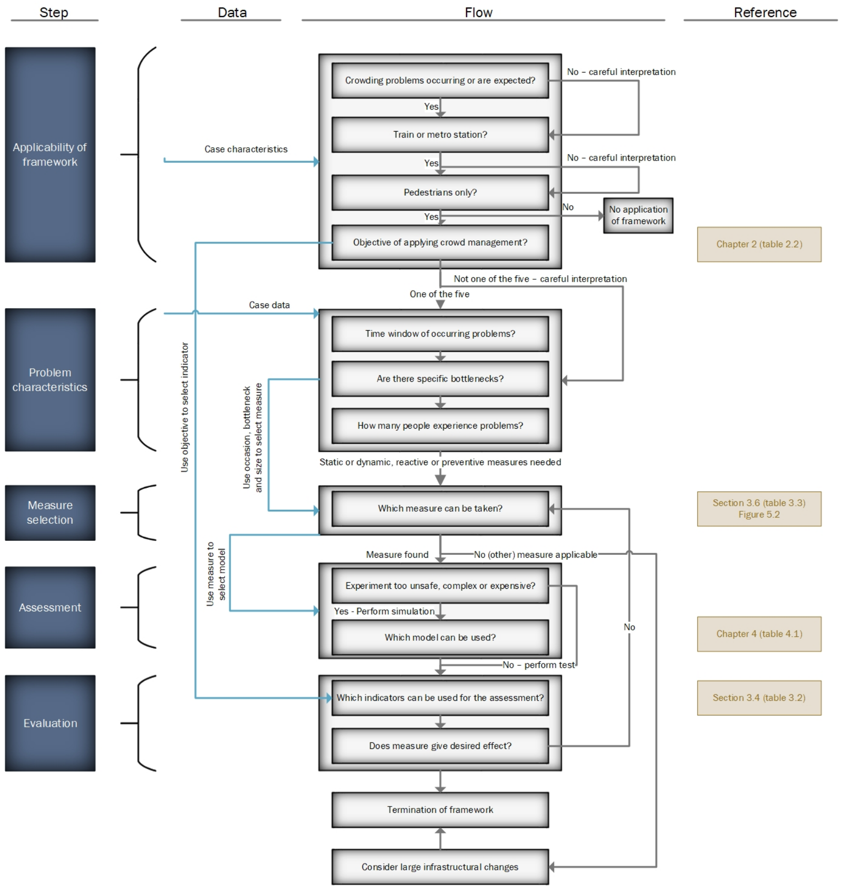

Figure 1: Framework to select and assess measures. Gray arrows represent the flow direction and blue arrows represent input flows.

The framework has been applied to a case study to assess its performance. A fictional station similar to the Weesperplein metro station in Amsterdam is modeled for two different load cases: one peak demand flow with 50% boarding and 50% alighting passengers and one event flow with 90% boarding and 10 % alighting passengers. For the peak hour load case, dedicated doors and decreasing the headway were selected as possible measures. For the event load case, gating and decreasing the headway were selected. All of these measures turned out to have positive effects in reducing the total time spent in the most critical levels of service (E and F) on the platform as well as the relative time passengers spent in these levels of service. Hence, using the safety is expected to increase using the LOS as an indicator for safety. However, it should be noted that measures can also come with drawbacks, such as an increased time from entering the station to boarding when gating is applied. The framework fulfills its requirements to use contextual information to help select possible measures, provide information on possible effects and field of application of the measures and help select a model to assess the measures. Therefore, this framework is believed to be beneficial to support multidisciplinary decision making.

Since crowd management has gained attention relatively recently, not much literature is available. Further research can be dedicated to new crowd management measures or to study when measures are most effective. The proposed framework is a first step to more systematically selecting and assessing effective measures. Improvements can be made by widening the scope to also include large infrastructural changes or policy measures to influence people on a strategic level. This could lead to a more complete framework to facilitate a more complete decision making process.

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1 Introduction

This chapter introduces the subject to be addressed in this thesis. It starts with the problem statement, after which the objective and research questions are stated. Then, the scope of the master thesis is set and the scientific and societal contribution explained. In section 1.5, the approach of the research is discussed and finally the outline of this thesis is explained.

1.1. Problem statement

Public transportation ridership has grown significantly in the Netherlands over the last decades. For example, train ridership with NS has increased from 8 billion passenger kilometers in 1970 to over 17 billion in 2014 [63]. Also other forms of transportation have shown this trend, with an increase of public transportation ridership in bus, tram, metro and ferry to 5.2 billion passenger kilometers in 2015 [73]. This growth of public transportation usage is expected to continue into the future [43]. Overcrowdedness is therefore expected to be experienced more frequently during peak hours in some stations, which could cause significant service disruptions [12]. Larger crowds in train and metro stations and increased travel times due to congestion are not only seen in the Netherlands. Just recently, the London metro experienced very heavy loads. This resulted in a station with so many people that a person fell on the track, and also in other stations serious safety issues arose [12]. In the end, this led to the temporary closing of seventeen stations [31].

The increase of public transportation ridership in the Netherlands so far has been noticed mostly in a few large railway stations in terms of absolute growth [63]. For example, at the train station of Schiphol Airport an investigation is held to discover the possibilities for an increase in the rail capacity [21]. Also the capacity of the station itself is subject to improvements, with extra space being created by removing benches and trash cans and fast escalators replacing stairs. This is done to better cope with crowds on the platforms. The demand for the station is monitored in real time in order to take appropriate measures if needed. For example, a team of employees is present to disperse people over the platform if crowd densities exceed a certain limit. Also, the 'Intelligent Platform Bar' will likely be placed next year, which shows through LED-bars where the train will stop and doors will be so travelers can spread more evenly over the platform.

There are many more examples which show that the crowdedness in train and metro stations can cause serious problems. Firstly, passengers being pushed off the platform cause significant safety issues [62]. The comfort of passengers will decrease, resulting in a lower utility experienced by passengers in public transportation and causes people to avoid public transportation and travel with other modes [62]. Lower comfort of travelers also leads to decreasing evaluations of operators. The operators are usually incentivized by the government to score sufficient on these evaluations. The efficiency of the system as a whole will decrease with larger crowds due to necessary larger dwell times. With more crowding at stations and thus longer access and egress times for passengers in the train and metro station, more connections are missed. The longer dwell times, access and egress times and possible missed connections lead to an increased total travel time for passengers. These reasons show the importance of taking measures to prevent crowding. Even though some measures are already applied in practice, little scientific research has been dedicated to study the effects of these measures or when to apply them.

1.2. Objective and research questions

The objective of this thesis is summarized as follows:

The objective of this thesis is to design a method to systematically select and assess effective crowd management measures to increase the safety and throughput at train and metro stations.

In order to achieve the objective, several research questions are formulated. The objective provides a focus for the research, and the research questions are formulated to fit within that focus and are narrowed down to the scope of the research. Each question is needed to eventually meet the research objective.

1. *What are the most important objectives of crowd management?*
2. *What are the characteristics of researched or previously applied crowd management measures?*
3. *What is required from a simulation model to accurately model and assess crowd management measures?*
4. *How can a framework be designed to systematically select and assess crowd management measures?*
5. *How does the framework perform when applied to select and assess measures in a realistic case study scenario?*

1.3. Scope

The scope of the project is summarized below.

- Crowds are defined as “the group of individuals in a train or metro station at the same time”. No clear consistent definition of crowds is available in literature. The broad definition of when more than two individuals are interacting with each other is used occasionally, and in sociology a similar definition is used [18, 79]. The definition used in this thesis is derived from Hoogendoorn and Bovy and is more related to the field of research [34].

- The definition of crowd management is taken from Berlonghi: “crowd management includes all measures taken in the normal process of facilitating the movement and enjoyment of people” [6].
- A distinction is made between crowd control measures and crowd management measures. Crowd management is about the facilitation of the activities and crowd members to ensure their safety and encourage them to behave in a desired manner, whereas crowd control concerns actions taken when the behavior of the crowd becomes undesired [18]. Thus, crowd management refers to the pro-active way to guide or influence the crowd and crowd control is regarded as a reactive way to guide or influence the crowd [6]. Crowd control is done in a later stadium and may involve more forceful measures such as using police forces during incidents. This thesis focuses on crowd management measures and hence will exclude measures taken when large crowds are already causing problems. This limits the scope to preventive measures and eliminates the need for real-time availability of data, application of the framework and modeling.
- No large physical infrastructural changes are considered as possible crowd management measures in the scope of this thesis. Instead, more flexible and cost-effective measures are considered since it is assumed that these are considered first by decision makers.
- Three different levels of pedestrian behavior can be distinguished: strategic, tactical and operational [34]. The strategic level involves departure time choice and activity choice, the tactical level is about the short term decisions such as activity area choice and route choice and the operational level is about walking behavior. This research will focus mostly on decisions on the tactical and operational level in order to exclude for example policy measures aimed to shift the mode of transportation.
- This research is not aimed at assessing a model for each crowd management measure. An existing and calibrated model will be used, adjusted if necessary and applied to the selected case.
- One train or metro station or a part of it will be chosen for the case analysis. This is done to limit the research to the part necessary to understand the effectiveness of the framework to select and assess crowd management measures and provides more possibilities to generalize the results to different stations.
- Only pedestrians in train and metro stations are considered to be part of the research. This excludes travelers with different modalities.

1.4. Scientific and societal contribution

This thesis is aimed to contribute to both practice and science, which is discussed below.

1.4.1. Scientific relevance

Little research has been dedicated to crowd management so far. A method to systematically approach a crowding problem in a train or metro station by applying crowd management measures is not available. Also, no systematic assessment of the effects of applied crowd management measures is available. Therefore, a framework is proposed to systematically determine which measures can be applied at a station and how to assess the effectiveness of the measures. Furthermore, no review of researched or previously applied crowd management measures is available. This thesis will address researched or previously applied crowd management measures, their field of application and their characteristics.

1.4.2. Societal relevance

There is increasing attention from the scientific field for crowd management driven by a demand from the market. With increasing passenger flows in public transportation a need is created for operators and train and metro stations to increase capacity while ensuring passenger comfort and safety. This could be done by performing expensive infrastructural improvements or station redevelopments. However, crowd management measures can be applied as a quick, flexible and cost-effective alternative. Public transportation users can then experience safer, more comfortable, reliable and faster journeys. The case study also contributes by giving recommendations to stations on which crowd management measures could be effective.

1.5. Research approach

This thesis is divided into multiple phases. The first phase is the formulation, in which the problem, scope, objective and research questions are set and stakeholders involved in crowd management identified. In the second phase, the analysis phase, a list of different crowd management measures is composed, including the possible effects, the field of application and the characteristics. Furthermore, the requirements for a model to accurately model a measure are stated. The third phase is to develop the actual framework of selecting and assessing measures. In the following fourth phase, the implementation, a case study is done to evaluate the workings of the framework. Finally, in the communication phase, the answer to the research questions will be reported and presented. Throughout the thesis, multiple methods are used, discussed below. An overview can be seen in figure 1.1.

- *Literature study*

  Since this is not the first study into crowd management, literature is studied in order to collect knowledge and to sort different measures. This knowledge can then be further built upon. Thorough searches with general keywords and with more specific measures in mind have been performed in multiple databases of scientific papers. Also citations from highly regarded papers have been followed to obtain other important contributions within the particular subject. For more widely available knowledge, the most highly regarded papers in terms of citations are selected to use in this thesis. However for many more specific information on for example crowd management measures, only one paper has been found and is therefore selected.

- *Expert interviews*

  Several interviews have been conducted, as can be seen in appendix A. The superscript numbers throughout the report denote which experts have been interviewed to generate the required input and refer to the numbers in this appendix. For all interviews, a summary has been sent back to the interviewee to check for mistakes. These interviews have been done with at least one person for each stakeholder and with people that generally know much about the subject. This has been established by obtaining references from both interviewees and employees of Royal HaskoningDHV (RHDHV) and TU Delft. Interviews were semi-structured so similar questions could be asked but also sufficient space was provided for interesting insights from interviewees.

- *Case study and data analysis*

  A case study is done with the help of a computer simulation tool of pedestrian flows. The model is selected with the help of the framework in order to obtain sufficiently accurate results from the model. The output is analyzed to see if measures in fact have positive contributions to the objectives, based on the chosen indicators.

- *Report and presentation*

  The final methods are the report writing and the giving of a presentation in order to communicate results that were found.

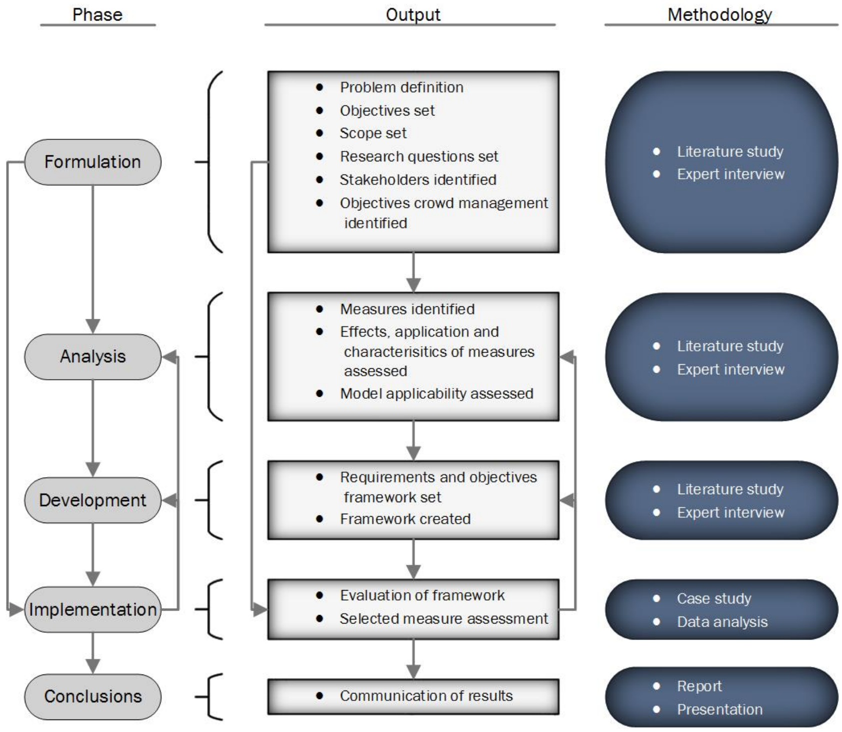


Figure 1.1: Research approach of thesis, based on Orwin et al. [50]

1.6. Report outline

An overview of the outline of this document is provided in figure 1.2. This contains the different phases, the topics to be addressed, where they belong in the chapters and where the research questions are answered. The gray arrows indicate the flow, which is from top to bottom, whereas the green arrows indicate the inputs in terms of data and information needed.

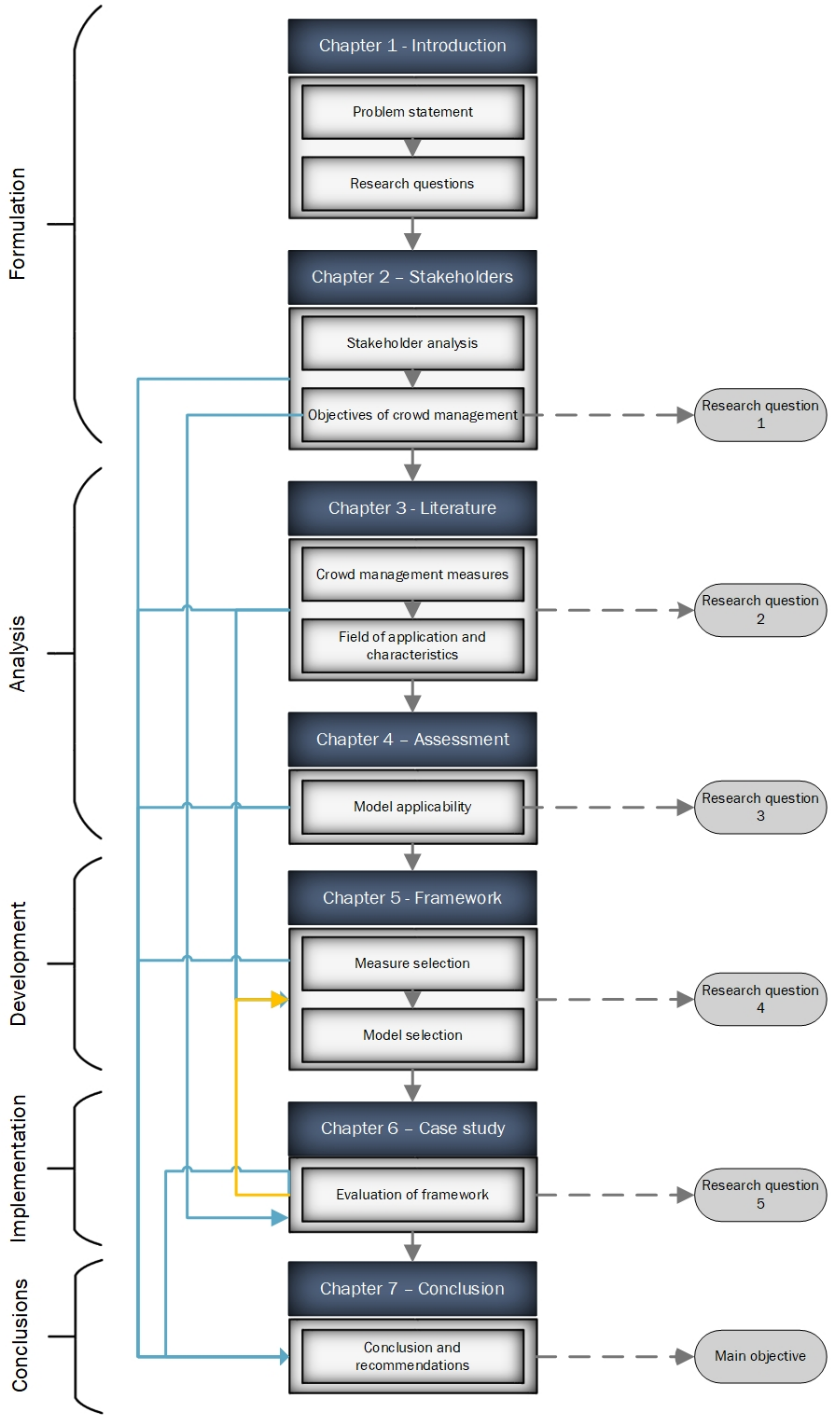


Figure 1.2: Outline of thesis, where gray arrows represent the flow, blue represent the data in- and outputs and orange the feedback loops.

2

Stakeholders of crowd management

In order to achieve the main objective of the thesis, first it needs to be determined what is considered to be effective when assessing crowd management measures. To do so, in this chapter the first research question on the most important objectives of crowd management is answered. Firstly, the different stakeholders involved in crowd management are identified. Then, their influence and interest is determined in order to establish the importance of each stakeholder. Also the desired objectives of crowd management for each stakeholder is determined. With a simple ranking, the most important objectives are established.

2.1. Stakeholder identification

A station is a complex public environment with multiple stakeholders. The different stakeholders may have different perceptions on the objectives of crowd management. Therefore, all stakeholders are identified first, in order to be able to describe their objectives of crowd management later. This identification is based on literature by Li and expert interviews (see appendix A).

Li identifies seven stakeholders for transfer stations in his thesis: rail infrastructure operator, station operator, passenger, national government, train operator, metro, tram and bus operator and municipalities [39]. The first five are used as stakeholders for crowd management in this thesis as well. Li identifies metro, tram and bus operators as a single stakeholder of transfer stations. Since their influence and interest is limited in crowd management at train and metro stations, not necessarily being transfer stations, this stakeholder is omitted. Instead of the municipalities, decentralized authorities are used, which also includes provinces or transport authorities on a local scale, because these have similar interests but on a different network scale (see figure 2.1). Furthermore, retail operators are added as a stakeholder, since their objectives can be different from the other stakeholders. The seven stakeholders then are the *rail infrastructure operator, station operator, retail operator, passenger, transport operator, decentralized authorities and the national government.*

In one interview with experts, also safety regions were mentioned to be included as a stakeholder. However, their influence is limited to periodic checks on small parts of the station or rails. Therefore safety regions are not included. Also the ILT (inspection for transport) was mentioned, but this is considered to be an executive part of the national government and thus no separate classification is needed.

2.2. Interests and influence of stakeholders

To determine which stakeholders in crowd management are most important, the interests and influence of all stakeholders are identified. No complete relative importance, interests or influence of stakeholders has been found in literature. Therefore, an analysis of the interests and influence of stakeholders is based on several conducted semi-structured interviews with experts, each representing a different stakeholder. The results are summarized in table 2.1. After that, a short description of each stakeholder and their interest and influence in crowd management is given.

A schematic overview of how the collaboration between the governments, rail infrastructure operator and transport operator works in the Netherlands that has been found in literature, is provided in figure 2.1. Their dependencies are shown with contracts and money flows, since these are formal indicators of relationships. Since the stakeholders identified here are not found to be complete and are based specifically on the Netherlands, table 2.1 is composed with the help of experts to provide a more complete overview.

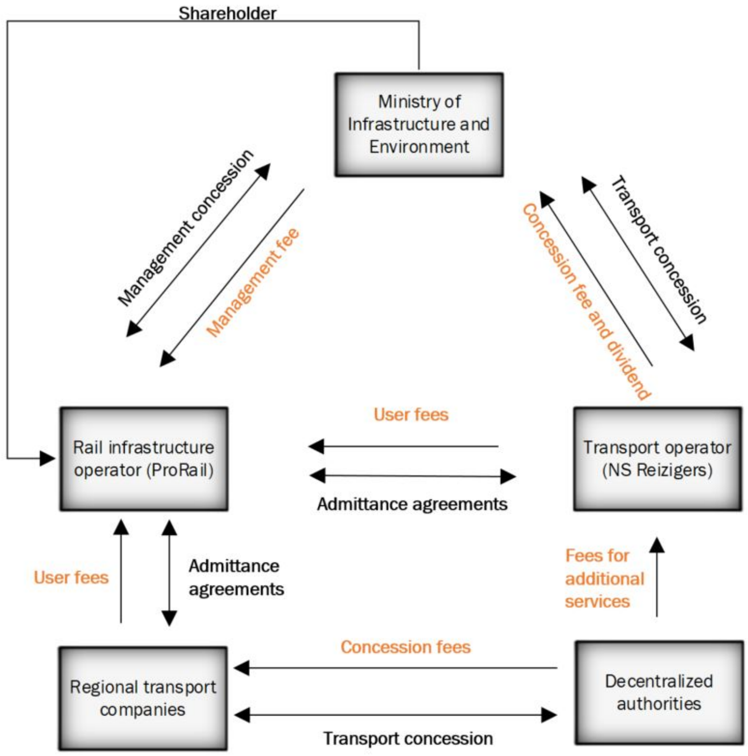


Figure 2.1: Example of collaboration of stakeholders of public transportation in the Netherlands (adapted from [14, 67]). Black arrows show contracts and orange texts money flows.

Table 2.1: Stakeholders, interests and influence. Based on interviews with [1,2,3,4,5,6,7,8,9,11,12,13] (see appendix A).

Stakeholder	Interest of stakeholder	Interest in crowd management	Influence in crowd management
Rail infrastructure operator	Ensure safe operation Efficient use of infrastructure Low investment and maintenance costs Easy management of infrastructure	Increase safety Increase reliability Increase punctuality	Allow rescheduling timetable Increase infrastructure throughput
Station operator	Ensure safe operation High revenues, low investment and maintenance costs Sufficient quality for transfering passengers	Increase safety Increase reliability Increase punctuality Increase revenues for shops and advertisement	Increase infrastructure throughput Influence inflow
Retail operator	Revenues	Increase waiting time Increase number of passengers	Influence station operators
Passenger	Safe operation Low travel times Comfort Reliability and punctuality	Increase safety Decrease travel times Increase comfort Increase punctuality	Subject of crowd management Choose mode of transport
Transport operator	Safe operation Low travel times Comfort Reliability and punctuality High revenues, low operating costs	Increase safety Decrease travel times Increase comfort Increase punctuality	Adapt schedule
Decentralized authority	Social welfare Accessibility Safety	Increase safety	Concessions Access roads to station Permits
Government	Social welfare Accessibility Safety	Increase safety	Concessions Subsidies

2.2.1. Rail infrastructure operator

The rail infrastructure operator is responsible for the construction, maintenance, management and safety of the infrastructure. Their objective is to increase the safety and reliability and to have a sustainable network with a punctual timetable [53]. For example for trains in the Netherlands, ProRail is responsible for the track infrastructure. Crowd management measures could have a positive effect on their objectives, since it can reduce the dwell times and increase the punctuality. It can therefore increase the efficiency of the operator and increase the frequencies at which the rail infrastructure will be occupied.

2.2.2. Station operator

The station operator is responsible for a proper functioning of the station. Passengers have to be able to safely and efficiently make use of the infrastructure inside the station until they board a train or metro or for alighting passengers until they exit the station. Part of the station is sometimes dedicated to retail and has places for advertisements, and these favor more exposure from passengers in order to increase the revenues. This means that within the stakeholder, there are multiple interests which could conflict, because transfers can be made more easily with fewer passengers whereas for the retail more passengers are desired. However, the top priorities are safety and sufficient practicality on which crowd management measures can have positive effects for the station operators.

2.2.3. Station retail operator

The station retail operator is dependent on the passenger flows for the revenue. Therefore, more passengers with a higher waiting time are desired for them. Their influence is limited however, since they have signed contracts with the station operator and are more dependent on them than contrariwise.

2.2.4. Passenger

Passengers want a safe and secure transfer in a station, a minimized and reliable travel time, a comfortable environment and a good overall experience [71]. Crowd management measures can have positive effects on these aspects but can also affect some passengers negatively in order to improve the system in general. Passengers make a decision on which mode to choose for travel and therefore influence other stakeholders such as the station and transport operator to satisfy their needs. As the subject of crowd management, the compliance and openness to information of passengers determines the success of the measures and therefore passengers have influence there, but not so much on an individual level.

2.2.5. Transport operator

Transport operators are responsible for the operation of the train or metro. In order to be profitable, the costs have to remain low and therefore efficient use of the available capacity is required. Crowd management measures may increase the efficiency by being able to decrease the headway because the time for the boarding and alighting procedure can decrease.

2.2.6. Decentralized authorities

Decentralized authorities consist of local and regional governments, such as provinces, municipalities or other concession grantors such as transport authorities. These are taken together here due to the similar characteristics. A maximized social welfare is aimed for by the decentralized authorities, meaning to have a good balance between travelers expenditures, operator costs and subsidies. In some cases, decentralized authorities make concessions with transport operators on the use of infrastructure and can therefore influence them (see figure 2.1). The influence of the decentralized authorities ranges from the access roads to station for which municipalities are responsible to permits that are needed to apply some measures. Furthermore, in extreme cases, local governments have the ability to shut down stations.

2.2.7. National government

Similarly to the decentralized authorities, the national government wants high accessibility and safety. The aim is for maximized social benefits and minimized costs. For the co-funding of some larger projects related to crowd management or infrastructural changes, subsidies may be available from the government.

2.2.8. Relative importance of stakeholders

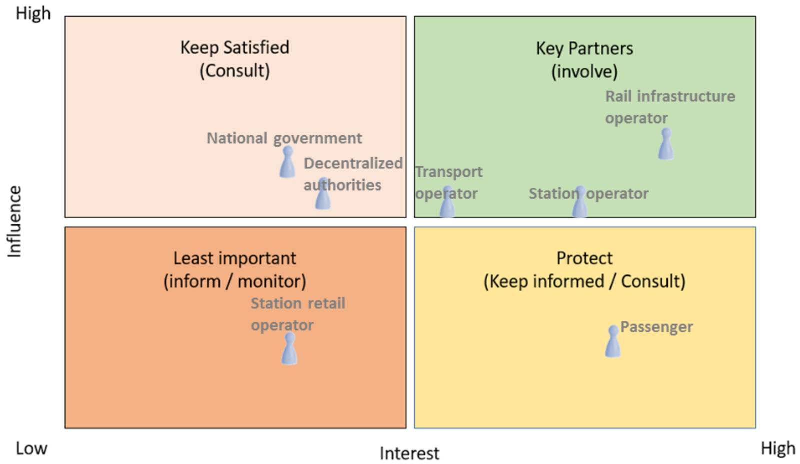


Figure 2.2: Interest and influence of stakeholders. Position based on input from experts [2,3,4,5,6,16] (see appendix A).

A schematic overview of the interests and influence of each stakeholder is presented in figure 2.2. Based on the position in this overview, the relative importance of stakeholders is derived, where a position in the top right is considered to be the most important. In the interviews with experts, six stakeholders have been asked to place the different stakeholders in the diagram. Two have been omitted because of the clearly different relationships and government involvement in Switzerland. That leaves four stakeholders from the Netherlands (from ProRail, Ministry of Infrastructure and Environment, NS Stations and NS Reizigers) to base the position in the interest and influence matrix on. The average relative position of the placings on the diagram of the different stakeholders has been taken as the input for the diagram. The Dutch perspective for this overview is chosen because of the availability and approachability of experts. It is important to note that the overview has other results in different countries because the level of government involvement in public transportation differs.

2.3. Ranking of objectives of crowd management

Now that the stakeholders and their interests and influence in crowd management have been determined, the objectives behind crowd management can be established. Firstly, using literature and expert interviews, possible objectives behind crowd management are identified. Then, the objectives are ranked to determine which objective is most important.

The possible objectives behind crowd management are based on literature ([17, 53, 71]) and each stakeholder was asked if any objectives were missing. Most stated that the objectives of *improving the safety, reliability/punctuality and comfort and increasing the ticket and shop revenues and decreasing the travel times* were the most important objectives. One stakeholder wanted to add the objective of more efficiently using rolling stock, leading to cost savings. Since the more efficient use of rolling stock can be seen as a result of the increased reliability and punctuality, this objective is not included separately. A summary of the interviews with stakeholders can be seen in appendix A.

In table 2.2, a ranking of the stakeholders' objectives of crowd management can be seen. The relative importance of each stakeholder is determined by the position of the stakeholder in figure 2.2, where a place in the bottom left has an importance of 0 and the top right corresponds to 1. The relative importance from 1 to 5 for the ranking of the objectives are directly asked to stakeholders in the interviews, where each objective is ranked independently. When more than one person belonging to a certain stakeholder was asked, the average is taken. For the rail infrastructure operator, the weights provided by the SBB and ProRail have been combined. For the station operator, transport operator and the decentralized authorities, only one person has been asked. For the station retail operator and national government, two people per stakeholder are asked and for the passengers four frequent users of public transportation are asked.

The last column shows the weighted average for each objective, where safety turns out to be the most important, followed by reliability/punctuality. Comfort and travel times have a more or less equal importance. The least important objective is ticket and shop revenues, where the shop revenues are only very important for retail operators. Large deviations from these results are not expected if stakeholders from different countries, more stakeholders or different stakeholders are asked to prioritize the objectives. As the relative importance of stakeholders differs per country, the most important objectives may also differ per country. However, because of the consistency in answers and relatively large differences in final weighted output, safety is assumed to remain most important.

Table 2.2: Stakeholder objective ranking. Importances based on input from experts [2,3,4,5,6,7,8,9,11,12,13] (see appendix A).

	Rail Infrastructure operator	*Station operator*	*Retail operator*	*Passenger*	*Transport operator*	*Decentralized authority*	*National Government*	Weighted Avg
Importance	0,9	0,7	0,4	0,6	0,6	0,5	0,6	
Safety	5	5	5	3	5	5	5	4,7
Reliability/punctuality	3	3	3	4	4	4	4	3,5
Comfort	2	3	3	4	3	3	3	2,9
Ticket and shop revenues	1	1	5	2	1	2	1	1,6
Travel times	2	3	3	4	2	4	3	2,8

2.4. Conclusions on stakeholders

The seven identified stakeholders of crowd management are the rail infrastructure operator, station operator, retail operator, passenger, transport operator, decentralized authorities and the national government. The rail infrastructure operator turns out to have the most interest and influence, followed by the station operator. From the questions on the objectives for stakeholders, it turns out that increasing the safety is by far the most important objective of crowd management, as indicated by almost all stakeholders. The reliability, punctuality and travel times determine the throughput and are of secondary importance. Increasing the safety and throughput will be used as the most important objectives behind crowd management in the following chapters.

3

Crowd management measures

This chapter addresses the research question on the effects of researched or previously applied crowd management measures. This knowledge is needed to know the possibilities of crowd management measures when a selection of the measures has to be made. Different measures that are thought of or already applied in practice are categorized and their effects and field of application determined. This is done by consulting literature and supplemented by interviews with experts. The list of measures and their characteristics serve as an important step in the framework when selecting effective measures.

3.1. Crowd management measures applied

The next step in the literature study is to determine the possible measures, their field of application and characteristics. In order to do this in a structured manner, first a categorization of all measures is made. After that, the measures that have already been applied in practice or are described in theoretical research are shown in an overview in table 3.1. The principles, characteristics and possible effects of the measures in this table are then explained per category in the sections thereafter. Some measures do not belong to one category of measures only, but have been placed under one of the categories here.

3.1.1. Crowd management categorization

According to Hoogendoorn and Daamen, there are four basic strategies for crowd management [33]. These will first be explained, after which the categorizations made by Wieringa [78] are explained. In the end of this section, a conclusion on the categorization of crowd management measures for this thesis is made.

The four basic categories of crowd management measures by Hoogendoorn and Daamen are to increase throughput, prevent blockades, distribute traffic and limit inflow [33]. In order to increase the throughput, most important bottlenecks in the infrastructure should be identified and possibly adapted. The second strategy is to prevent blockades such as people standing still on main routes and crossing flows. The available infrastructure should be efficiently used and an equal distribution of traffic over space or time contributes to that in the third strategy. The final strategy is to limit the inflow, in order to ensure the number of pedestrians remains below the critical density.

The categorization of crowd management measures as interpreted by Wieringa is based on her framework to mitigate risks at events with large crowds [78]. Baelde [4] has placed these measures into eight categories: information before and during the event or a combination of both, modifications to the area, planning, guidance, forcing or a combination of guidance and forcing.

The categorization by Hoogendoorn and Daamen is on a higher level than the one by Wieringa, which is more on a practical level. Furthermore, because of the scope of this thesis, the categorization of more reactive measures by Wieringa is less interesting. The four basic strategies by Hoogendoorn and Daamen can be applied more easily and are able to cover a wide range of measures and can therefore serve as a basis for the categorization of crowd management measures in this case. This will help structure the measures throughout the rest of the report.

3.1.2. Overview of crowd management measures

An overview of all measures that have already been applied in practice or are described in theoretical research is given in table 3.1. The order of the measures in the table is determined by how static or dynamic a measure is, which will be explained in chapter 5 (see figure 5.2). The costs of a measure are estimated by including both investment and operational costs over an application period of a year.

As can be seen, many measures have not been researched or applied yet, thus a scientific foundation on the most effective measure or the most beneficial circumstances to apply each measure is unavailable. The principles and possible effects of the measures are explained per category in the following sections.

Table 3.1: Crowd management measures, the field of application, basic strategy used, characteristics (+ indicate a positive effect, - a negative effect), indication on costs (€ up to €10,000, €€ for €10,000-100,000 and €€€ for more than €100,000) and reference to case studies.

↑ Static

Dynamic ↓

		Increase throughput	Prevention of blockades	Distribution of traffic	Limitation of inflow	Effects off-peak	Punctuality	In-vehicle comfort	Self-organization	Surface area	Effects on minority travelers	Complicated (multiple stakeholders)	Communication required	For specific group only		
Measure	**Field of application**	**Strategy**				**Characteristics**									**Cost**	**Ref**
Creation of doors for each direction	Stations with 1 large door	x				-			+						€€€	
Funnel shaped corridors	Large angle corners	x							+	-					€€	
Separating bi-directional flows on path	Wide platform with bidirectional flow	x				-			+	-					€€	
Handrail on stairs	Stairs wider than 6 meters	x							+	-					€	[61]
Gates/kiosks/vending machines relocation	Queue interference		x							+		-			€€	
Increase attractiveness of route	Predetermined locations of less used exits			x										+/-	€-€€	[60]
Markings on floor	Crossings	x	x			-			+						€	[61]
Arrival tracks separation	Simultaneous arrival of trains			x			+					-	-		€€	
Fast and slow walking lanes	Longer stretches with more lanes in same direction	x							+				-		€	
Boarding/alighting procedure change	Counterflows and pressure when boarding	x	x				+		+				-		€-€€	[3]
Arrival pattern offset	Simultaneous arrival of trains			x			+					-	-		€€	[37]
Direction gate placement	Large crossing flows towards exits	x	x								-		-		€€	[45]
Headway decrease - #pax constant	Large flows after arrival			x								-	-		€€€	
Object in front of bottleneck	Bottlenecks with arch-forming	x	x			-			+	-					€€	[61]
Clear indication of less used exits	On predetermined locations of less used exits			x		-								+/-	€	
Information provision on train stopping position	Inefficient use of platform length and train doors (first and last wagons)			x			+	+							€-€€€	[46] [75]
Light/music/scent	Inefficient use of platform length and train doors			x			+	+						+/-	€€	[49] [71]
Waiting areas	Inefficient waiting or preparation for activity locations		x	x										+/-	€	
Only exiting/entering from station	Many travelers temporarily in same direction	x			x						-	-	-		€	[17]
Walking time information provision	Inefficient distribution over routes			x							+				€€	
Headway increase	Platforms structurally occupied			x	x		+	-			-	-	-		€	
Crowdedness indicator	Inefficient use of train doors			x			+	+				-	-		€€€	
Train stopping position adjustment	Inefficient use of exits			x		-	+								€	[69]
Escalator direction change	Heavy temporary loads	x			x						-				€	
Holding	Delay of vehicle			x			+				-				€	[74]
Boarding limits	Next vehicle nearby				x		+	+			-				€	[19]
Gating	Demands exceeding capacity				x		+	+			-				€-€€	[5]
Delayed arrival	Platform occupied with passengers from previous train			x			+				-				€	
Manual intervention to disperse	Stations where problems are expected frequently	x	x	x					+						€-€€	

3.1.3. Increase throughput

The first category of crowd management measures is to increase the throughput. In order to do so, most important bottlenecks in the infrastructure should be adapted. The measures which are capable of relieving bottlenecks from table 3.1 are discussed below.

Separating bidirectional flows on path
The first measure is to place obstacles such as columns, trees or handrails on a path in order to separate the bidirectional flow into two lanes of unidirectional flow. This could lead to less interference because otherwise impatient pedestrians may try to find gaps to overtake, often leading to obstructions for the opposing flow [30]. Also, smaller pedestrian streams in one direction require relatively more space [15]. This measure is usually inflexible, but in Rio de Janeiro handrails are known to be accompanied by stewards who can move the rails to adjust the path widths. The measure can only be introduced in places with wide paths in order for the routes to remain of sufficient width. In case of equal flow from both directions (50/50%), a capacity loss of 4 to 9 % can occur, depending on the density level [8, 15]. When the directional ratio shifts to 90/10%, the capacity loss can increase 12 to 14 %.

Funnel shaped corridors
If there are corners in the infrastructure the pedestrian flow has to pass through, a funnel shaped object can be placed in the corner. A bottleneck is then convex, which is optimal according to Bolay [10]. This prevents people from taking a path from the corner which is perpendicular to the path straight through the bottleneck.

Creation of two doors
In order to separate flows, two smaller doors near the walls of a hallway are more efficient than one door with double width [30]. This is because with one door, walking directions are switched more frequently, leading to temporary deadlock situations. With two doors, self-organizing flow will allow each door to be used for only one direction. It must be noted that having open doors perpendicular to the wall can result in significantly lower capacities, so doors should be able to open completely or be sliding doors [68]. The presence of multiple doors in the station may also lead to confusion in the wayfinding process [9].

Object in front of bottleneck
Placing an object in front of a bottleneck can increase the outflow in panic situations by 50% [29]. This is because it can prevent the faster-is-slower effect and relieve pressure build up due to physical interactions. People can otherwise get injured and form an obstacle themselves for other panicking people in the crowd. Most efficient is to place the obstacle asymmetrically, as this prevents an equilibrium of forces which may temporarily stop the outflow [30]. The placement of the object may affect the flows negatively in non panic situations because of the blocking of visibility towards the exit leading to confusion for passengers. Thiellier et al. have studied the effects of placing an obstacle at different positions upstream a stairs [61]. It was concluded that an obstacle 0.5m before the staircase has a small positive effect on the capacity of the stairs (0-10%), the density decreases significantly when the obstacle is placed on the stairs and slightly when the obstacle is placed upstream the stairs. The speed did not change much with the placing of an obstacle at different locations.

Markings on floor
Markings on the floor can indicate the walking directions and therefore increase the throughput at crossings. Furthermore, the markings lead to a reduction in obstructive interactions [25]. In order for the markings to have an effect, they should be clearly visible and will therefore be less effective in more crowded situations. The measure is relatively cheap and easy to apply, but not much literature is available on the effects, where to apply and how the markings should look. Thiellier et al. conducted research on the effect of markings on stairs at the train station of Leiden and concluded that the markings had a negative effect on the

total capacity of the stairs in downward peak flows [61]. The indication of the markings were followed best by travelers when they came from the right side, with not too many travelers and with travelers also walking up the stairs.

Handrail on stairs

A more physical way to increase the throughput at stairs is to place a handrail in the middle of the stairs. This halves the effective width of the stairs, leading to less space for pedestrians to overtake on the stairs and less difference in walking speeds. Placing a handrail in the middle of wide stairs can increase the comfort for passengers and ensure that more of the width of the stairs is used. In the research by Thiellier et al. in the train station of Leiden, a handrail was placed on stairs wider than 6 meters, and evidence was found that this could increase the flow in downward direction [61]. Since maximum capacity was not reached in the experiment and the comparison between the measurement with and without the handrail might be flawed, no exact percentage is named. The density on the stairs seems to have been increased due to the reduction of effective surface area.

Fast and slow walking lanes

Similarly to the markings on the floor, also fast and slow pedestrian lanes can be created. For example, faster travelers can be stimulated to use the left lane, whereas people not in a hurry or on a telephone can use the slower right lane. In Liverpool, a fast pedestrian lane was introduced [27], but to the best of the authors' knowledge, no literature is available on the effects of the measure.

Escalator direction

Another way to increase the throughput is to temporarily change the direction of the escalators. Escalators have a measured capacity in the vicinity of 65 to 100 passengers per minute [36, 59]. Passengers heading towards the exit of the station are more clustered than departing passengers because of the train arrival schedule. When a train arrives, temporarily reversing the escalator direction towards the exit of the station can theoretically increase the outflow in the station by the number previously stated. However, a temporary closure of the escalator is required when reversing the direction. Passengers wanting to board a train then have to use the remaining escalator or the stairs heading to the platform. This measure is applied in multiple stations and is temporary, cheap and flexible [64].

Boarding and alighting procedure change

In many countries, there are unwritten rules about travelers first exiting from the metro or train before the boarding of new travelers begins. However, with high congestion or different cultures, it can occur that the boarding and alighting happens simultaneously resulting in bidirectional flows and a capacity loss. In the Rio de Janeiro and Sao Paulo metro, a different procedure for boarding and alighting has been applied where waiting lines where created in front of metro doors, with enough space for alighting passengers left. A steward released the queue after the alighting so boarding could start. This led to 3 times more efficient boarding at doors where this measure was applied than at the next door where the measure was not applied, even though travelers and employees were not used to the measure yet (M. Campanella, personal communication, March 9, 2017, see appendix A). The measure is relatively easy to apply at peak hours but does require the accompanying by stewards to increase the compliance of travelers. Baee et al. modeled three boarding and alighting procedures: space division by isolating the entrance and exit out of wagons, dedicated doors and time division. To use these interpretations of changing the boarding and alighting procedure, communication towards the traveler is required. The average dwell time turned out to be the least when space division was applied, with a reduction of up to 15%, depending on the initial occupancy of the wagon. The space division and dedicated doors resulted in less average number of collisions a person experiences, where the time division was not modeled [3].

3.1.4. Prevent blockades

The second strategy for crowd management measures is to prevent blockades. Separation of activity locations and crossing flows helps to do so.

Direction gates on platform
In order to prevent Braess' paradox, a direction gate can be used in order to force people to use a particular exit. An example is applied in a metro station in Santiago de Chile. At this station called Tobalaba, a gate was installed at a platform between the stairs of the two exits. This enforced people to board the metro depending on where they would exit Tobalaba station, people transferring to line 1 now have to board the back half of the metro and people exiting the station have to board the front half of the metro. This avoids the two flows from crossing and has significant effects on the egress times at the station [23]. The measure is only applied in peak hours, with the gates closed between 7:00 and 9:00. A decrease of the travel time for the passengers on the northern line of 6.5% is stated [45]. Moreover, since the frequencies of the lines could be increased, the transport capacity of the line at the station increased by 5% and standard deviation across days decreased almost 14%, meaning that trains run more frequently and reliably. The perception of the measure of passengers was collected by surveys and was quite positive. By the opening and closing of the gate on the platform, the measure can be applied temporarily, as was done in this case with the presence of stewards. It however requires exhaustive communication before the measure is applied, since passengers have to know where they have to board the metro and are negatively affected by having to walk much longer to the desired exit if they board in the wrong place. Also, some passengers are likely to have to walk longer, thus the measure affects the convenience of some passengers.

Relocate gates, kiosks and machines
Another way to prevent blockades is to place gates, kiosks and vending machines in a strategic place because queues in front of them can form a substantial blockade. Besides, the surface area occupied by the gates, kiosks or vending machines can be used by pedestrians. However, since the arriving of trains is crucial for the usage and the revenues of the kiosks, the application of the measure can be complicated due to conflicting interests [70].

Create waiting locations
Platforms at train stations in the Netherlands are required to have respectively a safety zone, a walking zone and a stand-wait zone next to the track [54]. Bosina et al. conclude in their work that pedestrians seem to prefer waiting locations where they are undisturbed and do not disturb other people. Only closer to arrival or if the densities become higher, pedestrian start to increasingly use walking space to wait [11]. Also in other parts of the station, waiting zones can be created in order to prevent blockades. For example when an activity such as checking in or out has to be done, travelers have to prepare by getting their ticket. When the activity can not be seen from far, the preparation can make people become a bottleneck, which a dedicated waiting zone can prevent. The measure can be applied relatively easy, by dedicating and indicating a clear waiting location, at a location where no interference between flows occur. This may however decrease the total area of the walking zone.

3.1.5. Distribution of traffic

The distribution of passengers can be done over space or over time, which are treated in separate sections here.

Distribution over space

Information provision on train stopping position
Information can help in many ways to distribute traffic more evenly. An example of a way to

provide the information is the 'Intelligent Platform Bar', which indicates where an incoming train will stop and therefore helps to disperse travelers over the platform [52]. This decreases boarding and alighting times and increases transfer capacity. The Intelligent Platform Bar was first introduced at station Den Bosch as a proof of concept but will also be introduced late summer 2017 at station Schiphol Airport [75]. Quantitative figures are not shared, but can be stated as significant (see page 78). With LED-bars over the full length of the platform, the measure is expensive and the station infrastructure needs to be suited to carry the bars. A simpler way to provide information on the train stopping position was mentioned in an interview with Jasper van Zanten, working for Dutch Railways, who said that also simple LED lights in the platform can indicate where the train will stop. This solution will be tested in the near future. A cheaper but static way to provide information on the stopping position of the train is to indicate the boarding zones with signs on the platform, which is applied in the train line between Amsterdam and Eindhoven for local trains [46]. Crucial for this measure is for the train driver to stop the train in the exact correct position and to have uniform rolling stock, making it less flexible than LED strips in the platform or the Intelligent Platform Bar.

Crowdedness indicators

Besides the information on the train stopping position, also information can be provided on the crowding in the train. This has been tested on one line between Zwolle and Roosendaal, the Netherlands. Eleven trains were equipped with infrared sensors to measure crowding of the train compartments. The outcomes could be viewed real-time in an app, where three different colors indicated the crowdedness throughout the train [65]. Even though the experiment was a success because of the increased comfort for passengers, it was not extended due to the costs of about €2 million [66]. The installation of the required sensors is expensive and inflexible. Galetzka and de Vries studied the effect of having information on the available seats on each wagon of a train shown on the information panel of trains, and discovered a marginally significant effect on the dispersion over the platform [25].

Lights, music and scent

Another way to distribute people over space is the introduction of strategically placed lights, music or scent, which may affect the travelers to disperse more evenly over the platform [71]. The theory behind this is that travelers prefer waiting in a comfortable area. Furthermore, light can increase the visibility and orientation of travelers and can optically widen entrances [25]. McDonnel states in his research that compared to a control group, people exposed to a pleasant scent or music report lower values of discomfort while waiting [42]. Van Hagen et al. state that recreational 'lust' travelers should be in a stimulating environment in order to positively influence the waiting time, whereas goal oriented 'must' travelers are more positively influenced by a calming environment [72]. Also, research by Oerlemans showed a trend for the effect of additional lights, but that effect was not found to be significant [49]. This indicates the sensitivity of the measure to have a positive effect in general. It has to be applied on predetermined locations where suitable waiting locations on the platform are established, but the decision on when to actually use the measure is quite flexible.

Increase attractiveness of route

In order to draw passengers to a less used route, the attractiveness of the route can be increased by for example placing art, water fountains, infotainment, vegetation or other visual attractions on the route [24]. In his study on the usage of tunnels at Amsterdam Central Station, Verhoeff also suggests that walking time is not the only factor influencing route choice. Also congestion and crowding, the available height of each tunnel, the aesthetic quality, available retail and available destinations can have an influence on route choice [76]. Measures can be introduced to increase the utility of routes using this information. Lust travelers tend to be more influenced by the increase in attractiveness than must travelers [25]. An example is the use of the piano stairs, where an increase of the use of stairs of 66% is reported [60].

Clear indication of less used exits

Another way to draw passengers to a less used route is to more clearly indicate these routes.

Extra visual or auditive signs can affect the wayfinding of unfamiliar passengers, as was done in Rio de Janeiro on new years eve [17]. Furthermore, it was found that throughput can be increased and blockades prevented by having subtle wayfinding signs [7]. This measure is more flexible but has to be applied carefully because it can also lead to confusion in the wayfinding process.

Train stopping position adjustment
The train stopping position also affects the passengers route after alighting or the entrance location in the station and boarding position because walking distance and time is a significant factor in the route choice of pedestrians [13]. The effect of this was studied by van den Heuvel by adjusting the stopping position of the train 50 meters in downstream direction at Schiphol station. Because of this better alignment to the stairs and escalators to the platform, the boarding and alighting times decreased. In peak hours with high demand, the station dwell times decreased from 144 seconds to 112 seconds [69]. Moreover, the station dwell times variation decreased by 50%. These effects are however not found to be significant with low passenger demands. The measure can be applied quite easily, as it only requires a temporary sign to overrule the regular stop position sign and no communication towards the passengers is required.

Arrival tracks separated
Since 2015, the train timetable in the Netherlands is structurally tested on overcrowdedness on platforms (see appendix A). Trains arriving at the same time at opposing tracks may otherwise cause problems at the platforms or the vertical infrastructure. By changing the arrival track of a train, the pressure can be relieved over multiple platforms. This measure can be complicated to apply, as it requires a change in the schedule, can influence the capacity of the rail and is limited by the rail infrastructure.

Manual intervention
Manual intervention can be applied in order to suggest people to disperse over the platform. For example, at the train station of Schiphol, a team is present to go down to the platform and ask people to spread if densities are becoming too high at certain parts of the platform. The measure requires the presence of a team and is therefore costly, but can be applied flexibly. As usually the team acts reactively, it can be seen as a crowd control measure but since it can be applied also in a more proactive way, it is also listed as a crowd management measure. The effects of the measure strongly depend on the size of the team and the method used to ask people to disperse.

Walking time information provision
In situations with high levels of congestion, the shortest route might not be the quickest route anymore. If there are multiple routes possible to reach a destination, a more efficient distribution over these routes can be achieved by providing people with travel information. This information can consist of walking times, as was done in Sao Paulo (M. Campanella, personal communication, March 9, 2017, see appendix A). To be able to provide accurate travel time information, the real-time status of the different routes needs to be known and shown to the travelers prior to where the routes split. The gathering of this data can be complicated because of the required sensors or observers. This measure is applicable in stations with multiple routes to the same destination and where the traveler is unable to judge the 'costs' of each route himself.

Distribution over time

Decrease headway
A rather drastic way to influence the distribution of passengers over time is to decrease the headway, assuming the number of passengers remains constant. With lines running

more frequently passengers will be less clustered, because the peaks of flow towards the exit are lower and people can have a more uniform arrival pattern at the station since less passengers plan their trip and arrive at the station at more random times. It can however be very complicated to decrease the headway because of the maximum capacity of the railway infrastructure and the extra resources needed to run extra trains such as staff and rolling stock. To make a new running schedule is a complicated task and requires communication towards the passengers so the measure cannot be applied quickly.

Adjust arrival pattern

The arrival pattern of trains or metros can be adjusted in order to avoid conflicting movements between passengers of different trains or metros. The demand of the station capacity will then remain lower in order to have higher flows and throughput of passengers. King et al. have for example examined the effect of the arrival pattern of trains on crowd congestion in interchange stations, with a case study at Bloor-Yonge subway station in Toronto [37]. In the simulation, the train loads, dwell times and headway are fixed and the offset between the arrival of different lines is varied. The output of the simulation is the average time in seconds a passenger experiences LOS F conditions for the 25 different arrival patterns. A reduction of congestion of up to a 43% was found between the best and worst case scenarios when at capacity and up to 63% when traffic volume was lower. The principle behind this method to reduce the congestion is the scheduling of the arrival pattern. It is generally advantageous when the offset of the arrival of two different lines is set at about half of the headway of the lines, because boarding and alighting passengers of different lines then have the least interference.

Holding

An operational strategy to maintain headways is holding. The holding of vehicles at stations can increase the reliability, resulting in shorter travel times and less crowding [74]. In a case study in the Hague by van Oort et al., the average level of irregularity was found to decrease from 20 to 15% [74]. The measure is relatively easy to apply in the case one vehicle is disrupted but the location of the holding should be carefully determined. Holding can negatively affect the travel times of passengers already on the vehicle and willing to continue on the line.

3.1.6. Inflow limitations

In order to remain below the critical density at a station, the inflow of pedestrians can be limited. This can be done by using gates, temporal closings of stations or changes in the schedule.

Gating

In exceptional cases such as events the inflow into the station can be restricted in order for the platform to remain below maximum capacity. Queues will then build up outside of the station, rather than inside the station, which can prevent dangerous situations. An example of the use of gates to limit the inflow is modeled for a case in Vienna. Bauer et al. simulate decision rules for access restrictions for a metro station next to a large football stadium [5]. In the simulation, all access gates to the station permit any amount of pedestrians lanes between 0 (doors closed) and six (fully open), which is adjusted depending on estimates of the number of people on the platform. Therefore, in the simulation, the overcrowding limit is not reached at the platform, whereas when there are no gating measures there would be serious safety concerns on the platform. The travel time required for the transportation of all passengers increases by almost 20 minutes as compared to when all entrances are fully open. However, this does not take into account that dense crowds on the platforms could increase boarding times significantly. The gating measure can be applied temporarily and in special cases with large peak demands. It can affect the comfort of passengers by relocating the waiting area and have a negative effect on some passengers with an increased travel time.

Delayed arrival

A measure that can be applied occasionally is to delay the arrival. If a train arrives while the platform is still occupied by alighting passengers from the previous train, interference between the boarding and alighting flows of the successive trains can occur. Waiting with the arrival until the platform is sufficiently cleared is a flexible measure but can negatively influence the passengers on the train, whom have a longer in-vehicle time.

Increase headway

Similarly to the delayed arrival to prevent the interference from boarding and alighting passengers from two successive trains, the headway can be increased. This is however a quite drastic and complex measure, as it requires extensive communication towards the passengers and negatively influences many passengers because the waiting times increases with increasing headway and this is badly perceived by the passengers [71]. Also, the congestion on other stations may increase. The measure can be applied in cases of events or holidays.

Only entering or exiting from station

To prevent bidirectional flows the station can be restricted to only exiting or entering passengers. This measure also requires extensive communication to prevent discontent by passengers unable to follow their regular patterns. The measure is complicated and can be applied for special events when many people travel in the same direction. Having a bidirectional 90-10% flow is prevented, which could otherwise lead to 13% capacity loss [15]. An example of the application is for new years eve in Rio de Janeiro, where multiple crowd management measures are taken in order to cope with the large flows in the metro stations for the celebrations in Copacabana [17].

Boarding limits

A final strategy to limit the inflow is to introduce boarding limits. Passengers wanting to board after the limit is exceeded are denied access to the station through the ticket gates or are asked to board the following train or metro. The measure can frustrate passengers with an increased waiting time. In a research by Delgado et al. about boarding limits in combination with holding, it was concluded that this can lead to excess waiting time savings of up to 77% and very low variability in performance in comparison to no control strategy [19]. However, it was found implementing boarding limits is only effective when the next arriving vehicle is nearby.

3.2. Conclusions on literature study

All crowd management measures are categorized into four basic strategies: increase throughput, prevent blockades, distribute traffic over available infrastructure and limit the inflow. Through literature research, interviews and new contributions, a list of 29 practical crowd management measures has been created under these categories. An overview of the measures' field of application and characteristics can be seen in table 3.1, which helps decision makers to select a measure. This table will serve as input for the selection of measures in the framework. No guidelines or framework exists to guide towards suitable measures and therefore this will be addressed in this thesis.

4

Assessment of measures

With all possible measures known from chapter 3, the next step is to determine how the effects of the measures can be assessed. The possible methods to assess measures are discussed in section 4.1. After that, the focus is on the method of using models to assess measures, as this can be a cost-effective alternative to testing measures in practice. This chapter then answers the research question on the functionalities that a model should have to model crowd management measures. Using this information, the reader can then determine if and which model is capable of assessing the effects of the measure accurately. The requirements that are needed to model a measure can be found in section 4.2, including an example of how a certain commercial model complies with given requirements. This knowledge is applied in the framework.

In order to assess the effects of measures on the established objectives, indicators are used. In section 4.3, a list of possible indicators to assess the measures (using either a model or a real life test) is discussed. The knowledge on the indicators is needed in the framework, when a decision has to be made on how to assess the effect of applied measures. Conclusions on this chapter are drawn in section 4.4.

4.1. Methods to assess measures

To determine if a measure can have the desired effect, an assessment is needed. This assessment can be done with choice experiments, experiments in real life or with simulations, which will be discussed in this section.

Stated choice experiments can be used to gain a priori insight into the effects of some measure. If measures are classified into "hard" measures to which travelers are obliged to comply, and "soft" measures where a traveler has the option to ignore it [44], only the "soft" measures are possible to test in stated choice experiments. The choice experiments can only be used to discover trade-offs in the decision making process and not to assess measures directly on achieving the objectives. Therefore, stated choice experiments will not be discussed further.

Tests in real life have the advantage that the complete human decision making process is captured, which can be complex to predict. Therefore, an accurate insight into the effects of a measure can be obtained. However, testing in many stations is generally undesired because of a risk for unexpected and unsafe situations. Furthermore, testing can be complex because communication to the passengers may be required and multiple stakeholders need to be involved. Depending on the measure to be assessed, this can also be expensive.

Models are used to predict and assess possible effects of applying crowd management measures. This can be a cost-effective alternative to testing measures in real life to determine if a measure gives the desired results. There have been many developments in the recent years concerning pedestrian models. Therefore, a wide range of models is available. For a review of scientific models, activity scheduling and route choice and pedestrian demand, the reader is referred to [20, 34, 35]. Models generally are unable to accurately model the full decision making, route choice and activity scheduling process. Therefore, models can be used as an indication for the effects of a measure, but the results should not be taken for granted. The choice for a suitable model depends on the measure to be assessed. In the next section, the selection of a suitable model to assess a certain measure is elaborated upon.

4.2. Applicability of models for the assessment of measures

When selecting a model, attention should be paid to the applicability of a model for a specific measure, the validation, calibration and computational expense of a model. This section focuses on the applicability of models and assumes that only valid models are considered. To evaluate the applicability of models, it is first determined which characteristics of a model are required in order to model a measure. Then, an example of an assessment of what requirements a certain commercial model can fulfill is given.

4.2.1. Requirements for models

The characteristics of a model that are required to model a measure differs per measure. In table 4.1, the model characteristics needed to accurately model a measure are provided. A “1” indicates that 1 of the 2 persons that filled in the table independently thought that this functionality of a model would be required to model a measure and a “2” indicates that both agree that it is needed. The people that filled in this table were the author, and a researcher from the TU Delft specialized in (the modeling of) crowd management ([15], see appendix A).

The characteristics *basic pedestrian motion cases, self-organizing flow, global and local route choice and multiple user classes* that are used in table 4.1 are derived from Duives [20]. The specific basic pedestrian motion cases or self-organizing flow phenomena that are not required to model any measure are omitted from the table. The distinction in models based on psychology, is used to derive the characteristics of *compliance to information and advanced human decision making* [51]. The final characteristic is the *demand arrival pattern*, which is derived from expert opinions. All these characteristics together are assumed to cover most of the pedestrian walking phenomena relevant in crowd management and within the scope of this research. Therefore, it is believed that using these characteristics a complete impression of requirements to model each measure can be obtained. The measures are taken from chapter 3. A brief elaboration of the characteristics follows hereafter.

Basic pedestrian motion cases
Duives describes eight pedestrian motion base cases, with only one predominant motion base case within each situation [20]. The basic pedestrian motion cases are reduced here to *bi-directional flow, crossing flow and turning corners*, because for all measures, these are the only three that are required from a model. These cases are treated separately here.

Self-organizing flow
According to Helbing, pedestrians move freely below a certain density and after that repulsive

interactions with other pedestrians occur, leading to self-organizing phenomena [28]. Examples of self-organizing flow phenomena are *the forming of separate lanes of uniform walking directions, the faster-is-slower effect and herding*. The faster-is-slower effect is when high densities of pedestrians cause arc forming upstream of a bottleneck and therefore limit the inflow. The herding effect describes the case where individuals follow others instead of the optimal route. Some of these phenomena can be crucial to represent in a model to ensure enough accuracy for particular modeled measures. The possibility for a model to accurately reproduce each self-organizing flow phenomenon separately is used to determine the fulfilling of the requirements.

Compliance to information
If a measure includes providing information to travelers, it needs to be known what the share is of complying passengers to whom the advice is given to. This psychological factor is then required to be incorporated in a model, or otherwise assumptions on the compliance have to be made.

Advanced human decision making
Decisions of agents on the route choice are in most models based on the desired destination, the distance and interaction with other travelers. Some measures affect travelers based on different factors and these can have influence on their route choice as well. For example the aesthetic quality, the available destinations and the availability of retail can also influence the decision making process.

Global route choice
The global route choice of pedestrians is made on the tactical level. The objective of pedestrians that are used in models can be distinguished into four groups: minimization of shortest path, minimizing deviation of destination, maximize utility while walking or minimize walking discomfort [20]. Since these objectives may differ between travelers, to effectively model some measures, different routes have to be used rather than an assignment based solely on the shortest path. Global route choice can be affected by measures, which should then also lead to a different outcome of the objective function and a global route choice that changes en-route. Also, not all travelers have a fixed destination and can switch destinations based on the circumstances. The effectiveness of some measures depend on the ability and willingness of pedestrians to change route.

Local route choice
The local route choice of pedestrians is made more on an operational level. The modeling of diversions from a selected global route because of current congestion levels, requires adaptive local route choice. A model is assumed to be capable of adaptive route choice on a local level if an objective for local route choice is implemented to cause local adjustments of the route.

Collision avoidance
In some models, long range vision can be implemented for a realistic representation of collision avoidance. Some other models have collision avoidance on a more local scale or even no collision avoidance method at all and therefore might provide less realistic results. If a model contains a set of rules to avoid local collisions, the model is assumed to fulfill this requirement.

Demand arrival schedule
The arrival of passengers can have large deviations and be shifted over time and space due to for example delayed vehicles or changed platforms. Models that are capable of incorporating and controlling these large peaks in demand are then needed. Also, the platform and specific stopping position of a train is required in order to model the inflow location.

Multiple user classes
Different travelers can respond in a complete different manner to certain measures. For example, already a distinction between lust and must travelers was made in chapter 3, where

lust travelers are more influenced by a stimulating environment. Some measures may affect one specific group of travelers only. Models are more accurate if they incorporate heterogeneity between these travelers groups, fast and slow walkers, tourists and commuters etc.

Table 4.1: Requirements to model each measure. A 1 indicates that 1 of the 2 rating persons (model expert [15] and the author) believes the requirement is needed for the measure and a 2 indicates that both agree that it is needed.

Measure	Bi-directional flow	Crossing flow	Corners	Lane formation	Faster-is-slower effect	Herding	Compliance to information	Advanced decision making	Global route choice	Local route choice	Collision avoidance	Demand arrival pattern	Multiple user classes
Creation of doors for each direction	2			1						2			
Funnel shaped corridors			2										
Separating bi-directional flows on path	2	1		1									
Handrail on stairs	2			1				1					
Gates/kiosks/vending machines relocation		1						1	1		1		
Increase attractiveness of route						1		1	1				1
Markings on floor	1	1		1			2	2		2			
Arrival tracks separation												2	
Fast and slow walking lanes	1	1		1			1	2		2			1
Boarding/alighting procedure change	1							1					
Arrival pattern offset												2	
Direction gate placement	2							1		2			
Headway decrease - #pax constant												1	
Object in front of bottleneck					2								
Clear indication of less used exits							2	2	2				1
Information provision on train stopping position							2	1					1
Light/music/scent								2	2	2			1
Waiting areas							2	2	1		1		1
Only exiting/entering from station												2	
Walking time information provision							2		2				
Headway increase												2	
Crowdedness indicator							2	2	1				1
Adjust train stopping position										1		2	
Escalator direction change										1			
Holding												2	
Boarding limits												2	
Gating													
Delayed arrival												2	
Manual intervention to disperse							1	2	1	2			

4.2.2. Example assessment of the suitability of a model

Now that the requirements to model each measure are known, it can be determined if specific models can fulfill these requirements and therefore model a measure sufficiently accurate. As an example to show how to determine which requirements are met, the MassMotion model is used here and the results are shown in table 4.2. No specific measure to assess is kept in mind, so the model is assessed on all characteristics mentioned in the previous section. MassMotion is a commercial software model developed by Oasys and offers an advanced pedestrian simulation and crowd analysis tool. It is a microscopic model, using a modified version of the social forces algorithm [48]. The characteristics in table 4.1 are assumed to be equally important here.

Basic pedestrian motion cases
MassMotion is based on a modified social force model. Most social force models are known to be suited for the modeling of pedestrian motion base cases [20]. The forces in MassMotion (either repulsive or attractive) consist of the goal of the passenger, neighbors, cohesion, collision, drift, orderly queuing and corners. MassMotion is therefore suitable to model flows from one or more directions and going around corners.

Self-organizing flow
With the cohesion force, travelers are pushed towards other travelers with the same target route, which means that lane formation can be simulated in MassMotion. However, the targets are established independently from each other. This means that only a part of the herding effect can be incorporated in MassMotion. The orderly queuing force is a force pushing travelers towards the middle of a target when approaching, thus the faster-is-slower effect can be modeled in MassMotion.

Compliance to information
In MassMotion, the route choice is performed by minimizing the costs, based on an assigned weight to different components of the route such as horizontal and vertical distance and queue costs, in order to determine the relative importance of those aspects when selecting the route. It is not possible to provide information to travelers to see what effect it has. Therefore, no assessment on the compliance to information can be derived from the model.

Advanced human decision making
The physical characteristics and personality of travelers are randomly assigned in MassMotion and can be adapted. This consists of the size of the traveler, a desired speed, a direction bias for when facing an opposing flow and a cost for the route choice. As mentioned previously, the factors that the route choice is based upon are limited. It is not possible to implement other aspects travelers can base their decision on such as the aesthetic quality, the available destinations and the availability of retail.

Global route choice
Travelers are placed on the scene with events, which can range from journeys with specific entry times to vehicles with regular schedules. All travelers have a task to perform such as going to the street portal, which determines their goal. The travelers are navigating to the best route to achieve that goal based on awareness on the environment and congestion and the route is periodically re-evaluated. Each traveler is executing its current first task and all tasks are executed in order. This means that an adaptation to the schedule of tasks to be performed is not possible.

Local route choice
The local route choice is based on the costs of each route per floor, consisting of horizontal distances, vertical displacements, queue time, opposing flows and penalties for closed targets and backtracks [48]. Each route choice has a small random factor, so some travelers will pick routes slightly less than optimal. With the different personalities and thus different weights for the cost determination of a route and the randomness factor, not all passengers will thus take the same route. With the periodically re-evaluated route choices as the situation changes, MassMotion is able to change routes based on new conditions.

Collision avoidance
Social force models generally are unable to deal with pedestrian-pedestrian contact and the

avoiding of collisions altogether and require extensive tuning of force parameters [38]. In MassMotion, all travelers are aware of other travelers location, speed and size within a particular range. The range is dependent on the speed of the traveler and the local density [48]. The modeling of collision avoidance is therefore possible in MassMotion but must be carefully interpreted.

Demand arrival schedule
In MassMotion, movements are based on events, which can be predetermined origin destinations, evacuations, vehicle arrivals and departures or timetables with a manipulation of the schedule. This allows for planning of the arrival pattern and also more advanced manipulations such as delayed arrivals or changed platforms or stopping positions.

Multiple user classes
As mentioned previously, travelers have physical characteristics and a personality. Adjusting these can ensure that multiple user classes can be implemented in the model.

In table 4.2, the results of the assessment of MassMotion can be seen. These results of the assessment of a model, in this case MassMotion, can then be used together with table 4.1 to determine whether or not a model is suitable to model a measure. It can be concluded that MassMotion performs particularly well for most “hard” measures, where passengers are obliged to comply such as funnel shaped corridors, arrival track separation and headway decrease. MassMotion generally performs poor on “soft” measures, where passengers have a choice to comply, such as markings on floor, clear indication of exits and crowdedness indicators. MassMotion is verified and validated [2], but like other microscopic models, can be computationally expensive.

Table 4.2: Example assessment of suitability MassMotion

	Bi-directional flow	Crossing flow	Corners	Lane formation	Faster-is-slower effect	Herding	Compliance to information	Advanced decision making	Global route choice	Local route choice	Collision avoidance	Demand arrival pattern	Multiple user classes
Suitability of MassMotion	++	++	++	++	+	-	- -	- -	-	+	+	++	++

4.3. Indicators to assess the effect of measures on the objectives

In chapter 2, the objectives of crowd management have been established. These objectives have to be translated into quantifiable indicators in order to assess the effectiveness of measures. In order to do so, first the case studies where measures are applied in reality or in simulations are examined on which indicators have been used, summarized in table 4.3. All indicators used are then explained. Finally, table 4.4 shows which indicator can be used for each objective.

4.3.1. Applied indicators in case studies

In the researched literature on measures taken at stations, indicators did not follow from the objectives but rather were established independently. In table 4.3, the indicators used for different cases are shown. As can be seen, for several cases, the Level of Service (LOS, see section Macroscopic flow properties) and macroscopic characteristics of flow served as indicators to assess the effectiveness of the measure. In cases where microscopic simulation models were used, the LOS and more complicated indicators such as walking speeds were used. In many practical cases, more qualitative indicators such as the perceptions of involved people on stressfulness or the observed smoothness of the process were used. Clearly, a lot of different indicators are used, not necessarily directly related to the established objectives. These indicators used in literature serve as input for the possible indicators to use for specific objectives.

Table 4.3: Indicators used in reference cases, where x shows that indicator has been used

		LOS	Density	Flow	Velocity	Waiting time	Walking time	Platform clearance time	Dwell times	Perceptions of stressfulness	People in emergency	Variability	Distributions over area	
Case	**Scope of case**	**Indicators**												**Ref**
Den Bosch	Spreading of people over platform			x									x	App A
No location	Decrease waiting times with holding					x						x		[74]
Kuala Lumpur	Assessing movement of pedestrians	x			x									[9]
Leiden	Increase throughput		x	x	x									[61]
Lisbon	Predict impact of access gates	x			x	x	x							[32]
Rio de Janeiro	Cope with event flows	x								x	x			[17]
Santiago de Chile	Increase platform efficiency			x			x	x				x		[45]
Schiphol	Increase platform efficiency								x			x		[69]
Toronto	Arrival schedule optimization	x												[37]
Vienna	Gates for access restriction			x	x									[58]
Vienna	Gates for access restriction		x											[5]

Now that the most commonly applied indicators are known, the suitability of these indicators can be discussed. The application of these indicators is explained below, in order to see which can be suitable for an assessment of crowd management measures. The indicators seen in table 4.3 are categorized into *macroscopic flow properties, platform, dwell and platform clearance times, perceptive indicators, incident counts and secondary indicators such as the variability and distribution of people over an area* and discussed below.

Macroscopic flow properties

The macroscopic flow properties: density, flow and velocity are used to derive the Level of Service (LOS), as introduced by Fruin [22]. The LOS is a table with six levels in terms of macroscopic flow properties. Pedestrians at level A or B can walk quite freely and pedestrians at higher levels will be more constrained in their movements. LOS F indicates a very densely crowded area. Some countries have developed design norms for the LOS at stations, which are usually not strictly enforced. Typically, it is required to maintain a LOS C or better [54, 55] or LOS B or better [16] for longer time intervals of several minutes. LOS D or better is required during smaller time intervals of a minute maximum [16]. LOS E is still accepted at bottlenecks for very short time instances [77]. These examples show the relation between the LOS and time, where passengers accept a poor LOS but only for small periods of time. This also shows the difficulty of capturing the desired dynamic properties using LOS. Taking the average LOS value of all passengers at a certain time instance also means that a poor experienced LOS by some passengers is averaged out. Taking the maximum LOS does not provide insight into the number of people experiencing that level.

The macroscopic flow properties of density, flow and velocity can be related to each other with the help of fundamental relationships [41]. The properties are also used for the determination of the LOS, making them similar indicators. The density, flow and velocity of passengers are typically used to assess the effects of measures on the throughput of particular sections. Depending on the measure, one or a combination of macroscopic flow properties can be used. Averaged values over certain time periods can provide enough information to determine the effectiveness of certain measures, but the time interval for the measurements should be carefully determined. The maximum values can be used for the assessment of critical theoretical values.

Platform, dwell and platform clearance time
Parts of the total travel time, platform clearance time or dwell time can be taken as indicators. The total travel time consists of access and egress times, waiting time, transfer time and in-vehicle time [57]. The waiting time can consist of both the waiting time at bottlenecks and waiting for the vehicle. Since the scope of this thesis is physically limited to inside train or metro stations only, the remainder of the access and egress times are the walking times inside the station. Depending on the measure to be assessed, these different times can be taken separately or together to serve as indicators. The sum of all times of all travelers can be taken to assess whether on average time for trips are saved using a measure or not.

The time that is needed from the alighting process until when the platform has been left is the platform clearance time. This is a particularly useful indicator when crowding issues occur on the platform and to see whether available infrastructure is used efficiently [70]. Cumulative flow curves can be used to illustrate the differences when a measure is applied. Also the total time can be taken from the beginning of the alighting process until the last person has left the platform, but that relies more heavily on a single passenger. The acquiring of the platform clearance time can be less straight forward due to interference with other arriving or departing trains or preoccupied platforms.

The dwell time can indicate the time needed for the boarding and alighting process [40]. Average values can be taken to assess different measures taken for dispersions at platforms. Dwell times are however also dependent on the schedule, because of set departure times. This causes that not all measurements with dwell time can be compared easily. Trains arriving behind schedule are therefore best to use for the assessment, as these depart right after the boarding and alighting procedure is completed. Also, trains that still have a red signal a certain time after arrival should be excluded from the sample (as was done by van den Heuvel [69]) to exclude trains that cannot depart even though boarding and alighting was completed.

Perceptive indicators
A more subjective indicator can be to evaluate the perceptions of people involved in the crowd management at stations about the stressfulness. This can only be applied in real life test and requires the presence of a team at location. This also implies that the real time gathering of information on the perceptions comes with added complexity.

Incident counts
At stations with exceptionally large flows and densities, the number of incidents or the number of people that end up in emergency rooms can be used. This can provide insight into the safety of a situation, but only afterwards. The indicator is hard to apply because many things will be done to prevent dangerous situations with incidents and emergencies. Typically, these situations hardly occur and therefore it is hard to derive representative statistics to assess a measure.

Variability and distributions
Indicators that are used in combination with other indicators are treated separately here.

The secondary indicators are the variability and the distribution of passengers. The variability of indicators such as the travel times, dwell times or platform clearance times can be used to determine if characteristics remain more constant. To quantify the amount of dispersion from the average values, the standard deviation can for example be used. Having low values of standard deviation for waiting, dwell and platform clearance times is generally desired because this indicates more punctual arrivals and departures, which helps passengers to better plan their trip. A low standard deviation of passenger velocities can indicate a homogeneous crowd or that the natural variations between people are diminished which could be caused by congestion.

The relative distribution of people over an area can be used in terms of a passengers count, flows, LOS or densities. The count of passengers per area on for example a platform can more directly influence the speed of the boarding and alighting process and ensure shorter dwell times. This indicator was for example used to assess the effects of the static boarding zones signs (D. Ton, personal communication, February 22, 2017) and is therefore added to the list of indicators. Large differences in the number of people at the predetermined areas on the platform will most likely cause larger dwell times. Therefore, an equal distribution of people over an area can indicate efficient boarding and alighting. Similarly, the relative distribution of people over station exits or the vertical infrastructure can indicate efficient use of infrastructure. Relative distributions can also be done in terms of LOS, density and flow.

4.3.2. Indicators for objectives

With the aforementioned indicators, the suitability of each indicator for all objectives can be established. In table 4.4, the results of the suitability check of the indicators is shown, which can help decision makers to select appropriate indicators related to their objective. Checks are placed for indicators that are known to have been applied in literature with a direct link to the objective. More indirect links or indicators that are not applied in literature but can be suitable are denoted by numbers and explained below. No literature has been found on how to maximize revenues for transport operators or station retail operators and what indicators can be used there. As can be seen, for most objectives multiple indicators can be chosen. Multiple indicators can be used for an assessment and the choice for the indicators should be dependent on the specific measure. There is no single indicator suitable for every objective. Thus, the indicator should be chosen carefully in accordance with the objective of the crowd management measure.

The numbers in table 4.4 indicate indirect links between indicator and objective or possible suitable indicators that are not used in literature. The explanations for these are as follows:
1 - Waiting time for the next vehicle to arrive can be spent on for example shopping at the station. A larger waiting time can therefore indicate more possibilities for expenses by passengers. As mentioned by Lavadinho, more diverse waiting activities and with sufficient waiting times generally lead to higher spendings (see appendix A).
2 - A low platform clearance time indicates that people are able to quickly go to the exit, which is desired with evacuations.
3 - The platform clearance time can say something on the minimum headway required, because it is undesired to have interference between passengers alighting from the previous and the arriving train. This would affect the reliability and punctuality.
4 - From the interview with Ton, it is known that the distribution of passengers over an area is applied as an indicator for the assessment of static boarding zone signs. The distribution in terms of counts, density or flows can be used as an indicator for safety, comfort and reliability/punctuality because it can show if the available infrastructure is used efficiently.

Table 4.4: Suitability of indicators for objectives. ✓ shows indicator is used. The number shows indicators that can be used (indirectly) but are not known to have been applied in literature and are explained in the text. Empty cells show indicators that are not suitable to use for an objective.

	LOS	Density	Flow	Velocity	Waiting time	Walking time	Platform clearance time	Dwell times	Perceptions of stressfulness	People in emergency	Variability	Distributions over area
Safety	✓	✓					2		✓	✓		4
Travel times				✓	✓	✓	✓	✓				
Comfort	✓	✓							✓			4
Reliability/punctuality					✓		3	✓			✓	4
Ticket/shop revenues					1							

4.4. Conclusions on assessment of measures

Modeling is a suitable method to have an indication on the effects that a measure can have if performing real life test is too complex, expensive or may lead to unsafe situations. In order to accurately model a crowd management measure, each measure requires different characteristics from a model, which is summarized in 4.1. Since no single model exists capable of fulfilling all requirements, the necessity for a careful selection of the model used for the assessment of a measure is demonstrated. Enough information should now be available for the analyst to see whether their model is suitable to assess a measure, which depends on the measure to be modeled. The knowledge on which models can be suitable to model each measure is used in the following chapters for the selection of a model. MassMotion was used as an example to assess which requirements this model can fulfill, and MassMotion is mostly suitable to model “hard” measures. Since MassMotion is verified and validated, the use of this model is interesting if these hard measures are selected in the case study.

Regardless of the used method to assess a measure, indicators have to be used to quantify the effects on the objectives. In the different literature on applied crowd management measures, many different indicators for the assessment of measures have been found. Multiple indicators can be used to assess the objective of safety. The number of seconds per LOS is considered to be a suitable indicator because with a worse LOS as well as a poor LOS over a longer period of time, safety issues are more likely to arise. In literature, different values for the specific levels of service that are considered to be crowding were used. Also how the desired dynamic properties of pedestrian flow can be captured by LOS is up for discussion. In this thesis, the total time spent in each LOS is taken instead of the average to show the results on all levels of service and to avoid averaging out the results. To assess the throughput, the average walking times, dwell times and their standard deviations can be used, depending on the measure to be assessed. The selection of the most suitable indicator to assess the throughput is therefore not performed yet and follows after the case and measure selection.

5 Framework

In the previous chapters, the objectives of crowd management, characteristics of measures and the assessment of measures has been discussed. In this chapter, this knowledge is combined in order to design a framework to systematically select and assess measures. This will answer the fourth research question and help to fulfill the objective of this thesis. The steps that are taken in the framework to select crowd management measures for a certain station and to select a model to assess the effects of the measure are explained. First, the objective and requirements of the framework are set, after which the framework is introduced and explained.

5.1. Objective and requirements of framework

The objective of the framework is to provide a means for stakeholders to select effective crowd management measures to apply at a particular train or metro station. From interviews with experts in the field (see appendix A) and the literature study, it became clear that no guidelines or framework exists in order to select and assess crowd management measures scientifically underpinned. This framework therefore serves as a tool to provide more insight and guidance into the subject and to assess measures to establish if the measures actually achieve the desired effects. The modeling of measures can remove the need for expensive practical testing of crowd management measures without putting the safety of pedestrians at stake. The requirements for the framework are derived from expert interviews and formulated to fill the gap in literature. They are summarized as follows:

- Use contextual information from the station to help select a measure
- Provide information on possible effects and field of application of a measure
- Help select a model to assess the measure
- Evaluate the effects of the measure
- Be applicable by stakeholders in the field with basic knowledge of crowd management

The framework first of all has to be able to derive relevant information of a station in order to identify particular problems or bottlenecks. The user has to see when and where the measure can be applied, and what the positive effects as well as the negative side effects can be. The user should be able to derive if a model is suitable to assess the selected measure. Using relevant indicators, the model can be used to evaluate if a measure has the desired effect on the objective and if not, a different or an extra measure can be selected. It is assumed that the user has some basic knowledge on pedestrian flows and the framework expands on that available knowledge. The complexity of the framework should not exceed that basic knowledge so the applicability should be centered around the user.

5.2. Framework steps

The proposed framework can be seen in figure 5.1. This framework has been made iteratively building on the knowledge from previous chapters and improved with information from the interviews and the testing in the case study. The arrows indicate the flow direction and the green arrows the data flows. The framework follows five consecutive steps: *applicability check, problem characteristics, measure selection, assessment and evaluation*, which will all be explained in the following sections.

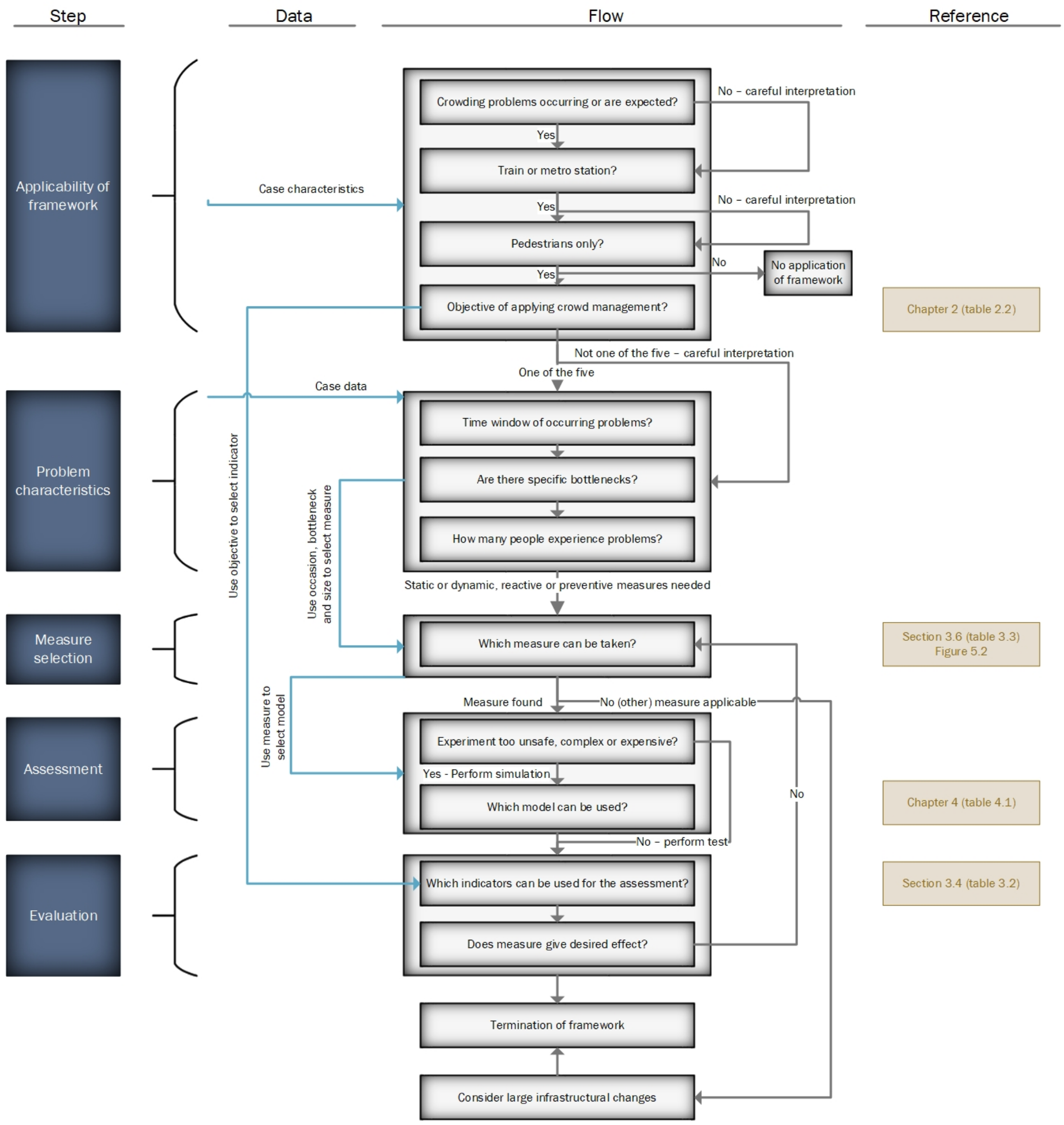


Figure 5.1: Framework to select and assess measures. Gray arrows represent the flow direction and blue arrows represent input flows.

5.2.1. Applicability of framework

The first step for analysts is to identify if this framework can be used for their purpose. The first question, *"Crowding problems occurring or are expected?"*, is to exclude stations that are operating well below capacity since measures will likely have limited effect or can even have negative effects. If either one is not the case, the results of the framework should be carefully interpreted.

The second question, *"Train or metro station?"*, is to establish that in fact a train or metro station is analyzed as other types of stations or airports can have differences with respect to layout, domains, platforms and areas, even though they might experience similar problems. If the problem is about a different type of station, the framework may still be applied but it is up to the user to carefully interpret the results.

The question *"Pedestrians only?"* ensures that the scope is on pedestrians and no other modalities are considered. If other modalities are considered, the application of the framework is not advised.

The final question in the first step, *"Objective of applying crowd management?"* is to determine if the objective is one of the objectives established (being safety, reliability/punctuality, travel time, comfort and revenues of tickets and shops). If different objectives are held for the application of crowd management measures, it can be questionable if the framework can be applied. It is up to the user to decide if the proposed measures can help in achieving their objective and find suitable other indicators.

5.2.2. Problem characteristics

The second step is to acquire data about the station and the crowding issues. The first question *"Time window of occurring problems?"*, determines whether problems occur frequently and on a day-to-day basis or incidentally, with for example events only. This helps to identify suitable measures in the following step.

The second question, *"Are there specific bottlenecks?"*, is to establish if more knowledge is available as to where problems occur. This can be in hallways, at platforms, at vertical infrastructures or no specific location, which can help to narrow down the number of possible measures to be applied.

If the bottlenecks are known, it can be determined how many people are suffering from this problem with the question *"How many people experience problems?"*. This can serve as an indicator for the complexity of the problem. Table 5.1 was created to elaborate on this step in order to obtain the necessary input for the measure selection in the next step.

Table 5.1: Guidance for selecting measures

Nr	Question	Case	Explanation
1	Are volatile and unpredictable passenger flows expected?	If not, more static measures can be suitable. If yes, both static and dynamic measures can be suitable.	Guidance towards suitable measures in the next step of the framework.
2	Are problems expected incidentally because of for example events?	If not, more preventive measures can be suitable. If yes, both preventive and reactive measures can be suitable.	Guidance towards suitable measures in the next step of the framework.
3	Is there a specific location such as vertical infrastructure or the platform that is frequently operating at or above capacity?	If yes, look besides 'no specific location' measures at vertical infrastructure or platform measures. If not, look only at 'no specific location' measures.	With specific bottleneck locations known, this can be more directly solved.
4	Are there intersections of flows?	If yes, look at bidirectional flow measures besides 'no specific problem' measures.	The separation of flows can increase the throughput and this focuses on measures to be able to do so.
5	Are some exits used less than others?	If yes, look (also) at uneven distribution exits measures besides 'no specific problem' measures.	To more efficiently use the available infrastructure, these measures are focused on the distribution of people.
6	Does interference occur between passengers performing different activities?	If yes, look (also) at human blockades measures besides 'no specific problem' measures. If question 4, 5 and 6 answered with no, look at 'no specific problems' measures only.	Waiting, queuing and walking at the same location can lead to human blockades and these measure can help to prevent that.

5.2.3. Measure selection

The third step is the selection of the measure. Figure 5.2 helps to select possible measures, where all measures from table 3.1 are visually categorized. Table 5.1 is aimed at obtaining the necessary input for figure 5.2. The classification of measures in this figure is done by the author and consulting two experts in the field of crowd management [10,14] (see appendix A) and the average relative position is taken. The distinction between preventive management, reactive management and crowd control on the axis is derived from Wieringa [78] and the limited scope of this thesis on crowd management is depicted in the figure. Since the effectiveness of crowd management measures depends greatly on many contextual settings of the station, the selection of the measure has to be done by the analyst. Information from the previous step can help to select the measure based on the specific problems or bottlenecks and whether problems occur frequently or more incidentally. If problems are expected incidentally because of for example large flows due to events, more reactive crowd management measures can be considered. If volatile and unpredictable passenger flows and demands are expected, more dynamic measures can be wise to apply to be able to quickly react to the situation. Static measures tend to have more investment costs, but can be more preventive in everyday operations. In the case particular locations are known to be frequent bottlenecks, measures can be applied to relief this specific problem at for example the platform or the vertical infrastructure. Some measures are not bound to specific locations but can be applied if specific problems are observed to occur, such as bidirectional flows, uneven distribution over the exits or human blockades. These are indicated with the different shapes in the figure. Other measures cannot be dedicated to specific problems or bottlenecks, indicated by gray rectangles, but can be equally suitable measures.

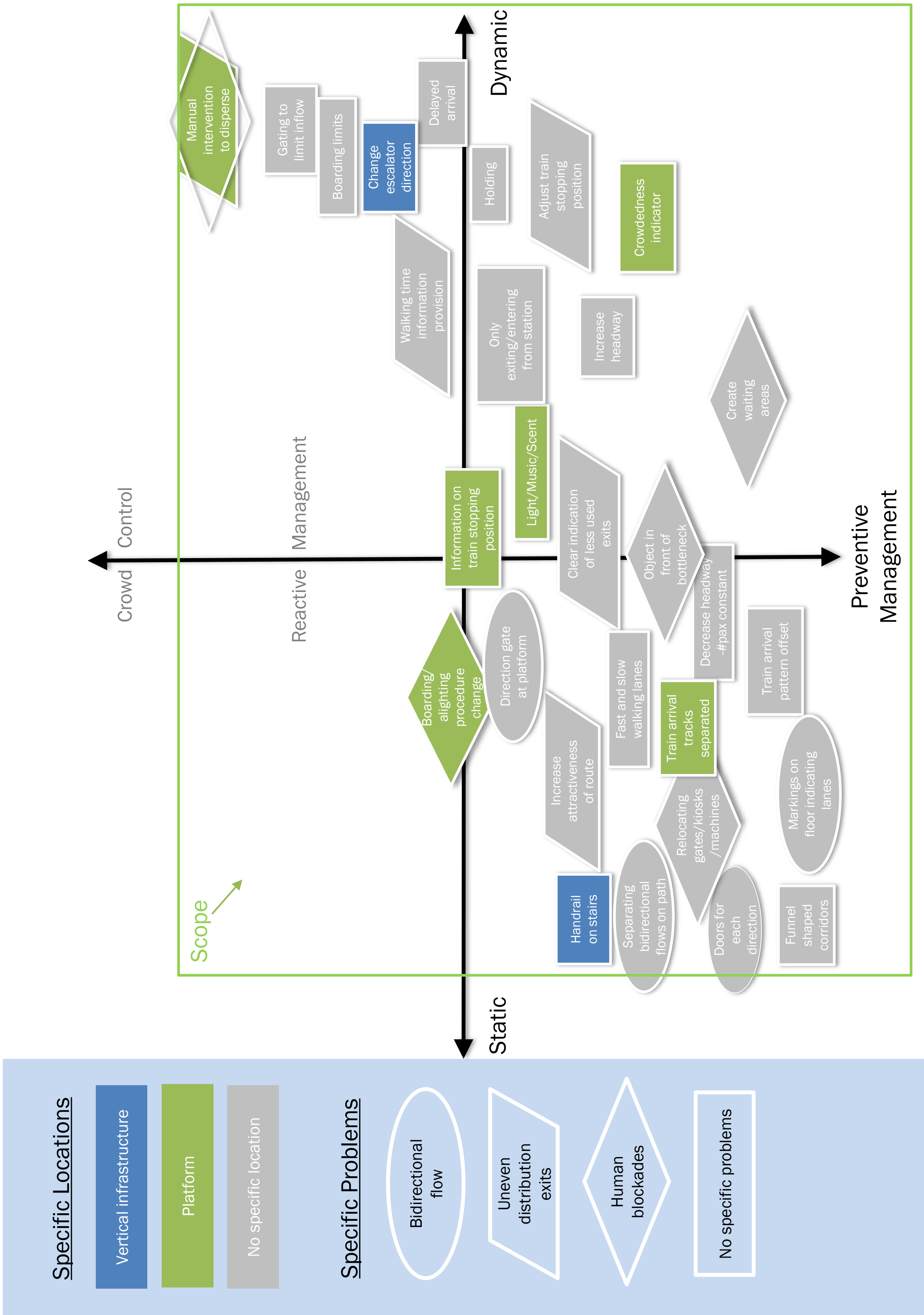


Figure 5.2: Classification of measures. Position based on input from experts [10,14] (see appendix A) and the author.

5.2.4. Assessment

Now that the measure is selected in the previous step, it can be determined if the measure can be tested in real life without creating unsafe situations, having to perform complex operations or spending too much of the total budget. Otherwise, a model can be used to assess the effects of a measure.

The model can then be selected with the help of table 4.1. With the requirements for a model with a certain measure in mind, it can be checked if a model that fulfills the requirements is available. The number of people affected by the measure can influence the complexity and accuracy of the model to be used. It is up to the analyst to determine if a model can reproduce the situation sufficiently to obtain a valid outcome.

5.2.5. Evaluation

The fifth and final step of the framework is the evaluation of the measure. Based on the objective established in the first step, using table 4.4, suitable indicators can be determined. These indicators are needed to study the effectiveness of the selected measure, possibly using the model selected in the previous step. The outcome of the model with and without the crowd management measure can be compared to determine if the measure gives the desired effect on the objective. If not, another or an extra crowd management measure can be selected in the third step. If that still does not give the desired result, the framework can be terminated and large infrastructural changes can be considered.

6
Case study

In chapter 5, a framework has been proposed to come up with effective crowd management measures based on the findings in the previous chapters. This framework is applied in this chapter to a realistic case study in order to evaluate the steps that are taken in the framework. The final research question on the performance of the framework can then be answered. This also has a strong connection to the main objective, as a tested framework is considered to be the final output of this thesis. This chapter starts with the selection of the case study, after which the framework is applied to select and assess crowd management measures. In section 6.3 a reflection on the working of the framework is given.

6.1. Case selection

As the objective of the case study is to evaluate the framework of selecting and assessing effective crowd management measures, a case study should be selected that most effectively reaches this objective. The station itself is therefore of secondary importance. An easy station or part of a station should be selected in order to limit the modeling complexity. The station should have crowding problems, a known network topology and realistic flows. A fictional station is therefore selected, since this provides the opportunity to easily control the demands, control for external factors, avoids the hassle of modeling a station into detail and makes the conclusions on the applicability of the framework and the effectiveness of measures easily generalizable.

The fictional station for the case study should contain general characteristics of stations in order to increase the practical relevance. To limit the complexity of the modeling, the station should contain one side platform with one or two exits, with one location for the vertical infrastructure at the end of the platform. Stations with these characteristics in the Netherlands can be found primarily for metros, for example Weesperplein metro station in Amsterdam. The main characteristics of these stations are used in the fictional station. A representation of the layout of the station can be found in figure 6.1, where the location of the arriving metro wagons is red, the stairs are green and escalators blue. Metros at these stations arrive usually every three minutes, so a headway of three minutes is chosen. This is kept constant throughout the simulation. The routes in Amsterdam are commonly run with the modern Alstom M5 rolling stock, so the characteristics of the length and width of the metro, the number of wagons and number of doors are taken from this metro [1]. The width of the stairs and escalators are taken to be equal to the observations from reference metro stations.

In order to better evaluate the framework, two load cases are analyzed. This could lead to two different selections of measures and will therefore help gain information on the effects of more measures and the circumstances under which measures are the most effective. The load cases are selected such that they have many differences because that allows for a better evaluation of the framework. The first load case is the everyday peak hour flow, where an equal number of alighting and boarding passengers are assumed (50/50%). The other load case is the event flow, where many passengers go in the same direction at the same time after for example a match or concert. For this load case, a share of 90% boarding passengers and 10% alighting passengers is assumed.

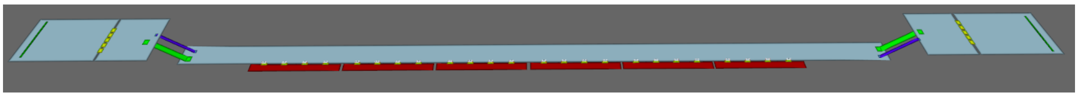


Figure 6.1: Overview of the station

Load cases

With the effective platform length and width known to be about 150 x 7 m, so 1050 m^2, it can be calculated how many people can at most be on the platform to still achieve an average LOS B, if an equal distribution over the platform is assumed. If the maximum number of people per square meter to still have LOS B is taken as 0.43 pax/m^2 [22], the design load for the maximum number of people on the platform is calculated as:

$$0.43 * 1050 \approx 450\, people$$

This means that if there are more than 450 people on the platform, the average LOS of the platform will worsen from B to C. It is important to note that also with less than 450 people on the platform, the LOS B will be exceeded locally because of a non-uniform distribution of passengers over the platform. With the headway of three minutes, the average level of service will thus be worse than B if more than 150 boarding people arrive per minute. With the assumed share of boarding and alighting passengers taken as 50/50 % (for the peak flow), each vehicle in peak hour is assumed to carry 450 alighting passengers. In the case of the event flow, where 90% of the passengers board and 10% alight, the same number of 300 people board and alight on average per minute. This means that 90 people are assumed to alight each metro (every 3 minutes) and 270 boarding passengers arrive each minute. Table 6.1 shows the final number of boarding and alighting passengers per load case. All travelers are assumed to arrive equally distributed over the station entrances and the train wagons. The departing passengers arrive at the station in a uniform distribution. The M5 metro has a seating capacity of 174 and a standing capacity of 786, so a total maximum of 960 passengers [1] and should therefore theoretically be able to cope with these loads if the metro is assumed to carry only people that board and alight at this station. If this is not the case, different problems arise (which is focused at in the problem characteristics step of the framework) which could lead to different measures to apply.

The two stairs are each about 2.8 meters wide, and with an assumed capacity of 1 person per meter per second [47], the theoretical capacity is then 336 persons per minute. The capacity of the stairs for people going down to the platform larger than the demand, thus no bottlenecks are expected upstream of the stairs. The escalators are then assumed to transport all alighting people going towards the exits of the station. With the estimated escalator capacity of 65-100 people per minute [36, 59], having two escalators would have a minimum capacity of 130 people per minute. This is therefore also sufficient.

Table 6.1: Flows per load case

	Everyday peak hour load case	Event load case
Boarding passengers	150/minute	270/minute
Alighting passengers	450/vehicle	90/vehicle

The number of people on the platform over time can be seen in figure 6.2 for the everyday peak hour load case for a 30 minute simulation. This is taken for the single run with the least deviations from the average. It can be seen at the local minima, that a slightly increasing number of people is still on the platform after a metro has departed and before the arrival of the next metro and therefore the station is operating slightly above capacity. It can also be seen that as expected, the number of people on the platform just before arrival (00:04:00) is close to 450 and therefore an average LOS B for waiting passengers is still obtained. These passenger demands are chosen because they are leading to crowding issues in the station and with the increasing public transportation usage, demands exceeding the capacity can be expected more often.

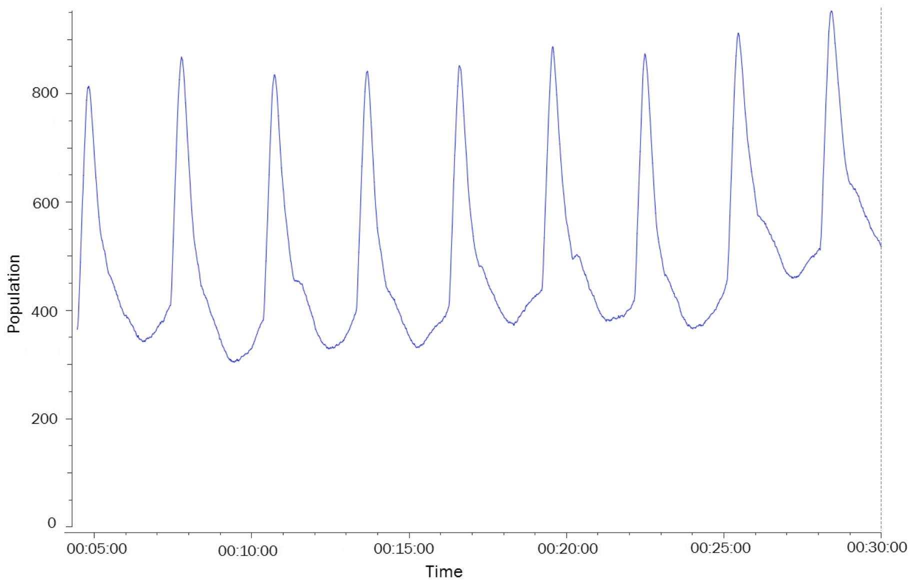
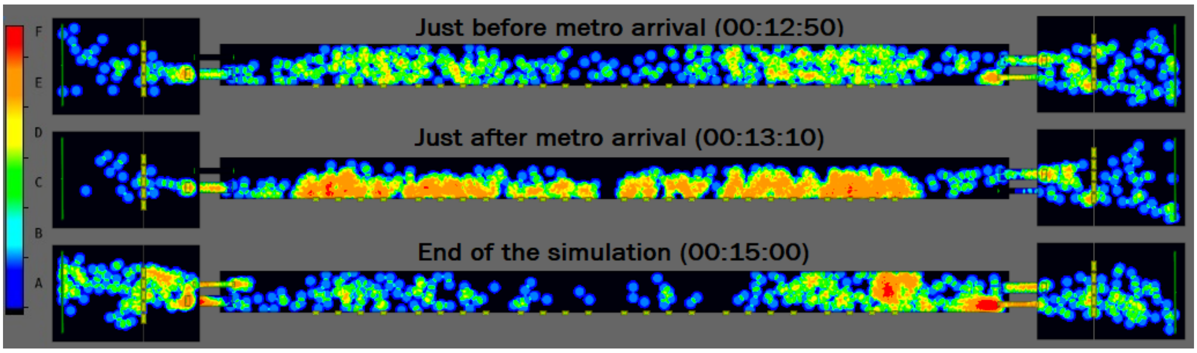


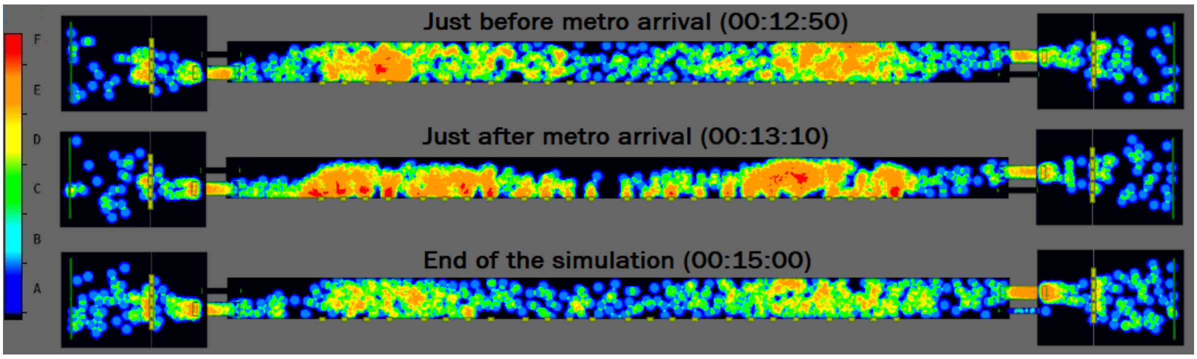
Figure 6.2: Number of people on the platform for everyday peak hour load

In figure 6.3, the instantaneous LOS at three different times during the simulation are shown for both load cases. Again, this is for the run with the least deviations from the average. The three instants chosen are just before, just after metro arrival and at the end of the simulation, in order to have three distinctive scenarios.

In this case study, no queues form upstream of the stairs for both the peak hour flow and the event flow. During the peak hour, just after a metro arrival a small queue forms upstream of the escalators going towards the exits of the station. These queues are small however and the escalator capacity is not reached for longer than a consecutive minute. The platform can get quite crowded just before and after arrival in both load cases. Most congestion occurs at the platform near the first couple of metro doors for both cases. There are no large intersections of flow and no large problems occur due to bidirectional flows. Since the metro stops at an about equal distance to the exits, both exits are used more or less equally. Also boarding passengers are assumed to arrive equally distributed over the station entrances. Some interference occurs between boarding and alighting passengers close to the vertical infrastructure on the platform. This information will be used in the problem characteristics step of the framework.



(a) Congestion in case of peak hour flow



(b) Congestion in case of event flow

Figure 6.3: Instantaneous LOS at three different moments

6.2. Applying the framework

In this section, the consecutive steps of the framework to select and assess crowd management measures are taken.

6.2.1. Step 1 - Applicability of framework

The applicability of the framework is the same for both load cases. With the calculations from the previous section, an inflow is created that will lead to crowding problems, so the first question of the framework 'Crowding problems occurring or are expected' is answered positively. Since a metro station is taken, the second question 'Pedestrians only' can be answered positively and the next step can be taken. The third question 'Train or metro station' can thus also be answered positively. The objective of applying crowd management measures is taken as the most important objectives as established by stakeholders in chapter 2: to increase the safety and throughput. These belong to the five objectives and thus all questions in this step are answered positively so the next step can be started. An overview can be seen in figure 6.4.

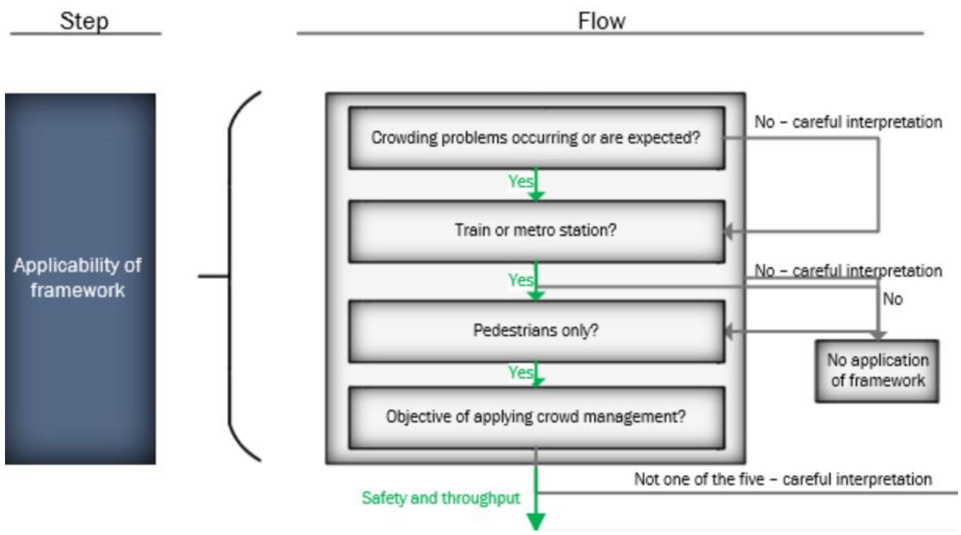


Figure 6.4: First step of the framework with the answers for this case in dark green

6.2.2. Step 2 - Problem characteristics

The first question in this step on the 'time window of occurring problems' is answered in two different ways. The two different load cases (everyday peak hour and event flow) could lead to two different solutions from the framework.

In the case of a real station, the grasp of where problems occur can be obtained from observations. This is needed in order to answer the second question of the framework. Since this case covers a fictional station, observations from real life are not possible and the problem identification is based on a model. As was shown in figure 6.3, short queues form upstream of the stairs for both the peak hour flow and the event flow. During the peak hour, after a metro arrival a short queue forms upstream of the escalators going towards the exits of the station. These queues are short however and the escalator capacity is not reached for longer than a consecutive minute. The platform can get quite crowded just before and after arrival in both load cases.

The third question is on how many people experience crowding problems, which can also be derived from the model. Since the station only has one platform, and a limited number of departing and arriving passengers, the station is considered to be small and not a transfer hub. The number of boarding and alighting passengers is known from the previous section (table 6.1) and is limited during the specified time intervals.

After that, table 5.1 is applied and the results are shown in table 6.2. This is done based on the analysis in section 6.1 and draws the criteria for the selection of measures in the next step. The conclusion on the criteria to use is shown in the last row of the table. The outcomes of the problem characteristics step are summarized in figure 6.5.

Table 6.2: Criteria for selecting measures (table 5.1) applied

Nr	Question	Everyday peak hour	Event
1	Are volatile and unpredictable passenger flows expected?	No - more static measures	Yes - both static and dynamic measures
2	Are problems expected incidentally because of for example events?	No - more preventive measures	Yes - both reactive and preventive measures
3	Is there a specific location such as vertical infrastructure or the platform that is frequently operating at or above capactiy?	Small queue upstream of escalators, crowded platform - vertical infrastructure, platform and no specific location measures	Crowded platform - platform and no specific location measures
4	Are there intersections of flows?	No large crossings on same location - bidirectional flow measures not needed	No large crossings on same location - bidirectional flow measures not needed
5	Are some exits used less than others?	No - uneven distribution exits measures not needed	No - uneven distribution exits measures not needed
6	Does interference occur between passengers performing different activities?	Interference between boarding and alighting - human blockades and no specific problem measures needed	No - no specific problem measures needed
-	**Conclusion**	Look at more static, preventive measures at the vertical infrastructure, platform or no specific location, and with human blockades and no specific problem measures	Look at both static, dynamic, preventive and reactive measures at the platform or no specific location, and with human blockades and no specific problem measures

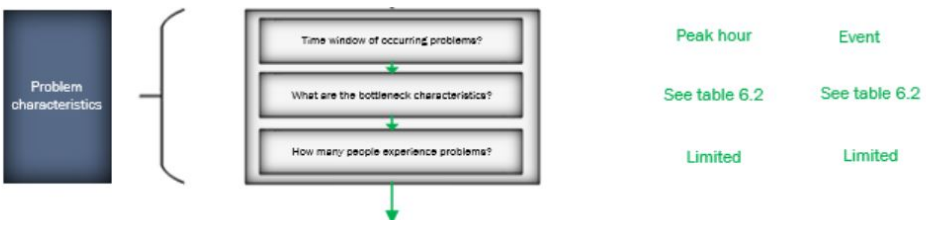


Figure 6.5: Second step of the framework with the answers for the two cases in dark green

6.2.3. Step 3 - Measure selection

The third step in the framework is to select possible crowd management measures. The information from figure 5.2 is combined with table 3.1 in order to select possible crowd management measures. In table 6.3, it can be seen which measures are suitable (in green) or why they are rejected (in red). The measures that are suitable are then discussed to determine which measure to apply first. This is done separately for the everyday peak hour and the event load case. An assessment of which of those measures to test first is not included in the framework because it involves multidisciplinary decision making that cannot be quantified. The assessment is therefore made by the author, and is assumed to be done by the user of the framework for other cases.

Table 6.3: Measure selection for the case study. Red cells indicate measure is not suitable for the load case, green cells indicate measures can be applied. FoA: field of action in table 3.1 makes the measure unsuitable. SP and SL are specific location and problem in figure 5.2, P is the position in that figure that makes the measure unsuitable.

Measure	Peak hour	Event
Creation of doors for each direction	FoA: no doors present	FoA: no doors present
Funnel shaped corridors	FoA: no large angle corners present	FoA: no large angle corners present
Separating bidirectional flows on path	SP: no bidirectional flows	SP: no bidirectional flows
Handrail on stairs	FoA: no wide stairs present	FoA: no wide stairs present
Gates/kiosks/vending machines relocation	FoA: no queue interference	FoA: no queue interference
Increase attractiveness of route	SP: no uneven distribution over exits	SP: no uneven distribution over exits
Markings on floor	SP: no bidirectional flows	SP: no bidirectional flows
Arrival tracks separation	FoA: no simultaneous arrivals	FoA: no simultaneous arrivals
Fast and slow walking lanes	FoA: no longer stretches	FoA: no longer stretches
Boarding/alighting procedure change		
Arrival pattern offset	FoA: no simultaneous arrivals	FoA: no simultaneous arrivals
Direction gate placement	SP: no bidirectional flows	SP: no bidirectional flows
Headway decrease - #pax constant		
Object in front of bottleneck	FoA: no bottlenecks where pressure builds	FoA: no bottlenecks where pressure builds
Clear indication of less used exits	SP: no uneven distribution over exits	SP: no uneven distribution over exits
Information provision on train stopping position		
Light/music/scent		
Waiting areas		
Only exiting/entering from station	P: too dynamic/reactive with dissatisfaction many travelers	
Walking time information provision	SP: no uneven distribution over exits	SP: no uneven distribution over exits
Headway increase	P: too dynamic/reactive with dissatisfaction many travelers	FoA: no alighting passengers still on platform
Crowdedness indicator		
Adjust train stopping position	SP: no uneven distribution over exits	SP: no uneven distribution over exits
Escalator direction change		SL: no vertical infrastructure problems
Holding	P: too dynamic/reactive leading to dissatisfaction many travelers	FoA: no delays
Boarding limits	P: too dynamic/reactive leading to dissatisfaction many travelers	
Gating	P: too dynamic/reactive leading to dissatisfaction many travelers	
Delayed arrival	P: too dynamic/reactive leading to dissatisfaction many travelers	FoA: no alighting passengers still on platform
Manual intervention to disperse	P: too dynamic/reactive leading to dissatisfaction many travelers	

Measure selection everyday peak flow

Seven measures can be selected for this case study with everyday peak hour flow. These are briefly discussed below to determine which measure is applied first.

- Boarding and alighting procedure change - According to table 3.1, this measure can increase the punctuality but it does require communication towards the passengers.
- Decreasing the headway - Complicated and expensive measure because of the extra use of infrastructure, rolling stock and staff.
- Information provision on train stopping position - Expected to have limited effect, because the first and last wagon of the metro are used the most since they are closest to the vertical infrastructure [26].

- Light, music or scent - Possibly has small effects because of relatively small waiting times.
- Creating waiting areas - Possibly has small effects because of relatively small waiting times.
- Crowdedness indicators - Not considered to be very feasible or realistic to apply for this case study due to high costs.
- Escalator direction change - The escalators are now going upwards and there are no capacity issues on the downward stairs, so (temporarily) reversing the escalator direction will not contribute to solving crowding issues.

The changing of the boarding and alighting procedure is selected as the first measure to apply because of the expected positive effects and the relatively small drawbacks. Dedicated doors are used to do so, because it is assumed to be more feasible than space or time division. A full compliance of passengers to use the dedicated doors is assumed. Decreasing the headway is applied separately as another measure because of the expected large positive effects. In this case, the headway is decreased from 3 to 2 minutes.

Measure selection event flow
Nine measures are suitable to apply in the case of event flow. These measures are discussed below, again to determine which measure to apply first.

- Boarding and alighting procedure change - According to table 3.1, this measure can increase the punctuality but it does require communication towards the passengers. However, this measure is assumed to be less suitable than the peak hour load case, because the full capacity of the doors can not be reached if the doors are used for either boarding or alighting in a 90/10 flow.
- Decreasing the headway - Complicated and expensive measure because of the extra use of infrastructure, rolling stock and staff.
- Information provision on train stopping position - Expected to have limited effect, because the first and last wagon of the metro are used the most since they are closest to the vertical infrastructure [26].
- Light, music or scent - Possibly has small effects because of relatively small waiting times. Expected to be less suitable in this load case because with increasing crowds going in one direction, less attention will be given to this 'softer' measure.
- Creating waiting areas - Possibly has small effects because of relatively small waiting times. Expected to be less suitable in this load case because with increasing crowds going in one direction, less attention will be given to this 'softer' measure.
- Only exiting/entering from station - Drastic measure that should only be applied in extreme situations, which is not expected often.
- Crowdedness indicators - Not considered to be very feasible or realistic to apply for this case study due to high costs.
- Boarding limits - Expected to have most effect on reliability, punctuality and travel times. However, if people are denied access, they have to wait for the next train so more people will be on the platform. This results in a lower safety on the platform, which is the primary objective in this case.
- Gating - Relatively simple to apply and expected to have a large effect on the number of people on the platform.

- Manual intervention to disperse - Strongly dependent on the execution by the team and therefore less suitable to be modeled.

Gating will be considered as the first measure to assess in this case study because of the easiness to apply and expected large effects. With an assumed capacity of 30 passengers per gate per minute inflow (based on [47, 54, 56]), 5 gates can be used for the flow onto the platform in order to remain below 150 passengers per minute and 450 on the platform just before a metro arrival. The remaining gates are used for checkouts and exiting passengers only. In appendix B, the results of when 4, 6 or 7 gates are available for checking in can be seen, but 5 gates turns out to have a good balance between reducing the LOS on the platform and an increased travel time. As an alternative to this measure, decreasing the headway is also applied here, with a decrease from 3 to 2 minutes. The application of the framework for this step is shown in figure 6.6.

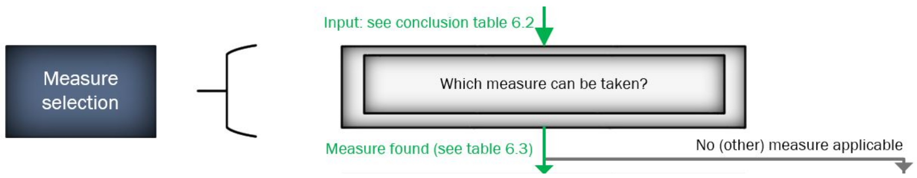


Figure 6.6: Third step of the framework with the answers in dark green

6.2.4. Step 4 - Assessment

Using dedicated doors requires communication in order to make passengers comply to using the correct doors. Therefore, the measure is considered to be too complex to test in real life. Decreasing the headway is a complex and expensive measure and therefore using a model to gain insights on the effects of using this measure is a good alternative. Gating affects some travelers negatively because the travel times may increase and it can possibly create unsafe situations where the queues build and therefore a model is more suitable to assess the effects of applying the measure. Therefore, for all four measures, a model is suitable to assess the effects.

Using table 4.1, it can be determined what is needed from a model to accurately model the measures selected in the previous section. For a change in the boarding and alighting procedure, it can be seen that a model is needed that can incorporate bidirectional flows and advanced human decision making. The latter is dependent on the type of procedure that will be used and for example needed in a much lesser extent when dedicated doors are used. Since 100% compliance of passengers to use the dedicated doors is assumed, modeling advanced human decision making is not necessary at all in this case. Instead, dedicated links for gating and alighting can be used. For gating, no specific requirements are needed. When a decrease of the headway is modeled, a model that is capable of modeling a different demand arrival pattern is needed. Therefore, using table 4.2, it can be concluded that all measures can be modeled in MassMotion. If different measures are selected in the previous section, most likely a different model should be used.

MassMotion is chosen here because of its availability and relative easiness to apply, obtain data from simulations and interpret results. MassMotion works on the tactical and operational level mostly, as is also the scope of this thesis. The model created can be seen in figure 6.1. It is assumed that boarding passengers have a uniform arrival pattern and that arriving passengers are distributed equally over the wagons. Boarding passengers have a normal distribution from both stairs independently, where they are most likely to wait on the train closest to the stairs they took (based on principles from NetworkRail [26]). They maintain sufficient distance from each other based on the social force. Furthermore, alighting passengers are assumed to take the nearest exit. An overview of how the framework is applied in this step can be seen in figure 6.7.

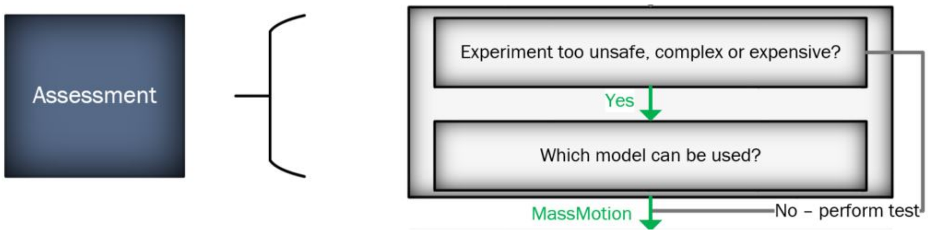


Figure 6.7: Fourth step of the framework with the answers in dark green

6.2.5. Step 5 - Evaluation

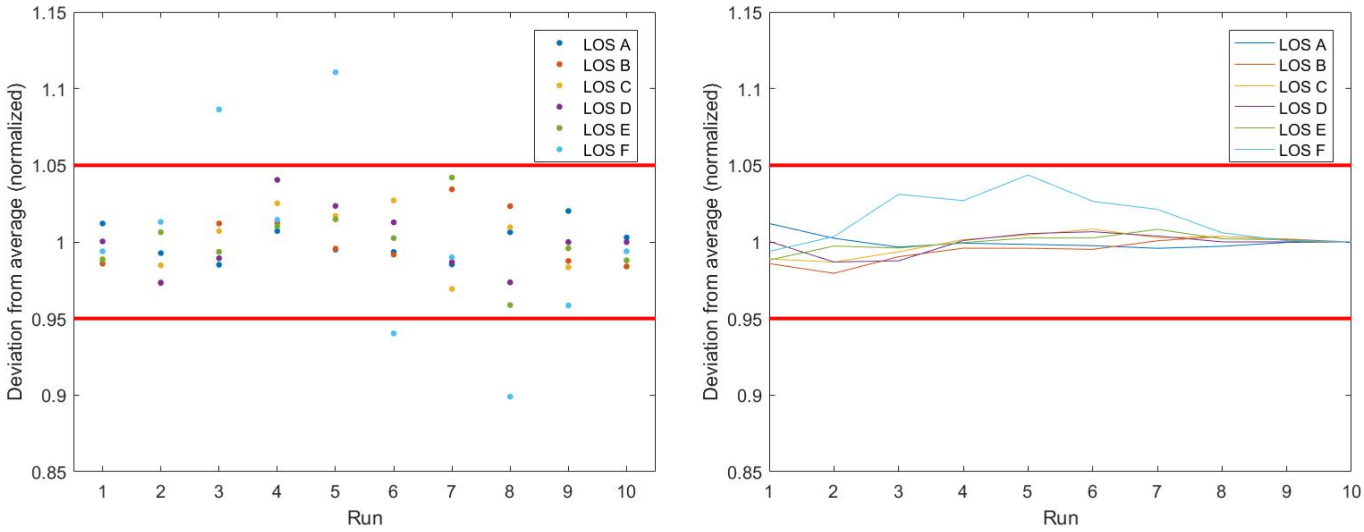
The first question in this step is on the indicators that can be used to assess the effectiveness of a measure. In order to answer this question, table 4.4 is used. For this case study, primarily the LOS will be used for the first objective of improving the safety. This is because the perceptions of stressfulness are impossible to model, the number of people in emergency is assumed to have a too small sample size and the density and LOS are closely related. For the LOS, the total time all passengers spent per level is taken and only on the platform. This is because unfavorable LOS levels affect the safety the most at the platform because of the risk of people falling on the track. In order to also see the experienced crowdedness from a passenger point of view, also the relative time per LOS is taken on the platform.

To evaluate the travel times, the time from entering the station until boarding is used as an indicator. This is done with a probability density distribution in order to see the effects for all passengers. The same indicators are used for each measure in order to compare the differences.

Number of runs required

MassMotion has a stochastic element, and therefore different runs lead to different results. It needs to be known how many runs are needed in order to draw statistically significant conclusions.

To show the error decreases with more runs, ten runs are gathered from the basic scenario station in MassMotion. The outputs of these runs are shown in figure 6.8. The output generated here is the total time all agents spent in one of the six LOS levels. This time sum has been normalized using the average of ten runs, so the 1 on the y-axis represents the average per LOS level and the deviation from this can be easily seen. Each dot in figure 6.8a represents the deviation from the average (of 10 runs) for each corresponding run. It can be seen that the deviation for each measurement is less than 15%. The lines in figure 6.8b show what happens if the average of just the first run, the first two runs, the first three runs etc. is taken and hence converges towards the average. The blue lines and dots represent the normalized time spent in LOS F and clearly has the most deviations. This is because the LOS F is reached relatively few times. The red lines indicate a 5% margin of error, which is reached immediately in this case. Ten runs are therefore considered to be sufficient to draw representative results and each measure is run 10 times.



(a) All obtained measurements

(b) Deviation from average of ten runs

Figure 6.8: Results of ten runs in MassMotion model

Results

To visualize the effects of applying the measures on the safety, the instantaneous LOS for three different moments are given. All results on the safety using the LOS as an indicator are then quantified and summarized in bar graphs. A closer look is then taken at the throughput using the travel time probability density function as an indicator. These steps are all first taken for the peak hour load case, and then for the event load case.

Everyday peak flow

In figures 6.9 to 6.11, the instantaneous LOS for the one run (out of the ten) in MassMotion which showed the least deviances from the average is shown. Just before the arrival of a metro, the spreading of the people over the platform can be seen. When no measure is applied, more people appear to be on the platform resulting in a less favorable LOS. Just after an arrival of a metro, when no measure is applied, unfavorable LOS are experienced near the metro doors. When the dedicated doors measure is applied, the unfavorable LOS occur mainly in front of doors used for boarding. A headway decrease seems to relieve the crowdedness on the platform overall. At the end of the simulation, many crowding problems are still occurring when no measure is applied, whereas people are a lot closer to exiting the station when the headway is decreased.

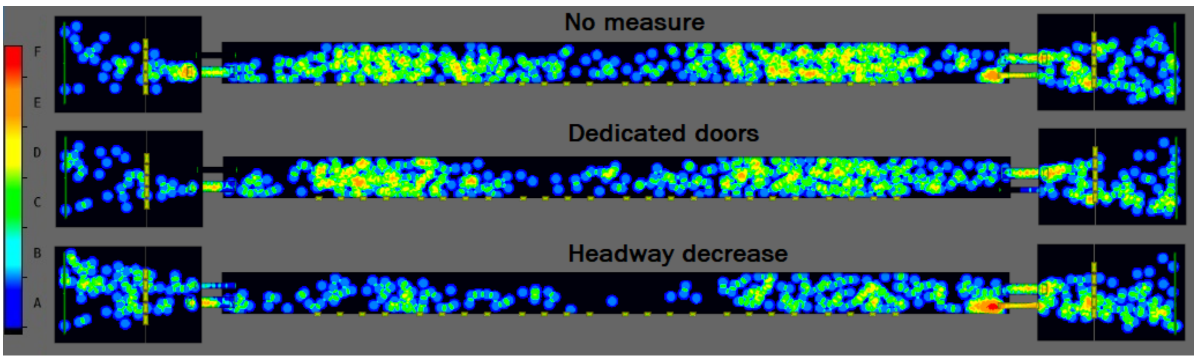


Figure 6.9: Instantaneous LOS for peak hour flow just before arrival metro (00:12:50)

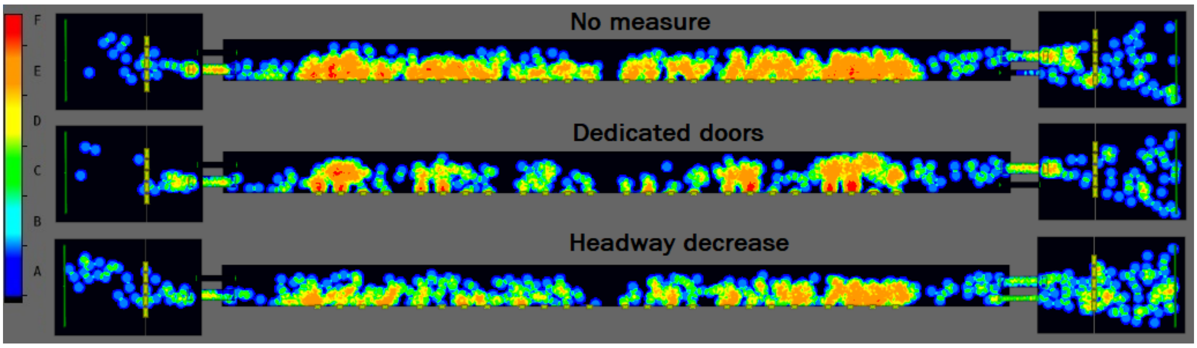


Figure 6.10: Instantaneous LOS for peak hour flow just after arrival metro (00:13:10)

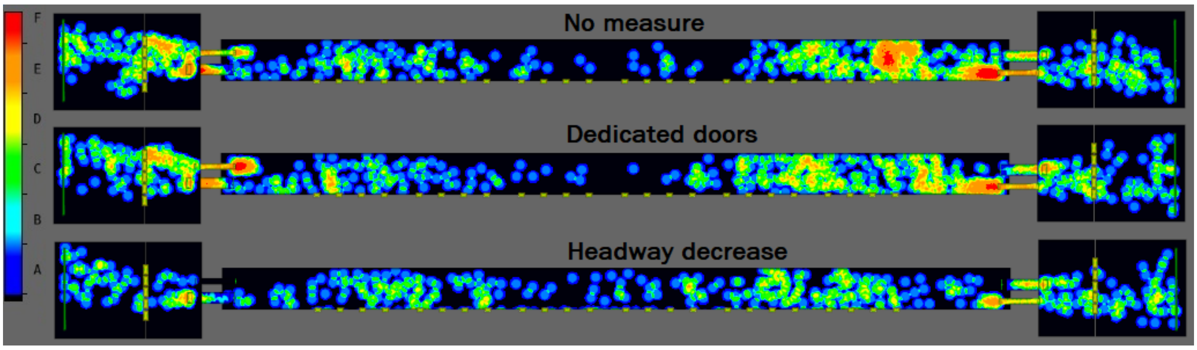


Figure 6.11: Instantaneous LOS for peak hour flow just before simulation end (00:15:00)

To quantify the figures above and the effects of measures on the objective of safety, the total time all passengers spent on the platform in a certain LOS for a 15 minute simulation is given in table 6.4. To also include the experienced LOS from a passenger point of view, the relative time a passenger spends per LOS is shown. The simulation time of 15 minutes is chosen because this includes 5 metro arrivals and departures and thus provides enough information on the dynamic movements in the station. Increasing the simulation time is assumed to lead to the same conclusions but with increasing differences between the scenarios because of an inability to recover for some scenarios. The results are visualized in figure 6.12 and 6.17. Where an average LOS B is calculated for waiting passengers on the platform, this rarely turns out to be the case. This can be because people do not spread out uniformly over the platform, resulting in worse LOS locally. This happens most when a metro has arrived and people are waiting in front of a train door to enter as quickly as possible. Also, after a metro arrival people alight first and after that the boarding begins, causing a much larger number of people to be on the platform for a small time interval.

Table 6.4: Total time spent on platform per level of service and percentage of time spent in certain level for the peak hour load case. For the measurement with the *, the hypothesis $H_0 : \mu_{nomeasure} = \mu_{measureapplied}$ is not rejected, based on a paired-sample t-test with a significance level of 95%. The p-value of this test is seen in brackets.

	Peak hour					
Total time ($*10^4$ s)	**LOS A**	**LOS B**	**LOS C**	**LOS D**	**LOS E**	**LOS F**
No measure	3.9	3.2	7.0	6.0	11.1	6.5
Dedicated doors	4.4 ($2e^{-9}$)	3.8 ($5e^{-9}$)	7.8 ($6e^{-10}$)	5.5 ($2e^{-7}$)	7.5 ($3e^{-13}$)	4.1
Headway decrease	3.6 ($2e^{-3}$)	3.1* (0.86)	5.9 ($9e^{-10}$)	4.2 ($2e^{-11}$)	6.4 ($9e^{-13}$)	1.9 ($5e^{-11}$)
Percentage of time						
No measure	10.3%	8.4%	18.5%	16.1%	29.5%	17.1%
Dedicated doors	13.3% ($5e^{-10}$)	11.5% ($5e^{-11}$)	23.6% ($2e^{-11}$)	16.6% ($4e^{-3}$)	22.7% ($8e^{-13}$)	12.4% ($6e^{-7}$)
Headway decrease	14.3% ($2e^{-11}$)	12.3% ($4e^{-12}$)	23.3% ($2e^{-10}$)	16.8% ($6e^{-3}$)	25.6% ($4e^{-10}$)	7.7% ($9e^{-11}$)

It can be seen in figure 6.12 and table 6.4 that having dedicated doors results in a higher total time spent on the platform in LOS A, B or C. Applying the measure also has positive effects for reducing the worse levels of service of D, E and F, where the total time spent in LOS F decreases the most.

When the headway is decreased, time spent in all LOS decreases, with the largest decrease in the most unfavorable LOS. However, it must be noted that when the headway is decreased, people spent less time on the platform and that greatly affects the measurements. The percentage passengers spent in a certain level of service is given to see if people relatively experience better LOS (independent of the total time) after a measure is applied. LOS E and F turn out to be experienced less by passengers if the headway is decreased or the dedicated doors are applied.

In figure 6.13, the results of applying a measure on the time from entering the station to boarding can be seen. For this calculation, the simulation is continued after the 15 minute period in order to also include passengers that arrive at the station before 15 minutes but board after the previous simulation end time. A headway decrease to 2 minutes obviously has the most positive effect on the travel time, because of the reduced waiting times. Having dedicated doors also results in a lower average travel time compared to when no measure is applied.

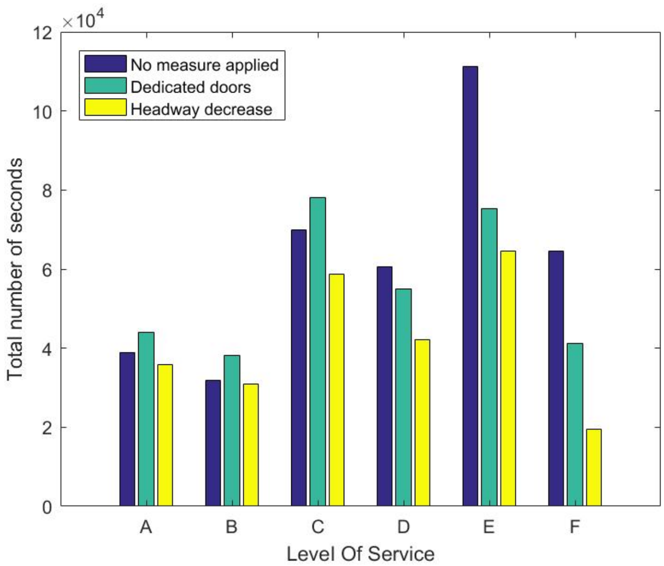


Figure 6.12: Total seconds spent on the platform in each Level of Service per scenario, in case of everyday peak hour flow

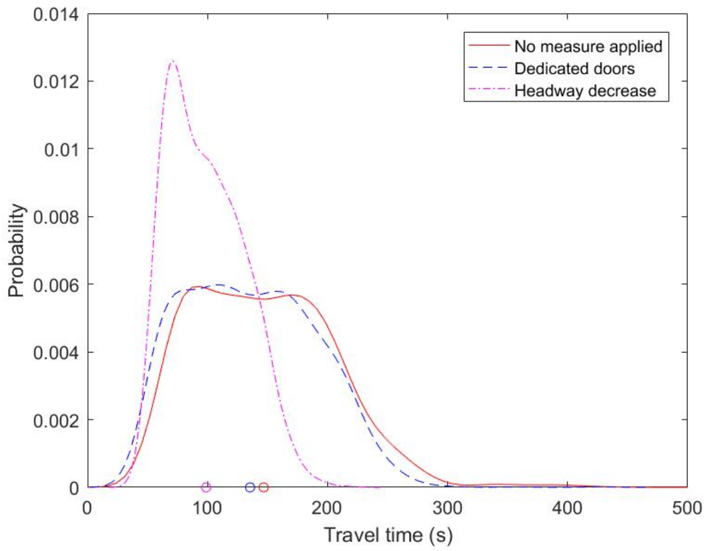


Figure 6.13: Probability density function of time from entering the station to boarding in case of peak flow. The circles on the axis are the average travel times.

Event flow

It can clearly be seen from figures 6.14 to 6.16 that when gating is applied, large queues with unfavorable LOS levels build up upstream of the check-in gates. The platform is however experiencing better LOS levels, which is also the case when the headway is decreased which indicates an increased safety. The same effects are noticed just after the arrival of a metro. At the end of the simulation, a lot more people and unfavorable LOS are experienced when no measure is applied. Gating appears to perform the best to increase the safety on the platform, but large queues are building upstream of the gates.

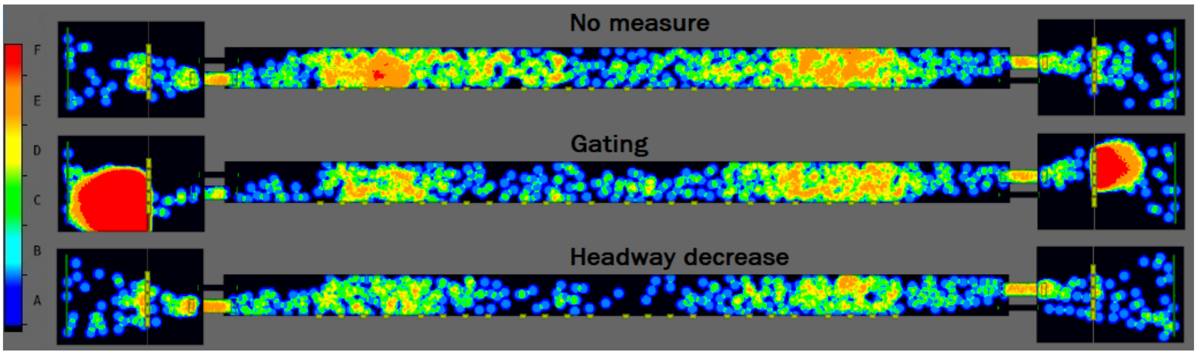


Figure 6.14: Instantaneous LOS for event flow just before arrival metro (00:12:50)

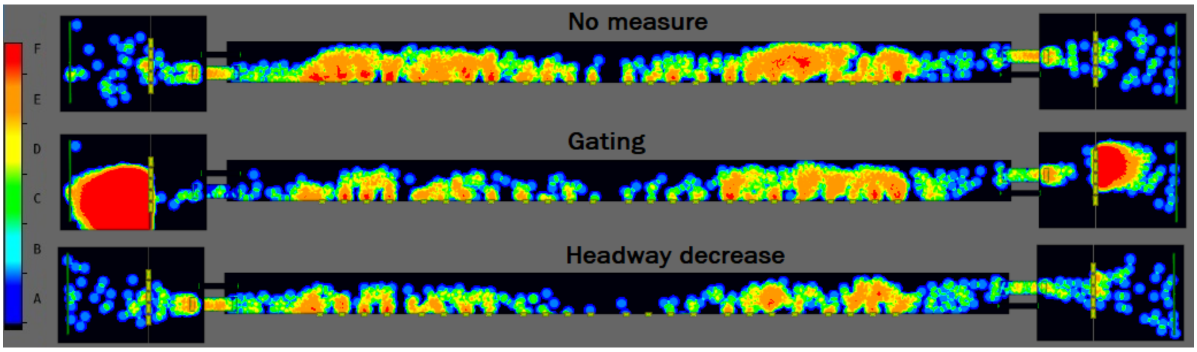


Figure 6.15: Instantaneous LOS for event flow just after arrival metro (00:13:10)

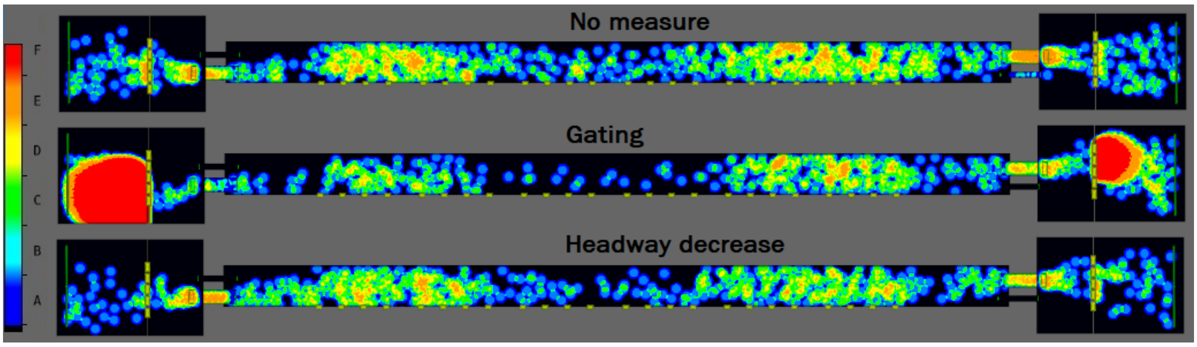


Figure 6.16: Instantaneous LOS for event flow just before simulation end (00:15:00)

In table 6.5 the effects of applying measures on the safety using the LOS as an indicator are shown. In figure 6.17, the results are visualized. When gating is applied, the total time spent on the platform in LOS C, D, E and F decreases greatly. However, it must be noted that the measurements on the total time passengers spent in a certain level of service are influenced by the fact that because of the gating, less people reach the platform during the simulation time. Therefore, the relative time spent in each LOS is considered to be a better indicator here. The relative time spent in LOS D, E and F decreases when gating is applied. Queues upstream of the check-in gates only increase over time unless the inflow is reduced. Even though this is not included in the results below, unfavorable LOS are experienced there which could cause safety problems if the queues are not handled well or do not dissolve quickly. Decreasing the headway from 3 to 2 minutes has a positive effect in decreasing the total time spent in all LOS. The relative time passengers spent in LOS D, E and F decreases when applying the measure.

Table 6.5: Total time spent on platform per level of service and percentage of time spent in certain level for the event load case. For all measurements, the hypothesis $H_0 : \mu_{nomeasure} = \mu_{measureapplied}$ is rejected, based on a paired-sample t-test with a significance level of 95%. The p-value of this test is seen in brackets.

	Event					
Total time ($*10^4$ s)	**LOS A**	**LOS B**	**LOS C**	**LOS D**	**LOS E**	**LOS F**
No measure	3.8	4.2	9.9	9.3	11.0	1.6
Gating	4.3 ($8e^{-11}$)	3.6 ($1e^{-6}$)	7.1 ($8e^{-8}$)	5.3 ($9e^{-10}$)	4.5 ($2e^{-10}$)	0.3 ($4e^{-9}$)
Headway decrease	3.7 ($4e^{-2}$)	3.8 ($7e^{-8}$)	7.2 ($1e^{-12}$)	4.8 ($6e^{-14}$)	3.7 ($6e^{-12}$)	0.2 ($3e^{-9}$)
Percentage of time						
No measure	9.6%	10.8%	25.1%	23.6%	27.9%	2.9%
Gating	17.5% ($1e^{-11}$)	14.4% ($3e^{-9}$)	28.1% ($5e^{-8}$)	20.9% ($5e^{-7}$)	17.9% ($1e^{-10}$)	1.1% ($4e^{-9}$)
Headway decrease	15.7% ($2e^{-12}$)	16.2% ($1e^{-11}$)	30.9% ($2e^{-10}$)	20.4% ($7e^{-10}$)	16.0% ($1e^{-11}$)	0.8% ($3e^{-9}$)

The queues that build when gating is applied also have the effect that many travelers experience increased travel times from when they enter the station until they have boarded, as can be seen in figure 6.18. When the headway is decreased, the average travel time decreases.

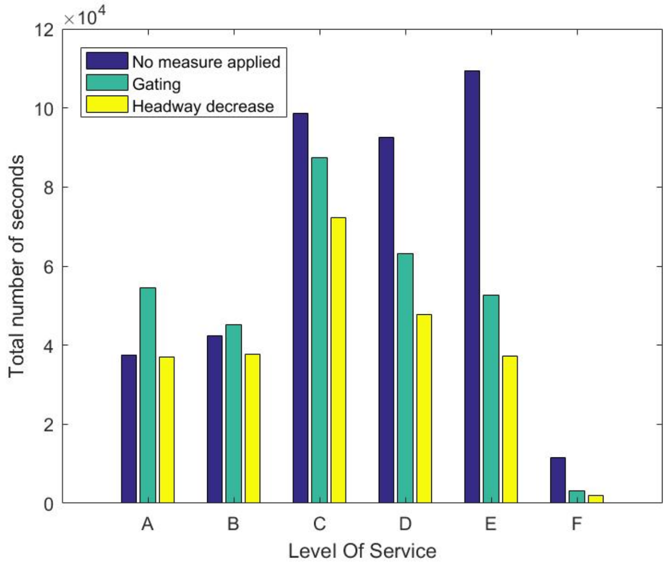


Figure 6.17: Total seconds spent on the platform in each Level of Service per scenario, in case of event flow

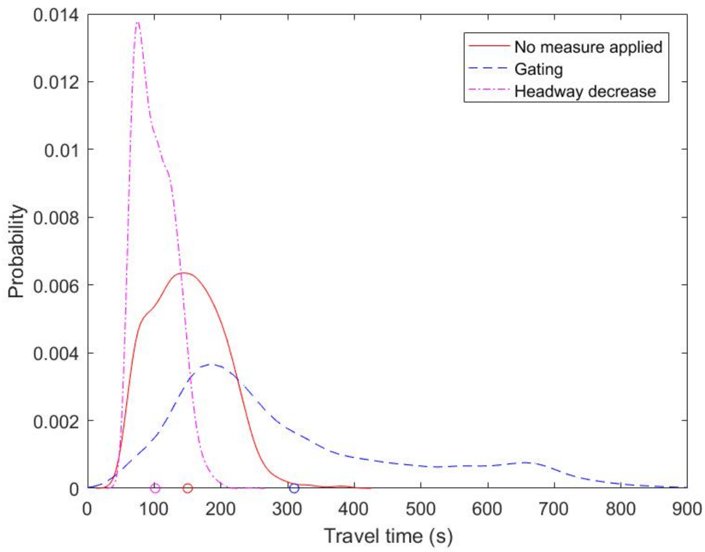
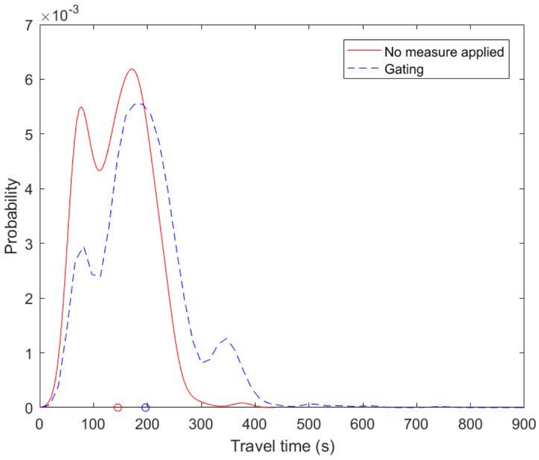
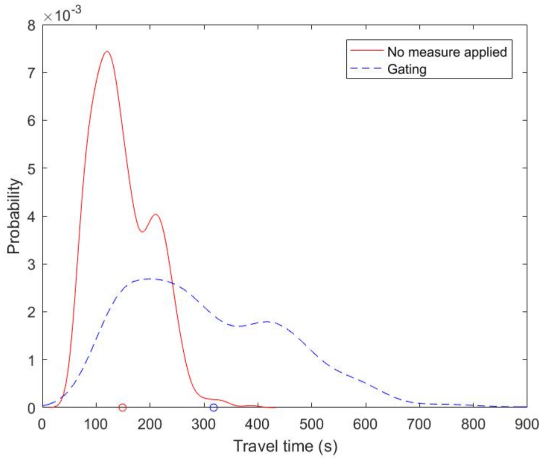


Figure 6.18: Probability density function of time from entering the station to boarding in case of event flow. The circles on the axis are the average travel times.

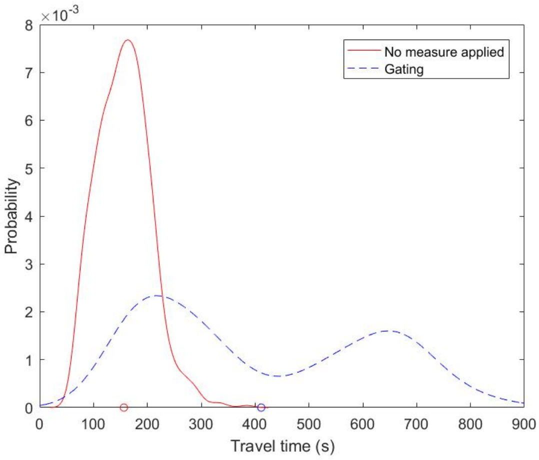
In figure 6.19, the travel time is plotted for three different time intervals of the simulation. In the first 5 minutes of the simulation, the travel times when gating is applied are slightly higher than when no measure is applied. The passengers entering between 5 and 10 minutes experience longer travel times than when no measure is applied. This difference increases for the people entering the station after 10 minutes. The queues are thus increasing, and gating comes with increasingly disadvantageous travel times when a larger inflow of people is experienced over a longer time period.



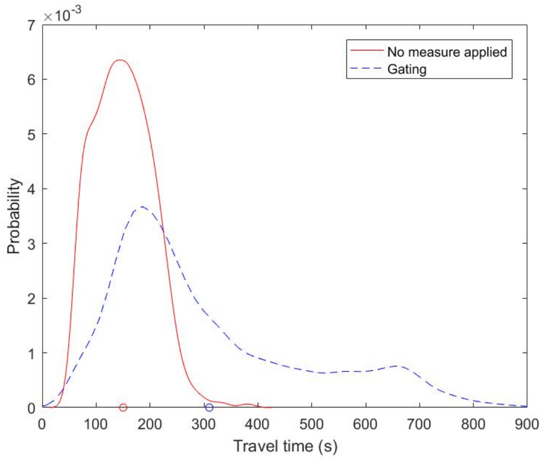
(a) Passengers entering the station until 00:05:00



(b) Passengers entering the station between 00:05:00 and 00:10:00



(c) Passengers entering the station between 00:10:00 and 00:15:00



(d) All entering people

Figure 6.19: Probability density function of time from entering the station to boarding in case of event flow. The circles on the axis are the average travel times.

Desired effect

The last question of the framework in the evaluation step, is if the desired effect is achieved on the safety and throughput when the measure is applied. As was concluded earlier, in the case of the peak hour flow both the dedicated doors and the headway decrease help in decreasing the total time spent in what is considered to be unsafe situations (LOS D, E and F). This also holds when gating and a headway decrease is applied in the event flow load case. From a passenger point of view, less time is spent in the most unfavorable LOS E and F for all measures in both load cases. Therefore, all measures can be considered to make the station safer using the LOS as indicator. All measures except for gating decrease the average time a person spends from entering the station to boarding, indicating an increased throughput. It is then up to the analyst to decide which measure (or both) can be applied for a particular load case, also taking the possible negative affects as mentioned in table 3.1 into account.

Since the desired effect on the safety and throughput can be achieved with each measure, the question 'Does measure give desired effect?' is answered with 'yes'. This leads to the termination of the framework. The fifth step and the termination can be seen in figure 6.20

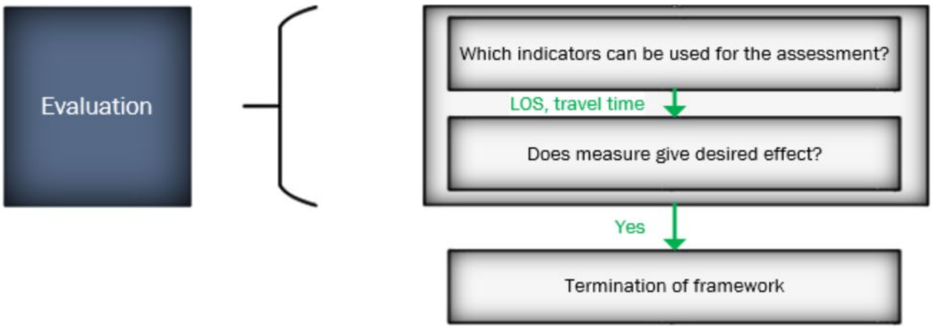


Figure 6.20: Fifth and last step of the framework with the answers in dark green

6.3. Reflection on Framework

In this section, each step of the framework is reflected upon. Possible alternatives, improvements and conclusions from the framework are discussed. Afterwards, if the framework fulfills the requirements that are set in chapter 5 is discussed.

Step 1 - Applicability of framework
The first step of the framework is the applicability check. In this case study, the input has been set such that crowding issues occur and that all questions in this framework are answered positively. If the framework is applied in a case study that is not at a train or metro station, such as an airport, mall or other large building with crowding issues, useful results may also be drawn from the application. However, many measures related to train stopping times or positions can not be applied anymore.

Step 2 - Problem characteristics
In the problem characteristics step of the framework, the input is gathered to select measures in the next step. This is done with the help of table 5.1. The filling in of this table is based on observations from either a model or real life situations. The questions are answered qualitatively and therefore up to the interpretation of the analyst. A quantification of the criteria could be performed to make the selection more objective, but this is expected to make the framework very complex and requires extensive measurements.

Step 3 - Measure selection
The third step of the framework is to select measures. In this case study, 7 and 10 measures were found to be suitable for the peak hour and the event load case respectively. Applying one or a combination of those measures could lead to achieving the desired effect. The process of which of those measures to select first is left to the analyst and requires knowledge on crowd management. Therefore, different users of the framework could end up with different measures to be applied if the same case study is selected. A more objective selection of measures would require more steps in the framework to be quantified. This is considered to be impossible or very limiting to the nuance of some steps in the framework, because the effectiveness of measures strongly depends on many contextual settings, the problem analysis and the objectives. Furthermore, the balancing of the benefits of a measure on for example

the safety versus the costs and the downsides of applying that measure is considered to be done by decision makers. This work is merely to support the decision maker in the process and not to provide only one possible solution. The framework could be expanded to insert more station characteristics in order to provide more guidance. This would however lead to a very complex framework which leaves out the wider interpretation of different measures.

Step 4 - Assessment
In this case study, measures were selected that could be modeled with MassMotion in the fourth step of the framework. The modeling complexity was limited due to the relatively small and simple station. If the complexity of the station is larger, the accuracy of the model may reduce. This would however only affect the complexity of the modeling and the assessment, and not the functioning of the framework or the effectiveness of a measure.

Step 5 - Evaluation
In the evaluation step of the framework, indicators are selected and the measure is assessed to determine if the desired effect is achieved. The indicators used for the assessment of the measure should be selected carefully. In this case study, the total time per LOS on the platform was taken and with for example the gating. The queues upstream of the check-in are thus ignored. Also an indicator from the passenger point of view was chosen with the relative time passengers spent per LOS level, which sometimes gives different results on the effectiveness of a measure. Some measures can have a positive effect on one objective but a negative effect on another and thus for a complete idea of the effects of a measure, multiple indicators should be used. The selection of the indicators is dependent on the objectives, the case study and the selected measures. The framework could be updated to take all these into account when selecting the indicators. However, that may lead to a complex selection process that is unable to capture circumstantial effects that occur. Therefore, the analyst is recommended to select multiple indicators based on the possible positive effects as well as negative side effects. The assessment on if the desired results are achieved are also left to the analyst, because this includes multi-disciplinary decision making. As mentioned before, this framework is merely meant to support this decision making process.

Results
The framework has been tested in a simple station with two different load cases. In both cases, the framework lead to measures that had positive effects in reducing the number of seconds spent in the least favorable levels of service. Hence, positive effects on the objective of safety are expected when the selected measures are applied. The framework is believed to guide towards possibly effective measures for other load cases or other train or metro stations experiencing crowding problems as well.

The requirements set for the framework in chapter 5 are met. The framework used contextual information from a station to guide towards measures that can be effective. Information on the principles, field of application and possible other effects of a measure are given and the requirements needed from a model are provided. Through using an indicator dependent on the objective of applying crowd management measures, the measure can be assessed. Stakeholders in the field have sufficient knowledge to apply the framework, as was checked with expert interviews. The objective of this thesis was to design a method to systematically select and assess effective crowd management measures to increase the safety and throughput at train and metro stations. With the proposed framework, this objective is fulfilled. The framework can help in the decision making process by providing knowledge on the measures and can help to raise awareness for the crowding issues that are faced. Even though the framework is proposed for train and metro stations, also application at for example airports or other large buildings is possible with a careful interpretation of the results.

Validation
The proposed framework has also been discussed with experts in the position of applying the framework ([17, 18], see appendix A). The conclusion drawn by them was that the framework

is useful as a guide to the selection of measures and to support in the decision making process. The broad perspective of all measures that can be applied is now clarified. The next development of the framework could be to integrate into one easy to use framework which more specifically selects measures.

6.4. Conclusion case study

This chapter started with a station which has many similarities with the metro station Weesperplein in Amsterdam, with two different load cases. The developed framework was used to obtain crowd management measures for the two situations where the station was suffering from crowding issues. All the measures selected with the framework turned out to have positive effects to decrease the total time all passengers spent in the most critical LOS D, E and F at the platform and are therefore expected to positively influence the safety on the platform. For most measures, the travel time at the station also decreased, indicating an increased throughput. All in all, it can be concluded that the framework does its job to guide to possible effective measures. It is then up to the decision maker to weigh the positive effects of a measure to the negative effects and the costs to select and apply certain measures.

7

Conclusion, discussion and recommendations

This chapter first discusses the answers to the research questions and the main research objective. Thereafter, the methodology and results of this paper are critically reflected upon. Based on the knowledge developed when writing this thesis, practical recommendations are given as well as recommendations for further research.

7.1. Conclusion

Each of the research questions described in chapter 1 is answered. The answers on these questions are needed to draw the final conclusion on whether the main objective of the thesis is achieved.

What are the most important objectives of crowd management?

Seven stakeholders are identified and analyzed to evaluate their objective, influence and interest in crowd management. These are the rail infrastructure operator, station operator, station retail operator, passenger, transport operator, decentralized authorities and the national government. Increasing the safety turns out to be the most important objective behind crowd management, as indicated by almost all stakeholders. After that, increasing the reliability and punctuality, the comfort and decreasing the travel times follow.

What are the characteristics of researched or previously applied crowd management measures?

A thorough review on studied and applied measures is performed to come up with a list of 29 crowd management measures, their field of application, possible other benefits or disadvantages, and an estimate of the costs. This has been done qualitatively because the effects of measures depend greatly on the context in which they are applied. Measures are found that can increase the throughput, prevent blockades, distribute passengers over time or over space and to limit the inflow. Some measures were also found to have a positive influence on the punctuality, in-vehicle comfort, self-organization. However, negative effects of measures or limitations to the application were also found, such as a minority of travelers that experiences negative side-effects, a decreased surface area, complexity to apply measures or measures that first require communication to travelers. For many measures, a scientific underpinning of their principles and effects is missing.

What is required from a simulation model to accurately model and assess crowd management measures?

To assess the effects of measures, models can be used as an alternative to testing measures in real-life. In order to accurately model each measure, different requirements are needed from the model. For each of the 29 measures from the previous question, it is determined if the model needs to be able to model basic flow scenarios, self-organizing flow behavior, compliance to information, advanced human decision making, global and local route choice, collision avoidance, demand arrival pattern and multiple user classes. No single model is available that is able to fulfill all these requirements. This shows the necessity to select a model dependent on the desired measure.

How can a framework be designed to select and assess crowd management measures?

Based on requirements derived from expert interviews, a framework is developed to guide to possibly effective crowd management measures. This is done building on the knowledge obtained from the previous questions. In the first out of the five steps of the framework, it is checked if the framework can be applied. The next step is to identify the characteristics of the station, the load case and the bottleneck. In the third step, using this information, the 29 measures can be narrowed down to the ones that could have a positive effect. For the measure(s) selected to assess, it is then determined if it can be tested in real life. Alternatively, a model can be used, and it can be determined what is required from a model in order to accurately assess this measure. In the final step, the measure is modeled to see if the effects on the objectives are as desired. If not, a different measure can be selected or large infrastructural changes can be considered. If this works, the framework is terminated.

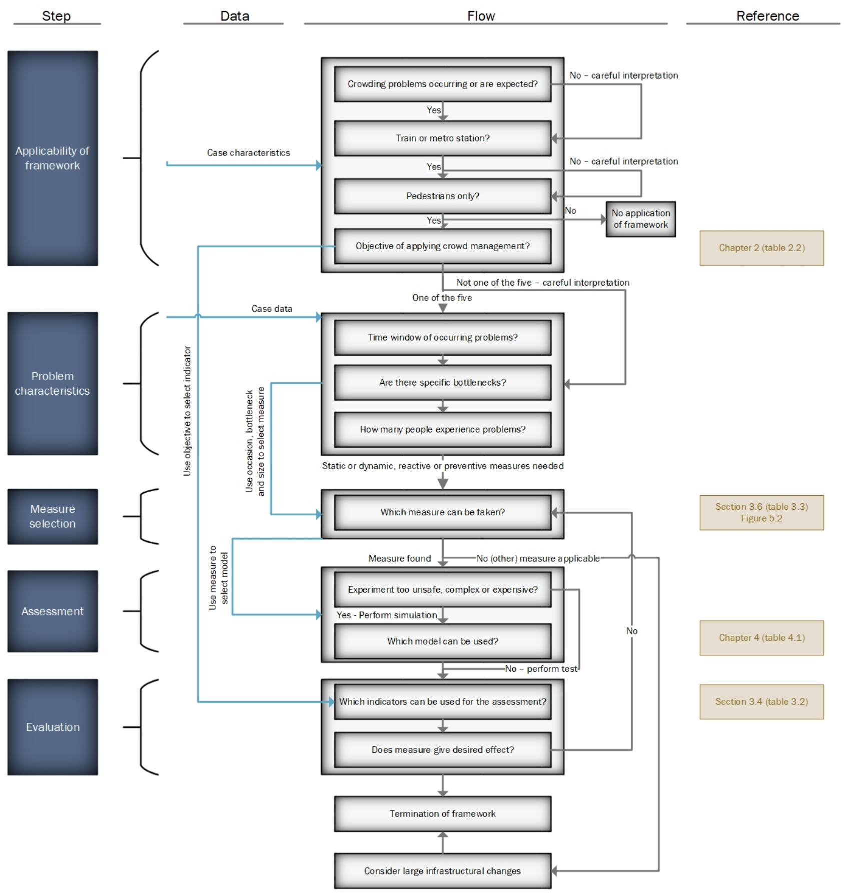
How does the framework perform when applied to select and assess measures in a realistic case study scenario?

The framework is applied on a fictional station which has many similarities to the metro station Amsterdam Weesperplein. Two different load cases are considered: a peak hour demand where the share of boarding and alighting passengers is 50/50% and event flow, where the share is 90/10%. A change in boarding and alighting procedure (dedicated doors) and decreasing the headway are the selected measures to be modeled because they are believed to have the most effect. For both measures, the total time spent on the platform by all passengers decreases for the most critical LOS D, E and F. The relative time an average passenger spends in LOS F also decreases, thus the measures are considered to be effective in order to increase the safety. The average time a person spends from entering the station to boarding also decreases with both measures.

In the case of event flow, ten measures can be used of which gating and a headway decrease have been selected because they are assumed to be the most effective. These two measures both help to decrease the total and the relative time on the platform spent in LOS E and F. However, when gating is applied, queues form upstream of the check-in gates and this leads to an increasingly large time for passengers between entering the station and boarding. Because the framework is guiding towards measures that have positive effects to increase the safety and throughput, the framework is considered to function properly. With the advantages from applying the measure(s) and the negative effects as well, the decision maker can make an underpinned decision on whether to apply the measure(s) or not.

The objective of this thesis is to design a method to systematically select and assess effective crowd management measures to increase the safety and throughput at train and metro stations.

In this report both qualitative and quantitative methods have been used to get to the final result of the framework presented in the figure below. From literature and expert interviews, a list of crowd management measures, and their characteristics is composed. A model can be used to assess the effectiveness of measures in terms of safety and throughput without having to perform unsafe or expensive real life experiments. In order to accurately model a measure, different requirements are needed from a model, which have been established in this thesis. The developed framework starts with an applicability check, the objective of the user when applying measures, grasping the contextual information from the station and the load case in order to select measure(s) that could be effective. Then, a model can be selected based on the recommended measure(s) in order to assess the measure(s). Using the model, the effectiveness of the measure(s) can be objectively established so that a more substantiated decision can be made on whether or not to apply the measure(s). The developed framework meets the functional requirements. With the framework, the objective of the thesis is considered to be fulfilled. However, a complete, exhaustive, and objective selection of a single measure that is most effective to apply for a station and a case cannot be provided because of the many contextual variables and other factors playing a role in the decision making process. Yet, this framework is believed to be beneficial to support multidisciplinary decision making.



7.2. Discussion

In this section, the authors interpretation of the results, assumptions and uncertainties are provided. This is done for each chapter separately.

Stakeholder analysis
The thesis started with the stakeholder analysis. Based on literature and interviews with stakeholders, seven stakeholders were identified. No complete consensus was achieved for these seven stakeholders, indicating that a different method to identify the stakeholders leading to a different result is possible. The interviews with the stakeholders could be conducted in such a way that socially desirable answers could be excluded. However, it is assumed that the primary objective of safety then remains the most important, because a large consensus was achieved here by all interviewees and safety is far more important than the secondary objectives of throughput. For this same reason, having more different interviewees from the same stakeholder is also assumed to have little effect. The outcome of the objective ranking is focused on the case in the Netherlands and could differ for other countries. It was noticed for example that the national government plays a larger role in crowd management on stations in Switzerland than in the Netherlands.

Crowd management measures
Not much literature is available on the working principles and effects of crowd management measures. Therefore, also less known or highly regarded research is incorporated in this thesis. Furthermore, less scientific or reproducible results of measures applied in practice are used. This can possibly affect the reliability of the statements on the measures. Even though an extensive literature review has been done, it is possible that crowd management measures have been applied that are different from the 29 listed measures.

Assessment
To obtain the requirements needed for modeling a measure, literature is consulted and some requirements are complemented by the author and checked by model experts. The requirements needed from a model are determined by the author and an expert and filling the table in again could lead to slightly different results. Consulting more experts to fill in the table could therefore lead to more reliable results. However, much of the requirements needed depend on the specific way in which a measure is applied and hence this rough overview is considered to be sufficient. The relative importance per requirements is assumed to be equal, but some requirements might be more important than others to accurately model a measure. Therefore, different weights for all requirements can be considered to determine more accurately whether a model is suitable to model a measure.

The section on the indicators to use for the assessment of measures showed that no single indicator exists to capture all effects of a certain measure. The indicator should be carefully selected depending on the objective of applying a measure. Some measures can have negative side effects which should also be included as an indicator in order to form a complete assessment on which a decision can be based.

Framework
The proposed framework meets with the set requirements. It used the contextual information from the station to help select a measure, provides information on the possible effects and field of application of this measure, helps to select a model to assess the measure and is usable by stakeholders in the field. The framework provides guidance to select measures but does not strictly point to one measure only. The latter is not considered to be helpful because much contextual information and other possible measures are lost. Furthermore, it would require a very complex framework. However, the framework can possibly be improved by incorporating all necessary figures and tables in order to have a stand-alone document. Also, it can be expanded to cover what was considered to be outside of the scope of this

project: small modifications are needed to make the framework applicable to for example airports or other large buildings. Also, different policy measures to prevent a station from crowding by influencing travelers on a strategic level are excluded from the framework, such as discounts for off-peak travelers. A decision tool to choose between crowd management measures or large infrastructural changes is furthermore missing.

Case study

The results of the MassMotion output have to be interpreted carefully. Although MassMotion is validated software that is used commercially, the output of when a measure is applied is not validated. It merely serves as an indication on the possible effects of when a measure is applied. A real life experiment is advised if the effects of a measure need to be known more specifically. Also other models available can be used to study the effectiveness of measures. The input for the model should always be carefully tweaked to prevent unreliable output. In this thesis, the model was checked to provide realistic output. The model showed a close resemblance to real-life operations in metro stations. It should always be noted that not all effects are captured in a single indicator, and thus be checked that also possible negative effects of applying a measure are taken into account.

7.3. Recommendations

This section deals with recommendations for further research and practical recommendations. As the field of crowd management is rather new, much research still has to be done. The most important aspects of the discussion are translated into recommendations in this section.

7.3.1. Recommendations for further research

- Many measures have not been researched or no scientific studies are publicly available. This leaves room to research the principles behind measures and under what circumstances they are most effective. For example, it could be researched if the dedicated doors work better for smaller or larger metro doors. This information could then be used to update the framework to include more contextual information and more accurately select possible effective measures. Also innovative new measures can be developed. Some measures such as the Intelligent Platform Bar or the fast and slow walking lanes have only been introduced recently and such new measures can be researched on effectiveness and sensitivity.
- Different weights for each characteristic of a model can be considered. This could lead to more accurate determination if a model is suitable to model a measure.
- Pedestrian models are continuously being developed and improved. Having models that meet with an increasing number of the stated requirements accurately are desired because this makes it easier to assess different measures in the same model and obtain more accurate results. Accurate models reduce the need for expensive or unpredictable experiments in real life.
- Many papers on crowding use the Level Of Service as an indicator, which was developed by Fruin in 1971. This macroscopic indicator is used to qualitatively express the crowdedness but is unable to capture all effects that are needed to assess a measure. Research can be done to come up with a new indicator or go more in depth on what can be the most suitable indicators.
- Finally, it would be interesting to see if the proposed framework can be developed further. More contextual information from the station or load case can be incorporated,

and new measures and possible effects included in order to get to a more accurate guidance towards measures. Furthermore, the scope of the framework could be widened. Then for example large infrastructural changes and measures that influence travelers on a strategic level can be incorporated as an option in the decision making process.

7.3.2. Practical recommendations

- A typical example of application of the framework is for stations experiencing a sudden growth of passengers and thus crowding problems. Large infrastructural changes then require too much time and thus crowd management measures can provide a relieve of crowding issues. Application of the framework is advised in all cases with stations experiencing crowding issues, as it provides a structured step-by-step approach to solving problems.
- Many stakeholders can be involved when measures are taken. Therefore, it can be difficult to finish the multidisciplinary decision making process. An essential part of possibly taking crowd management measures is therefore to convince other stakeholders of the need to do so. For this, current scenarios or growth scenarios for future planning can be put into a model to see the crowding issues that could occur when no measures are taken.
- A model can be used to assess possible measures. Besides fundamental principles of the measure, also a closer look can be taken at how the functioning of the measure can be optimized.
- The framework can be used to guide towards possible measures. However, other measures can be considered as well. The framework can continuously be updated in order to cover new measures or other researched effects of measures.
- Always be critical towards the obtained results from the model and the indicators used. Determine if all effects from a measure are monitored and if enough resemblance with a real station is obtained.
- The framework is designed for train and metro stations, but can with some modifications also be used for airports or other buildings suffering from crowding issues.
- If measures are taken, it is very important that passengers are aware of the measure. Some measures can affect some travelers negatively and it needs to be known that this is for the greater good. The success of crowd management measures is after all for an important part dependent on the compliance and the appreciation of travelers.
- With increasing usage of public transportation expected in the future, plans need to be made for the future in order to have sufficient capacity. Where crowd management measures are especially suitable for short term application when capacity is exceeded, for the long term it is wise to consider large infrastructural changes to increase the capacity.

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Appendices

A

Interviews

All conducted interviews were semi-structured, because this provides enough consistency to address the desired topics, but also ensures freedom for the participants to provide their personal insights when necessary. A summary of all interviews has been sent back to each interviewee to check for mistakes. Since some interviews were conducted in Dutch, these summaries are provided in Dutch in order to prevent misinterpretation due to faulty translations. An overview of all interviewees can be found in table A.1. This list is not complete and more experts were talked to but not written down.

Table A.1: Overview of interviewees

Name	Function	Topic	Page
1 Marja van Bijsterveldt	Gemeente Delft - Mayor	Stakeholders, crowd management measures	74
2 Lee Verhoeff	ProRail - Station design engineer	Framework, measures, stakeholders, objectives	75
3 Jasmin Thurau	SBB Infrastructure - Pedestrian flow expert	Measures, assessment	76
4 Rik Schakenbos	NS Stations - Researcher	Stakeholders, market needs	76
5 Wouter Gillissen en Inge Jongerius	Ministerie van Infrastructuur en Milieu - Policy advisor	Influence, stakeholders, measures	77
6 Nicolas Keusen	Federal Office of Transport - Facility manager	Stakeholders and measures	78
7 Jasper van Zanten	NS IT Operatie - Business consultant innovation	Stakeholders, measures and assessment	78
8 Danique	ETOS - Store manager	Objectives and influence	79
9 Jolanda	AKO - Store manager	Objectives and influence	80
10 Mario Campanella	Pedestrian Research - Director and consultant	Measures and assessment	80
11 Sonia Lavadinho	Bfluid - Director and consultant	Objectives, measures	80
12 Falco Bentvelsen	MRDH - Member transport authority committee	Objectives	See table 2.2
13 Three independent public transportation users	Frequent users of public transport	Objectives	See table 2.2
14 Nicholas Molyneaux	EPFL PhD in management strategies of pedestrian flows	Measures categorization, models and framework	See table 4.1 and figure 5.2
15 Flurin Hänseler	TU Delft Post-doc in pedestrian modeling	Measures categorization, models	See table 4.1
16 Danique Ton	TU Delft PhD in pedestrian modeling	Stakeholders, framework	See figure 2.2
17 Samir el Gamal	Royal HaskoningDHV Senior Projectmanager Transport Hubs	Framework	See figure 5.1
18 Wieger Pasman	Royal HaskoningDHV Consultant Transport Hubs	Framework	See figure 5.1

Interview Marja van Bijsterveld, 06-03-2017, HNK, Delft

Marja is burgemeester van Delft en is verantwoordelijk voor de veiligheid in de gemeente.

Crowd management in Delft
Het Delftse station kent niet zodanig drukke momenten dat actief crowd management noodzakelijk is. Zelfs bij grote evenementen of storingen is de drukte beperkt. Crowd management in geval van een grote storing blijft beperkt tot extra inzet van de NS service en veiligheid medewerkers, bebording naar alternatief vervoer (busplein en tram) en het creëren van opstelruimte op het stationsplein voor passagiers die met busvervoer verplaatst worden. Veiligheid Advies is nu bezig met een onderzoek naar de mogelijkheden van crowd management bij grote evenementen met meerdere locaties in de binnenstad, conform de prioritering in het beleidskader. De uitkomsten hiervan zijn nog niet bekend.

In Delft zijn er geen evenementen waarbij grote loopstromen vanaf het station verwacht worden: de Delftse evenementen trekken vooral Delfts publiek en mensen uit de omgeving die met eigen vervoer komen. De grote evenementen waarbij crowd management een rol speelt in Delft zijn Koningsdag, lichtjesavond en Westerpop. De eerste verantwoordelijkheid voor crowd management ligt bij deze evenementen bij de organisator. In de veiligheidsplannen worden de maatregelen vastgelegd die de organisator neemt op het gebied van crowd control. Waar nodig vullen gemeente en politie dit aan.

Invloed van gemeente
Het treinstation en de stalling is in bezit van NS/Prorail. Die gaan over beheer en gebruik. De gemeente en de OV-vervoerders hebben een Lokaal Veiligheids Arrangement waarbinnen afspraken worden gemaakt mbt veiligheid (en dus ook crowd control) en beheer (schoon en heel) van het stationsgebied. De invloed van de gemeente op de daadwerkelijke inrichting en dienstregelingen van NS is zeer beperkt.

Andere stakeholders
De politie is aangesloten bij het LVA (red: Lokaal Veilgheid Arrangement). De veiligheidsregio houd zich alleen bezig met de tunnelveiligheid van de treintunnel en het ondergronds station en zijn dus geen onderdeel van het LVA. Contact met de veiligheidsregio beperkt zich tot de wettelijke controle en oefenmomenten.

Interview Lee Verhoeff, 13-03-2017, Tulpenburgh, Utrecht

Lee is plantontwikkelaar (Engels: station design engineer) bij ProRail. Hij houdt zich veel bezig met projecten bij Amsterdam CS en is expert op het gebied van loopstromen.

Een van de lopende projecten is het Programma Hoogfrequent Spoorvervoer (PHS). Om dat te kunnen accommoderen gaan op Amsterdam CS bijvoorbeeld perrons verbreed worden ten koste van de middensporen en wordt de Oosttunnel verbreed. Daarnaast worden er op Amsterdam CS perrons opgeruimd door bijvoorbeeld vuilnisbakken en kiosken te verplaatsen, wat helpt voor de zichtlijnen op het station en voor het creëren van extra oppervlakte.

Op een aantal stations zijn capaciteitsproblemen maar het oplossen daarvan kost geld en het is de vraag of men het dat waard vindt. Het gaat dan om wat nog acceptabel wordt gevonden. Binnen NS en ProRail worden er normen gehanteerd op basis van LOS van Fruin, maar er zijn binnen ProRail bijvoorbeeld geen normen over het wachten voor een stijgpunt. Assessment van crowd management maatregelen gebeurt onvoldoende. Via de stationsbelevingsmonitor komen we iets te weten over de hoofdlijnen, maar kan er niet precies herleid worden wat de passagier precies prettig of onprettig vond.

NS Stations, NS Reizigers en ProRail zijn samen vaak probleemeigenaar. ProRail is verantwoordelijk voor de basis operatie, maar de vraag is dan wat die basis is. Bij evenementen zoals koningsdag is het aan NS Reizigers om met extra maatregelen te komen. NS Stations is verantwoordelijk voor ontruimingen van het station bij calamiteiten. ProRail heeft namelijk geen personeel op stations. Naast de stakeholders in het schema heb je nog de vervoersregio (valt onder gemeente te scharen) en retail om stations heen. Zo had winkelcentrum Hoog Catharijne invloed op de looproute bij het station, waar geen extra trappen naar het perron zijn gegaan zodat er nog wel reizigers langs het winkelcentrum zouden komen.

Een framework is moeilijk, want het probleem is dat het rijk en de vervoerder te weinig interesse hebben. Daarom komt voor veel projecten de financiering niet rond. Een onderbouwing van de noodzaak van crowd management maatregelen zou daarom nodig zijn.

Objectives:

- Reliability/punctuality 4
- Comfort 3

- Revenues from tickets and shops 1
- Travel times 4
- Safety 5

Telephone interview Jasmin Thurau, 02-02-2017

Jasmin works for SBB infrastructure, which can be seen as a combination of the rail operator and the station operator, located in Switzerland. She is working on pedestrian flows, and currently working on research on crowd management methods possibly to be applied in the station of Basel. In that station, there might be a problem with the flows on the overpass. Concerning safety on platforms, no solid framework to determine which measure to apply or scientific foundation for the effectiveness of the applied measures is available. In order to assess the measures, stereo cameras are installed which measure the x-y coordinates of each pedestrian, with full respect to privacy protection.

Jasmin states that traveler groups are also an important stakeholder as they have much influence, representing the travelers.

Travel times – 1/2
Comfort – 1
Revenues of tickets and shops – 1
Safety – 5
Reliability/punctuality – 3

Interview Rik Schakenbos 02-02-2017, Katreinetoren, Utrecht

Rik werkt voor NS stations en houdt zich vooral bezig met loopstromen over stations. Rik zegt dat er pas sinds 2015 structureel wordt getoetst op drukte op perrons/stijgpunten etc. bij het opstellen van de dienstregeling. Uit ervaring weten ze ongeveer welk station problemen op kan leveren. Op een aantal stations zoals Amsterdam Zuid, Utrecht Centraal en Schiphol hangen veel sensoren om beter te kunnen meten op een aantal plekken waar drukte wordt verwacht en sensoren om het aantal mensen per vlak te kunnen tellen.

Wie zijn belangrijkste stakeholders in crowd management?

NS Stations, NS Reizigers en ProRail zijn belangrijk. Vervoerders maken zelf hun gewenste dienstregeling en dienen deze in bij ProRail, die vervolgens wel of niet kan toewijzen. Daar zitten ook bijvoorbeeld goederenvervoerders bij die ook ruimte nodig hebben op het spoor. ProRail heeft dus ook veel belang bij crowd management. Op Schiphol bijvoorbeeld staat er een team voor crowd management (met maatregels als roltrap stoppen of mensen vragen te spreiden) klaar. Deze operatie wordt uitgevoerd door NS Reizigers. NS Stations gaat zelf niet over de maatregelen. Gemeente is verantwoordelijk voor een goede bereikbaarheid binnen de gemeente en heeft dus ook een belang in het interwijkverkeer. De nationale overheid, en dan met name I&M is nodig als er ergens een knelpunt is en dus geld nodig om op te lossen. Retail op stations is deels in handen van NS Stations (bv kiosks) en deels extern. Kiosks kunnen we dus ook nog op plekken plaatsen om het gevoel van veiligheid te vergroten terwijl we weten dat ze niet zoveel klanten gaan trekken, terwijl externen wel zoveel mogelijk passanten willen hebben. Samenhangend met de gemeente is er ook nog de veiligheidsregio, die in ernstige situaties kan besluiten om een station te sluiten.

Is er een leidraad om crowd management maatregelen op stations toe te passen?

Crowd management is relatief nieuw. Per station kan worden bekeken of het gaat om incidentele of structurele drukte en waar de bottlenecks zijn om vervolgens maatregelen te bedenken.

Safety 5
Travel time 2/3
Reliability/punctuality 2/3
Comfort 3
Revenues of tickets and shops 1

Interview Wouter Gillissen en Inge Jongerius, 28-02-2017, Ministerie van I&M, Den Haag

Wouter en Inge werken allebei bij het ministerie van Infrastructuur & Milieu. Ze zijn beiden beleidsmedewerker. Wouter is onder andere landsdeelcoördinator Noord-Nederland en heeft ook contact heeft met regionale vervoerders. Inge houdt zich bezig met de aansturing van NS en ProRail, op basis van beheer- en vervoerconcessies.

Invloed van I&M

In de beheerconcessie met ProRail worden afspraken vastgelegd, zoals dat bij transfervoorzieningen ProRail verantwoordelijk is voor de veiligheid. Naast de beheerconcessies kan het ministerie ook subsidies geven. Dat geld is geoormerkt en zit in verschillende programma's, zodat aan partijen kan worden gevraagd of ze ideeën hebben hoe binnen dat programma zaken zo efficiënt mogelijk geregeld kunnen worden. Of en hoeveel geld er in de diverse programma´s wordt gestopt is afhankelijk van de politieke prioriteit die er voor het onderwerp is. Mediaaandacht kan bijdragen aan politieke prioritering. Er is bij I&M nog geen apart programma voor transfercapaciteit. Op basis van de uitkomsten van de nationale markt en capaciteitsanalyse wordt duidelijk waar op het spoor in Nederland knelpunten kunnen ontstaan. Op basis van die analyse kan het nieuwe kabinet prioriteiten gaan stellen en bepalen of transfercapaciteit daar onderdeel van is. Naast de subsidies en beheerconcessies schuift I&M ook aan bij veel overleggen op bestuurlijk niveau, waarin ze invloed kunnen uitoefenen op het verbeteren van de deur-tot-deur reis via overleg.

Crowd management maatregelen

Wouter en Inge zijn bekend met een aantal maatregelen op het gebied van crowd management, maar de oplossingen die worden bedacht door bijvoorbeeld ProRail worden ze niet altijd in meegenomen omdat de uitvoering daarvan meer bij die partij ligt. I&M kan bijsturen met de prestatie-indicatoren en via de uitwerking van verplichtingen uit de beheerconcessie, zoals met het beheerplan. Daarnaast gaan sommige dingen in afstemming, zeker als er (lokale) politiek-bestuurlijke aandacht voor is, maar is voor deze acties geen instemming van I&M voor nodig. ProRail heeft lijstjes met knelpunten en ook openbaar gemaakt wat voor oplossingen in 2017 aan gewerkt worden. In principe heeft ProRail dus budget om oplossingen zelf uit te voeren maar grotere knelpunten worden ook bij het kabinet neergelegd of het prioriteit heeft. Het kan ook voorkomen dat gebruikers zoals universiteiten of hogescholen of decentrale overheden met problemen komen of extra capaciteit willen, ProRail probeert hen dan ook mee te laten betalen.

Belangrijkste doelen crowd management

Veiligheid is het belangrijkste doel, maar ook daar moeten natuurlijk keuzes worden gemaakt hoe veel een stukje extra veiligheid mag kosten. Verder heeft I&M ook prestatie-indicatoren met ProRail en/of NS over betrouwbaarheid/punctualiteit en comfort (zitcapaciteit in treinen is actueel) dus zijn die ook vrij belangrijk. De omzet is niet van belang.

Reistijden - 3

Omzet voor vervoerders en winkels - 1
Comfort - 4
Veiligheid - 5
Betrouwbaarheid/punctualiteit – 4

Stakeholders

Naast de partijen al genoemd gaat I&M ook nog veel om met o.a. goederenvervoerders, reizigersorganisaties, tweede kamer en omwonenden. Als stakeholder in het crowd management worden verder nog provincies of andere concessieverleners genoemd en de Inspectie Leefomgeving en Transport (ILT).

Interview Nicolas Keusen, 15-02-2017

Nicolas works for Federal Office of Transport, the supervisory authority responsible for public transportation in Switzerland.

Being responsible for public transportation in Switzerland, do you ever have the need to apply crowd management measures? If so, what measures are taken and who decides which measures are taken and funds them?

The Federal Office of Transport (FOT) in Switzerland orders only exceptionally crowd management measures by real dangerous situations (correction's measures). The usual way is to prevent the problems: the FOT controls and approves the projects of the rail infrastructure operators and can, in the approve act, order to the operator to take measures to avoid critical situations. The second way by real dangerous situations is to order to the rail infrastructure operator to eliminate the critical situation. In both cases, the FOT doesn't choose the measure, but orders to develop and take measures. The rail infrastructure operator has to propose measures to the FOT and the FOT approves it, if it is proved that the measure is appropriate to reduce or eliminate the dangerous situation or the risk. The responsibility of the security ever remain by the rail infrastructure operator.

If crowd management measures are applied, from your governmental point of view, what objectives are important? Could you give the objective below a number from 1 to 5, where 1 is not important at all and 5 is very important. Are there any objectives missing?

Travel time – 3
Comfort – 2
Safety – 5
Revenues of tickets and shops – 1
Reliability/punctuality - 4

Nicolas states that no objectives are missing in this list.

Interview Jasper van Zanten 31-01-2017, hoofdgebouw NS, Utrecht

Jasper werkt voor NS (IT Operatie).

Wie zijn de belangrijkste stakeholders in crowd management?

NS Reizigers en NS Stations spelen een grote rol. Prorail speelt daarnaast een belangrijke rol op stations. Zij hebben namelijk belang bij goede verloop van reis, want vertraging kan propageren naar andere vervoerders. Gemeenten zijn nog wel eens belangrijk bij bijvoorbeeld vergunningen (licht en monumentale pand vergunning bijvoorbeeld bij LED bar op station Den Bosch). Het project IPB is een gezamenlijk project van NS en ProRail met

50/50 financiering. Uiteindelijk wordt ProRail eigenaar van het display (de fysieke Intelligent Platform Bar) en NS van het bronsysteem dat het IPB voorziet met de juiste real-time informatie. Nationale overheid speelt nog rol voor subsidies, maar die kunnen ook uit EU komen. Eerst wordt project gestart en betaald, subsidies die daarna worden binnen gehaald zijn een meevaller.

Hoe werden de resultaten van de Intelligent Platform Bar proef gemeten?

De exacte resultaten zijn intern, maar het spreidings effect van het IPB is significant gebleken. TNO heeft het onafhankelijke onderzoek naar de effecten van de maatregel uitgevoerd. Ruim 30 camera's zijn achter het IPB opgehangen en hebben bij elke haltering het aantal in- en uitstappers per deur vastgelegd. Het bleek dat mensen beter over perron waren gespreid. Dwell times had het niet heel veel invloed op, maar dat kwam omdat conducteurs niet eerder weg gingen en zich aan de exacte dienstregeling hielden. Na de succesvolle proef op station den Bosch hebben de directies van ProRail en NS besloten het IPB op Schiphol Airport te gaan implementeren. Dit station heeft momenteel door het stijgende reizigersaantal en verhoogde inzet van treinen een acuut transferprobleem op het smalle perron van spoor 1 en 2.

Zijn er naast IPB ook nog andere maatregelen overwogen?

IPB begonnen we omdat we toevallig materiaal voor displays al hadden na de drukte-indicator proef op de Ijssellijn. We gaan binnenkort ook een proef doen met een LED strip in het perron in Amsterdam Zuid om de treinlengte aan te geven maar dat is dus minder gedetailleerd. Op Schiphol kan je op je app naast de grootte van de trein ook waar de trappen in het station zitten zien. De verwachting is dat het IPB, wellicht in een aangepaste (kosten efficiente) vorm ook op meeredere stations geïmplementeerd zal worden. De informatie op de app zal geleidelijk landelijk beschikbaar komen. Materiële informatie is reeds (real-time) beschikbaar voor elk station, maar het digitaliseren van de perronobjecten, inclusief hun exacte locatie, moet nog plaatsvinden.

Wat zijn objectives achter crowd management?

Safety - 5
Travel time - 2
Reliability/punctuality - 4
Comfort - 3
Revenues of tickets and shops - 1

Toevoegen: spreiding over trein. Wanneer we in staat zijn reizigers beter te spreiden in en over ons materieel, stijgt het klantoordeel (reiscomfort en zitplaatskans) en kunnen we ons materieel effectiever inzetten.

Interview Danique, 15-02-2017, Utrecht CS

Danique is waarnemend manager van ETOS op Utrecht Centraal Station. ETOS valt niet onder Servex (red: nu NS Station Retail). Crowd management maatregelen die genomen worden op stations zegt Danique als winkel niet veel invloed op te hebben, Servex heeft dat wel meer. Daarom weet ze ook niet van maatregelen die genomen zijn op Utrecht CS.

Safety 5
Travel time 3
Reliability/punctuality 2
Comfort 2
Revenues of tickets and shops 4

Interview Jolanda, 15-02-2017, Utrecht CS

Jolanda is manager van AKO op Utrecht Centraal Station. AKO is een aparte boeken franchise die niet onder NS Retail valt. Jolanda weet niet wat voor crowd management maatregelen er op het station zijn of worden genomen, maar merkt wel verschil in aantal mensen dat langsliep tijdens de verbouwing van het station, wat tot wisselende omzetten leed. Jolanda zegt dat de NS het voor het zeggen heeft bij het bepalen van maatregelen en dat zij daar als winkel nauwelijks invloed op hebben. Ze zijn al blij dat ze op die locatie mogen zitten.

Safety 5
Travel time 3
Reliability/punctuality 4
Comfort 3
Revenues of tickets and shops 5

Interview Mario Campanella, 09-03-2017, TU Delft

Mario has recently completed his PHD thesis on microscopic pedestrian modeling and is now consultant in simulation models and analyses. Most of his projects are for metro stations and some for train stations.

Mario was involved in crowd management cases in Rio de Janeiro and Sao Paulo. Congestion and extreme high densities in stations are problems on a regular basis there. People tend to be less polite there with for example boarding and alighting when compared to other situations. The people cannot be blamed however, because commuting with so much congestion is unpleasant and annoys people. A solution for the boarding and alighting was introduced in the metro in Rio, where waiting lines where created in front of metro doors, with enough space for alighting passengers left. A steward then releases the queue when boarding can start. This measure was later introduced and tested in Sao Paulo, where films were taken from 4-5 experiments, with one metro door with the measure and the next without. The doors where the measure was applied turned out to be about 3 times more efficient.

Another measure introduced in Sao Paulo was to create buffer zones for the escalators. This measure was thought of by station managers based on their observations. The particular station has many levels and after an upward escalator, people have to make a sharp right turn in order to get the next upward escalator and densities get extremely high. A barrier was placed between these escalators so people had to walk a bit further to the next upward escalator, creating a buffer for the inflow from the escalators and preventing people from falling.

Different measures that were used were handrails to separate bidirectional flows, accompanied by stewards. The position of the handrails could be changed manually by the stewards, in order to accommodate larger flows from one side for certain time windows. Other measures that were proposed are communication and information on walking times per route, enlarging the floor surface area in corridors and the control center to stop trains if a platform is still occupied.

Measures were usually selected based on observations and tests. Not enough resources are available so the assessment of measures is done only periodically and mostly with observations. Principles for the selection of measures could be useful here, more so than guidelines.

Skype interview Sonia Lavadinho, 2-3-2017

Sonia has worked at the transportation center at EPFL and now is a consultant with a special emphasis on pedestrian planning. She carries out own research on pedestrian flows and has conducted experiments as well.

Transfer time can be seen as lost time, or it can be seen as an opportunity. In the Saint-Lazare station in France for example, it has been researched what the effects of providing more pleasant waiting opportunities are. By retaining or accelerating people at desired places, a better distribution of pedestrians can be achieved. In Grenoble, retention space has been created with green, benches and a Wifi connection so people are willing to wait longer. The minimization of stress is an important objective to achieve desired behavior. People usually have less stress if they are at a waiting location such as a coffee place if that is on the same level as the platforms, with visibility giving the impression of being in control. Also with more free space and diversity of opportunities of waiting activities, people tend to spend more money.

The decision where to place retention spaces is based on desire lines. Nowadays more thought is put into dedicated zones for different activities. Sometimes infrared sensors are used to determine where decelerations occur and where bottlenecks are to find out more about suitable retention locations. In airports there is a lot of knowledge on other measures that can be taken in crowd management. An important objective of crowd management is thus to minimize stress. The objective of comfort is therefore very important. The travel time is dependent on the comfort, since people for example mind waiting less if it is in a place that is comfortable, with many things to do. Shops are thus important to provide activities for waiting passengers. Safety is important, but considered more as a basic layer which should be sufficient. The reliability and punctuality is more important if headways increase. Also the provision of departure information is essential to reduce stress.

Comfort – 4/5
Travel time – 2/3
Revenues of tickets and shops – 3
Safety – 1/2
Reliability/punctuality – 4

B

Reflection on measures

In this appendix, the application of the measures is reflected upon. The workings of the model are discussed, as well as the assumptions used to model a measure. Variations on the measures are furthermore discussed and finally, if the measure is easily generalizable to other stations is discussed. This is done for all measures used in chapter 6 separately.

B.1. Gating

The gating in the model is done by limiting the number of gates available to check-in to five. The number of gates that should be available to check-in in order to relieve the LOS on the platform is strongly dependent on the capacity of the gates, which was an input variable in the model. The capacity was based on a theoretical capacity, but if in practice the capacity turns out to be higher, the results can be completely different.

When the travel time is calculated from entering the station to boarding the metro, a constant dwell time is assumed. However, gating can have a positive influence in decreasing the dwell times, because less people have to board the metro and this effect is not incorporated in the model. Therefore, the lost travel time because of gating could in real life be lower than the obtained results, and gating could have a positive influence on the reliability and punctuality.

In chapter 6, 5 gates were available for checking in and the rest for checking out because according to the calculation, this number ensures that the platform remains better than LOS C on average. To see what happens if a different number of gates is available for checking in, also 4, 6, and 7 gates are simulated. The results can be seen in figure B.1 and B.2. It can be seen that if less gates are available to check-in, the critical LOS levels D, E and F are experienced less. However, this comes at the expense of increased travel times because of the building queues. When no measure is applied, the average travel time is the lowest.

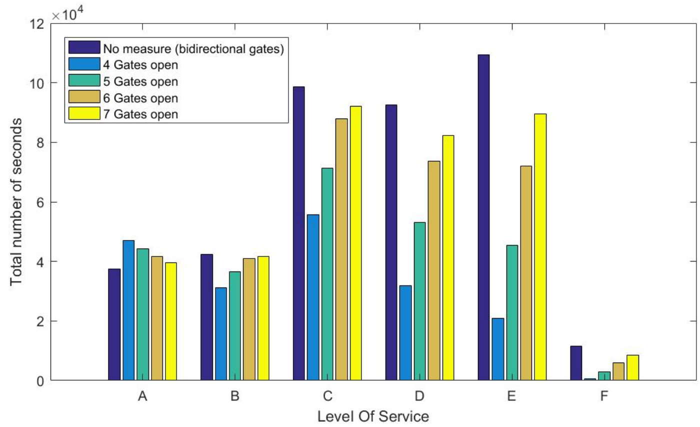

Figure B.1: Total seconds spend in each Level of Service, where the number of check-in gates is altered

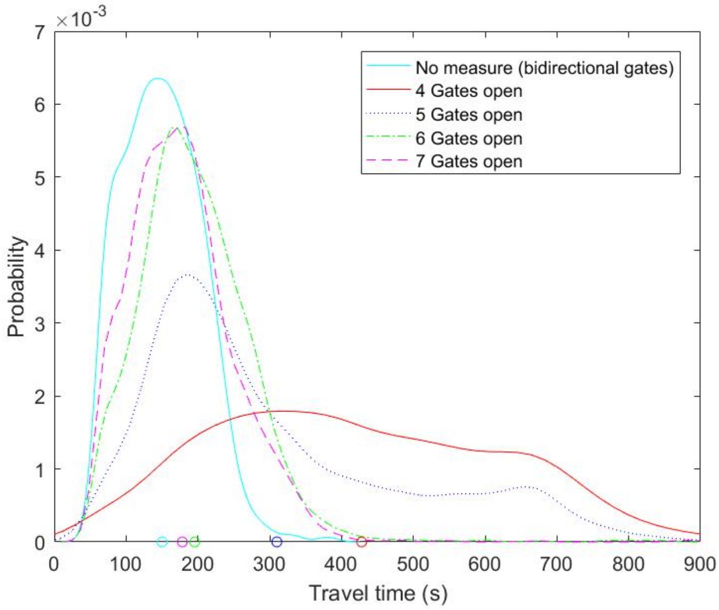

Figure B.2: Probability density function of time from entering the station to boarding where the number of check-in gates is altered. The circles on the axis are the average travel times.

Even though the indicators show positive effects in this case study when gating is applied to limit the inflow, the measure should be carefully and dynamically applied. In this case study, the number of available gates to check-in is adjusted to limit the inflow, but also for example station doors can be used to achieve the same. In either case, gating can ensure that fewer people wait at the platform, but this means that somewhere else queues will build up. A station should therefore have a sufficiently large waiting location upstream of the station doors or check-in gates. The queues that build up at these locations should be carefully managed to avoid that the high levels of service cause new problems that would not exist without gating. When the demand remains high for a longer period of time, gating can be unfavorable because of the increasing queue lengths, pressure and travel times. Therefore, it is recommended to apply gating only when the safety on the platform is the objective, the demand is high for a small time period and sufficient space is available for the queues that are expected.

B.2. Boarding and alighting procedure

In this case study, dedicated doors were used as the change of the boarding and alighting procedure. A 100% compliance of people to use the correct doors was assumed. In real life, in order to obtain such a compliance rate all travelers need to be aware of the procedure and this requires a lot of communication. If the compliance is lower than 100%, at some metro doors the problems of interference between boarding and alighting passengers would occur again, which would lead to a lower effectiveness than described in this case study. On the other hand, rational people are likely to not comply to the dedicated doors if there are no passengers alighting through one door. The unused alighting door will then be used for boarding and this would possibly have positive effects on the dwell time and on the LOS on the platform.

In MassMotion, it is possible to give priority to alighting passengers when a door is used for both boarding and alighting, as is observed in real life. The agents do however not necessarily form an ordered queue at both sides of the door during the alighting process. If this shown behavior is incorporated in the model, the results of the simulation could be better in the scenario where no measure is applied. Using a different model such as the one by Baee [3] could therefore be wise to get a more realistic idea of the effect of the measure.

Dedicated doors are especially suitable at stations where an approximately equal share of boarding and alighting passengers is expected. Changing the boarding and alighting procedure can also have a positive effect on the dwell times and hence the reliability and punctuality can be increased. The initial occupancy of a train is known to have influence on the effectiveness [3], but it is not known what other factors have an influence, such as having many or few doors.

B.3. Decreasing headway

In the case study, the headway was decreased from 3 to 2 minutes, where the total number of people arriving on the station during the simulation time was assumed to remain constant. In reality, an increased frequency leads to a lower total travel time which means that people tend to use this modality more.

A 3-minute headway already gives a quite high frequency and decreasing this to 2 minutes can be difficult or even impossible because of the limited track capacities. Positive effects are expected from decreasing the headway by 1 minute also when the base frequency is lower. The increased use of the rail capacity can however also make the timetable less resilient

Decreasing the headway is expected to contribute to solving crowding issues in many occasions. Only when the platform clearance time is larger than the headway, crowding issues may occur more on the platform, leading to a worse LOS.