Planning Safe Pedestrian Mass Events

Proposing a Framework for Mitigating Risks of Crowd Disasters at Mass Events in the Public Urban Space

Sjouke H.P. Wieringa
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AMSTERDAM INSTITUTE FOR ADVANCED METROPOLITAN SOLUTIONS
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S.H.P. Wieringa
Preface

“Engineering for People”, that is the theme which captures my intrinsic motivation totally. My interest for the most dynamic part of traffic, the people, is founded during travelling and while visiting crowded events around the globe. It is always fascinating to see patterns in flowing crowds and experience crowd management alive. With this in mind my search for a challenging subject for my graduation started a year ago. When I discovered the need for more research on risk mitigation of crowd disasters, I found myself challenged to undertake the research within this complex field of science. The ambition was born to focus on the fragile balance between a pleasant mass event and a harmful mass event. The decision on which mass event to focus was easily made since my interests in the sailing sport and beautiful ships: SAIL 2015.

This thesis is dedicated to the Delft University of Technology and AMS Institute for Advanced Metropolitan Solutions (AMS Institute) in Amsterdam. Herewith, I would like to thank AMS Institute for the opportunity to have interviews with the most busy (and thus important) people for crowd management in Amsterdam and provide a nice working space in the city centre of Amsterdam during the 6 months of this project. To keep the link with reality I have interviewed authorities in crowd management, crisis management and crowd control as well as mass event organisers and logistics team members of SAIL 2015. This gave me an in-depth view of crowd management in Amsterdam and the Netherlands. Therefore, I would like to thank everyone who made this possible and let me ask tough questions on crowd safety.

From TU Delft, I would like to thank my supervising committee for guiding me through the process of graduating. Herewith, I would like to thank you all for your inspiring, stimulating and eye opening advice and encouraging me in my academic ambitions. I would first of all thank Prof. dr. ir. Serge Hoogendoorn for placing me with this interesting subject at AMS Institute. Also, I would like to thank my daily supervisor during this project Dr. ir. Winnie Daamen for her consistency in advising me and letting me take the responsibility and authority of my own work, though be there if I needed it. Furthermore, I would like to thank Prof. dr. ir. Pieter van Gelder his help in studying risks.

During my research, I chose to combine two different science fields from 2 different faculties of TU Delft. For this reason I needed additional feedback on System Dynamics. Thus last but certainly not least, my special thanks go to ir. Floortje d’Hont from the Policy Analysis department at the faculty of Technology, Policy Analysis & Management of the TU Delft. She supported me in my aim to combine these two science fields by modelling a macroscopic flow model in a System Dynamic approach. She not only helped me in the modelling process, but also provided advice on reporting in the last two months of the project.
Summary

Since both population and mobility increase worldwide, visiting mass events is becoming more popular with rising number of mass events and visitor numbers as an effect (Krausz & Bauckhage, 2011). In particular mass events in the public urban space will encounter problems in handling crowds (Plowman, 2001), (Barrett, et al., 2000). According to Pel et al. (2011), the rising demand of visitors of mass events in the public urban space is not met with the available road capacity to accommodate crowds. In addition, especially for public (open access) mass events the number of arriving visitors can easily rise over the expected numbers of visitors, making these type of mass events vulnerable to crowd disasters. Since for these mass events road infrastructure is a constraint and visitor numbers are uncertain but rising, the question is how to maintain the safety of the crowd while still being able to organize massive festivities in the public urban space. Crowd safety implies a tolerated risk of crowd disasters. To illustrate this threat on crowd safety, it is stated that the number of stampedes (incentives for crowd disasters) increase in general with the growth in number of mass events organised (Helbing & Johansson, 2010).

If no action is taken, the risk of crowd disasters will rise with this trend. Despite the available knowledge on preventive measures and the aim of mass event organisations to prevent injuries and fatalities during mass events, current strategies to cope with these risks involve mainly repressive measures. To close this gap between crowd management by authorities and the available state-of-the-art scientific knowledge on crowd disaster mitigation measures, a framework on mitigating risk of crowd disasters by preventive management is needed. This framework functions as a guide for crowd management authorities to acknowledge risk of crowd disasters, to assess risks of crowd disasters and provide advice on effective measures for risk mitigation.

The main research goal is to propose the crowd management framework for mitigating risks of crowd disasters at mass events in the public urban space, by studying cases of SAIL 2015. The approach for designing the framework is derived from two theoretical lenses: Traffic Flow Theory & System Dynamics. The methodology consists of 3 phases. In the first phase of the research a literature study has been conducted. Hereafter, the framework conceptualisation started from where macroscopic flow models could be specified to assess risks of crowd disasters. The latter phase in the research approach was to implement the risk mitigation measures in the models and to draw conclusions and state recommendations. In total 12 research questions related to crowd dynamics, crowd disaster development, risk definition, mitigating crowds, assessing risks, designing a framework and modelling macroscopic flow models have been answered by applying this methodology to design the new framework for risk mitigation.

**Framework for Risk Mitigation**

The framework functions as a tool for any stakeholder responsible for crowd management to assess the risk of crowd disaster development and be provided with a set of measures to mitigate these risks. Potential clients are mass event organisers, government on crisis control and mobility and the policy department of crowd management.

**Framework Steps**

In Figure 1 on page ix the framework is presented. This framework captures the total process for a client to get advice which measures to implement. Each of the 6 steps is dedicated to a process in this application. These steps are being verified by the application of the archetypes for mass events to the framework. The numbers in the framework overview in the figure represent the framework application in chronological order.
The 6 steps have been structured into 5 blocks related to the input needed and the order of application. Furthermore, the domains of application are represented by the colours of these blocks. There are 4 domains of application. Green stands for the initialisation, yellow for gathering data, blue for applying the macroscopic flow models and red for selecting risk mitigation measures. The arrows on the left side of the framework figure represent the input needed for the step(s) in the 5 blocks. The arrows on the right side represent the information flows. These arrows show which information is acquired by application of the step(s) in the block and which information is needed for application of next steps.

The framework can be applied generic or specific. The framework can be applied generic by following 3 steps for GAP being 1, 2 and 5 and all 6 steps for SAP. During the application of the SAP steps the user is asked to derive Event Blocks, which are a stretch at an event area with a certain width, length and a direction of flow. Event Blocks are used for defining those event areas for modelling in the framework. The arrow on top of this figure represents the client. The framework clients can be all actors with interest in crowd disaster development and risk estimation of crowd disasters. Especially for event organisers, local government and crowd managers this framework can be applied to support crowd management decision making.

**Figure 1 Outcome of the research: Framework for Mitigating Risk of Crowd Disasters.** This framework contains all 6 steps for Specific Application (SAP) and 3 steps for General Application (GAP) which are 1, 2 and 5. The outcome of the GAP is general advice and for SAP is specific advice on risk mitigation of crowd disasters.
Framework Contents

From the frameworks’ objective and interviews with potential clients the functional framework requirements have been derived which are to provide information on crowd disaster development, provide advice on measures to mitigate risk of crowd disasters, and provide an estimation tool for calculating the risks.

The framework provides information on how crowd disasters develop. This information is incorporated in both the qualitative and quantitative part. While applying the framework the information is presented to the user via various models: by the Layered Crowd Disaster Model, the Scenario Measure Charts and the design of macroscopic flow models.

For the quantification of risk of crowd disasters, macroscopic flow models have been modelled in System Dynamics with software Vensim\(^1\). Three different archetypes of mass event area have been modelled which are called Archetype Macroscopic Flow Models. These models function as basic model to adapt to new mass event areas with either unidirectional flows or bidirectional flows, or queuing areas. The risk decision-making tool is provided in the models by incorporation of performance criteria for crowd management. These performance criteria are derived from literature and interviews with potential clients and relate to travel time, throughput and risk development. With the models and the evaluation tool consisting of a multi-criteria analysis the user can assess the performance of risk mitigating scenarios in comparison with the null-case scenario and with other measures. The advice provided in this evaluation tool incorporates stakeholders’ tolerance towards risks. For the complex task on deciding on risk tolerance, this tool is believed highly beneficial to effective multidisciplinary decision-making.

The framework provides preventive measures on crowd management. The measures are at tactical crowd management level. This tactical level deals with on-road behaviour of pedestrians for influencing route and activity choices. Measures involve the regulation of the inflow by measuring crowd density, maintain a tolerated level of density in an event area, grouping people to regulate inflow, distribute the crowd over the event areas according to capacity, provide information for distribution over the available routes, guide on-route routing according to actual density, separate directional streams, allow for standstill areas, and whether or not to provide sight on landmarks for routing. A combination of measures can be implemented to mitigate risk of the development of crowd disaster phenomena. These combinations of preventive measures are provided in the Scenario Measure Charts and Archetype Measure Macroscopic Flow Models. Advice on measures to implement is provided by the Scenario Measure Charts and the Layered Crowd Disaster Model, by the macroscopic flow models and by the evaluation tool.

Evaluation of the Framework & Design Process

The framework concept is proven by its application to archetypes of mass events. The framework has been improved iteratively throughout the design process by evaluating the application of the archetypes. These archetypes have been derived from SAIL 2015. Next to that, the application of the framework to the three archetypes of mass events provided insight in the effectiveness of measures for mitigating risks of crowd disasters in general. On top of that, the 3 archetypes led to the development of Archetype Macroscopic Flow Models which are part of the quantitative part of the framework. The Archetype Macroscopic Flow Models are verified and validated by an extreme value test and a sensitivity analysis and are proven robust to assess risk of crowd disaster development at different event areas with a flowing purpose, for either unidirectional or bidirectional streams and for queuing.

\(^1\) © 2014 Ventana Systems, Inc.
**Framework Applicability**

Even with limited data on passenger arrival and departure distributions available this framework can be applied generally (GAP). The only premise for case-specific application (SAP) is that the infrastructural dimensions of the walkable spaces of selected Event Blocks should be known.

The time necessary to apply SAP is greater than for GAP. This is due to the fact that in SAP the Archetype Macroscopic Flow Models should be adapted to the new cases, whereas in GAP only qualitative part of the framework is used.

The framework is fully applicable to event areas with a flowing purpose or queuing purpose for unidirectional and bidirectional streams. In addition, the framework is in a larger extent applicable to also multidirectional flowing areas of the event when the framework is applied GAP (generic).

The output of the framework is suitable for decision making upon risk mitigation on the tactical level of crowd management. Options to overcome or mitigate crowd disaster development phenomena are provided as well as specific advice. Furthermore, an extra feature of the framework is a decision simulation tool for dealing with subjectivity on risk mitigation by stakeholders.

**Results of Case Study SAIL 2015**

Two of the three archetypes of mass events in this framework have been derived from SAIL 2015: Wide Dam and Sumatrakade Mooring. The Wide Dam is a long dam of 280 [m] and at its widest point 15 [m] and at its narrowest point 5.5 [m]. The Wide Dam is located upstream of the Sumatrakade Mooring. The latter archetype functions as queuing area for departure per boat to continue walking another route at SAIL. Both stretches are used for unidirectional streams.

Because the Sumatrakade Mooring is located downstream of the Wide Dam, the inflow and throughput from the Wide Dam will determine the inflow at the Sumatrakade Mooring. When considering the capacity of the Sumatrakade Mooring for regulating the inflow to the Wide Dam, a crowd disaster can be prevented. A measure is to discretise the inflow by forming groups of inflowing people far upstream of the bottleneck at the Wide Dam and thus preventing a breakdown caused by a too high inflow. By grouping people the inflow can be regulated to remain under its maximum without people having to wait for a long period before flowing into the Wide Dam. For the Wide Dam grouping could for example take place every 10 [s] for 62 people or every 5 [s] for 31 people. Furthermore, risk is mitigated by not allowing the occurrence of a higher density than the critical density. In combination, monitoring to maintain tolerated densities per Event Block and controlling the inflow a full prevention strategy has been derived.

For the Sumatrakade Mooring the throughput of the Wide Dam, the available queuing space at the quay, the capacity of the boats and their frequency of departure are considered all together to assess the risk of crowd disasters. With a maximum tolerated inflow at the Wide Dam (no breakdown occurs here), only approximately one third could continue per boat at the Sumatrakade Mooring to also prevent a breakdown here by assuming a departure rate of 300 people every 10 minutes. This means that in case the throughput of the Wide Dam is this high, two third of the inflow should continue walking (not take the boat) or the capacity and/or frequency of the boats should increase.

Similar to the findings in literature it is demonstrated by the application of this framework to the archetypes that the efficiency will be lower for bidirectional flows in general. As such, the occurrence of bidirectional flows should be avoided at all times to increase local efficiencies which will be highly beneficial for the total networks’ throughput.
Recommendations for Mass Events

It is recommended to do a risk assessment of crowd disaster prior to the moment the event takes place for improving preventive crowd disaster management by applying this framework. This will support decision-making on complex subject of risk of crowd disasters and provides more insight in crowd disaster development.

A main solution for improving the flow is to avoid bidirectional streams. If this is not possible, the next option would be to restrict the inflow till the maximum arrival rate and/or control the flow by maintaining the critical density as maximum density. The third solution is to increase the width of the bottleneck, however this does not necessarily result in a higher throughput, but only that risk is being reduced for the same inflow of visitors. Increasing the queuing space or bottleneck space is seen as a temporarily measure when not maintaining the inflow below its maximum rate. Maintaining the critical density as maximum density is not as beneficial in a queueing system as in a free flowing system for the reason that the function of waiting allows for a higher densities.

Reflection

The process for designing the framework has started in December 2014 and ended in May 2015. The first finding was that there is no methodology on designing a framework and secondly that limited knowledge on crowd dynamics was incorporated in crowd management plans by authorities. This emphasizes the need for the framework. By combining system engineering with Traffic Flow Theory I tried to close this gap between knowledge in science and practice. The stock-flow structures and causal feedback loops used in System Dynamics allow for modelling flows of people over an event area at aggregated level without the necessity to derive data sets first. The first contribution of System Dynamics applied for pedestrian macroscopic traffic flow modelling, is by providing a simulation tool for assessing risks in pedestrian flows. I have applied over 15 different methods from both science fields to come to the presented framework. The research outcomes function as a confirmation that with the current methodology, such a complex system could be structured in a framework. This may become of use for designing frameworks in the future.

Further Research Issues

- Strengthen fundamental diagrams for bi- and multidirectional pedestrian flows with empirical data
- Quantification of factors influencing desired walking speeds, wayfinding and route choices
- Testing for correlation of factors leading towards a crowd disaster
- Innovations on risk mitigation measures by embracing big data
- Strategic and operational crowd management measures to mitigate risks incorporating in the framework for mitigating risk of crowd disasters
- Risk assessment for other bottlenecks of SAIL by applying this framework
- Quantification of factors leading towards a crowd disaster
- State transitions in fundamental diagrams for uni-, bi- and multidirectional pedestrian flows, also related to the factors leading towards a crowd disaster
- Verifying the risk stages defined in this research by strengthening the knowledge on phase transitions in the pedestrian fundamental diagram.
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### Units & Variables

- $k$: density [$p/m^2$]
- $k_c$: critical density
- $k_i, k_S$: initial density corresponding with initial desired speed, density of the stock
- $k_{max}$: maximum density
- $m$: meter
- $min$: minute
- $p$: # persons
- $Q(k)$: Flow $[p/m/s] = $ Density $[p/m^2] \times$ Speed $[m/s]$
- $s$: second
- $S_{-1}$: previous stock [$p$]
- $tt_{S-1}$: travel time of previous stock
- $u$: speed $[m/s]
- $u_i$: initial desired speed $[m/s]
- $u_{k,S}$: speed corresponding to stock and density
- $w$: width of the stock

### Functions

- **IF THEN ELSE(x, true, false)**: function with a premise x, upon true, upon false
- **Lookup function**: table function for assigning the speed by function of the density
- **MAX Inflow**: function to restrict the inflow for the next stock in direction of the flow
- **MIN(a ,b) or MAX(a ,b)**: function which returns the minimal or maximum value a or b
- **Transfer in Batches**: pulse function to discretize flow in groups
- **Transfer Flow to S1**: function to regulate the inflow from one stock to the next stock in direction of the flow

### Definitions

- **Activity**: a happening with a location and duration
- **Breakdown**: a crowd disaster in terms of flow throughput, which becomes 0 $[p/m/s]$
- **Capacity drop**: the occurrence of a lower reached flow than the maximum flow downstream of a bottleneck or in case of congestion resolves
- **Crowd**: mass of people
- **DIVV**: (Dienst Infrastructuur Verkeer en Vervoer or in English Service for Infrastructure, Traffic and Transportation)
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Event</td>
<td>any activity organised by professional organisation</td>
</tr>
<tr>
<td>Event Block</td>
<td>is a stretch at an event area with a certain width, length and a direction of flow. Event Blocks are used for defining the areas of focus for modelling in the framework.</td>
</tr>
<tr>
<td>Flow</td>
<td>a stream of entities (visitors, pedestrians, persons or people) $Q(k) \ [p/m/s]$</td>
</tr>
<tr>
<td>Free Flow State</td>
<td>is a traffic flow regime without restriction in walking behaviour by actual density</td>
</tr>
<tr>
<td>GAP</td>
<td>General Applied Parts of the Framework (Steps 1, 2, 5)</td>
</tr>
<tr>
<td>Level of Service</td>
<td>is a determinant for the comfort level of service for moving through that area. Fruin (1971) separated the Level of Service into 6 segments from A to F. A stands for very low density thus a high level of Service and F for highest densities and lowest Level of Service.</td>
</tr>
<tr>
<td>Management</td>
<td>organisational tasks or the organisation which execute organisational tasks</td>
</tr>
<tr>
<td>Overcritical risk</td>
<td>function of the duration of a density above the critical density of $2 \ [p/m^2]$</td>
</tr>
<tr>
<td>Route</td>
<td>a course of traveling from origin to destination</td>
</tr>
<tr>
<td>Stakeholder</td>
<td>in this research a group or individual who can affect or is affected by the achievement of risk mitigation of crowd disasters, based on definition of (Freeman, 1984).</td>
</tr>
<tr>
<td>System</td>
<td>a group of interdependent elements forming a whole</td>
</tr>
<tr>
<td>SAP</td>
<td>Specific Applied Parts of the Framework (all steps)</td>
</tr>
<tr>
<td>Under critical risk</td>
<td>function of the duration of a density under the critical density of $2 \ [p/m^2]$</td>
</tr>
</tbody>
</table>
PART A Research Approach

1. Introduction to the Research

This chapter introduces the research by first familiarising with the problem context and deriving the need for a framework on mitigating risk of crowd disasters in the next subsection. Thereafter, the research goal and goal of the framework are emphasized. The fourth subsection provides the scope of the research and in the last subsection the methodology is presented together with the reading guide for the thesis.

1.1 Problem Context

Since both population and mobility increase worldwide, visiting mass events is becoming more popular with rising number of mass events and visitor numbers as an effect (Krausz & Bauckhage, 2011). In particular mass events in the public urban space will encounter problems in handling crowds (Plowman, 2001), (Barrett, et al., 2000). According to Pel et al. (2011), the rising demand of visitors of mass events in the public urban space is not met with the available road capacity to accommodate crowds. In addition, especially for public (open access) mass events the number of arriving visitors can easily rise over the expected numbers of visitors, making these type of mass events vulnerable to crowd disasters. Since for these mass events road infrastructure is a constraint and visitor numbers are uncertain but rising, the question is how to maintain the safety of the crowd while still being able to organize massive festivities in the public urban space. Crowd safety implies a tolerated risk of crowd disasters. To illustrate this threat on crowd safety, it is stated that the number of stampedes (incentives for crowd disasters) increase in general with the growth in number of mass events organised (Helbing & Johansson, 2010).

Crowd disasters can easily lead to unmanageable situations. According to Ale (2009) unmanageable situations can be defined as hazardous situations that can occur without warning, have a fast development, and where no stabilization is possible within available response times. In such situations the risk of crowd disasters is evident when local densities rise up for a longer period of time. Conversely, even within a short period of time the density can increase substantially up to even 10 pedestrians per square meter (Hoogendoorn & Bertini, 2012; Helbing, et al., 2007). As such, crowd disasters can occur as soon as free walking behaviour is being suppressed due to little disturbances.

Mitigation aims to diminish the consequences of risks of crowd disasters. Crowd disasters in dense urban public space should and can be avoided by crowd management. Such management involves preventive measures to handle crowds, whereas crowd control purely entails repressive actions. Preventive measures aim to mitigate risks of crowd disasters by preventing dangerous accumulations of people. Currently, crowd management plans in The Netherlands do not entail such risk mitigation strategy, as could be concluded from several interviews with team members in the crisis and crowd management of mass events, public safety, and security authorities of Amsterdam (see stakeholder analysis in Appendix A.2 on page 93 and the interview summary in Appendix A.3 and 95). On the contrary, current crowd management plans embrace a crowd control strategy rather than a preventive management focus. This implies that reactive management is currently chosen over preventive management in Amsterdam for three reasons.

The first reason is the inability to measure flows because of technical challenges. Currently, crowds are monitored by the use of cameras. Specialists watch the life footage to intervene when ought necessary. In addition, measurements with Bluetooth, Wi-Fi and GPS signals are used to assess the crowdedness at a place. One of these challenges is that measurements with these signals become less
accurate when accumulation of people rises. When these measurements are most relied on, they are often performing less accurate. Furthermore, better measurements are becoming more available but are currently financially less attractive compared to the current measurements used. This means that without (financial) collaboration between government, measurement exploiters, police and mass organisations these measurements are less likely to be considered. AMS Institute is currently involved in closing this gap by doing a pilot study for real-time GPS tracking of pedestrians at SAIL 2015.

The second reason why the focus on crowd control is dominant, is because professionals with a practical crowd control background are often fulfilling top positions within the police force on crowd management. The experiences of these professionals are leading in crowd management strategies, so that management strategies focus on crowd control, which may imply that the crowd management strategy relies on repressive actions more than on risk mitigation measures. This does not mean that the action taken upon analysing life footage by these experts is not adequate. What is means is that if a crowd disaster situation arises, there is sufficient crowd control backup to stabilize order. However, limited attention is given to the development of these disasters or how they could have been prevented in the first place.

The third reason for crowd control strategies within crowd management authorities is the inability to simulate flows of an event accurately, and thus not be able to design options for crowd management measures in advance. This is both because of a financial disadvantage of state-of-the-art pedestrian traffic simulation, and because there are limitations in accuracy and application of simulation for a large event area of a mass event. As such, because of a lack of information and knowledge on pedestrian accumulation and flows, crowd control is chosen over crowd management.

The fourth reason for the reactive management approach might be due to the complexity of prevention of crowd disasters from a stakeholder perspective. Firstly, if a crowd disaster occurs there is not a single problem owner. For deriving a firm preventive strategy the tolerance towards risk of crowd disaster needs to be agreed upon. However, because of difference in stakeholders objectives with mass events and because knowledge is lacking on how these disasters occur, tolerance towards these risk differs among stakeholders. Therefore, it is complex to derive a preventive crowd management strategy for risk mitigation of crowd disasters.

1.2 Need for Framework for Mitigating Risks of Crowd Disasters

The expected trends on the rising number of mass events and visitors press a need for providing a state-of-the-art crowd management strategy for mass events in the public urban space. To be not mistaken, best mass event crowd management strategies both incorporate risk mitigation and plans for crowd control. Because a timely response is needed in case of the people potentially being harmed, real-time and close monitoring of crowds is a primary measure to reduce risks on fatalities, as is also currently used by public order authorities. However, monitoring only is not enough to be able to maintain tolerated safety. In addition, tools to predict risk of crowd disaster development are necessary to improve crowd management.

Aforementioned reasons together underpin the belief that crowd management practice has not been developed as the science of crowd management has. For a few decades, human crowds and pedestrian dynamics were studied and new insights were provided for crowd management (Lee & Hughes, 2006a), (Krausz & Bauckhage, 2011). However, from interview statements it can be derived that these insights are rarely translated into crowd management practice plans, see for those statements derived from interviews Appendix A.3 on page 95.

What is needed on top of these monitoring and control systems is a risk mitigation system. The tools to predict risk development at an event area together with the incorporation of risk mitigation measures deduced from scientific literature can close the gap between science and practice and fulfil the need for a risk mitigation strategy. One way to close this gap is by providing a framework which
both incorporates state-of-the-art crowd disaster mitigation and functions as a guide for stakeholders in crowd management to incorporate risk of crowd disasters for their crowd management plans.

To conclude, this research will focus on the need for a framework that functions as a guide to plan crowd management measures for mitigating risks of crowd disasters.

1.3 Research Goal and Definition of Relevant Concepts

The purpose of this research is to propose a guide that allows different type of mass event organisations to plan crowd management measures in order to mitigate risks of crowd disasters. For this reason, the research focuses on developing a framework for mitigating risk of crowd disasters by providing tactical crowd management measures. The following goal statement formulates the presented need into the aim of this research:

The main research goal is to propose a crowd management framework for mitigating risks of crowd disasters at mass events in the public urban space, by studying cases of SAIL 2015.

SAIL is a public mass event organised the city centre of Amsterdam. Next to stated objective that cases of SAIL 2015 are studied and forming a part of the framework, these cases are also applied in the design process of the framework as evaluation tool. The cases are used here to test and improve the applicability of the framework throughout the design process.

In order to apply the framework, the user should acknowledge the risk of crowd disasters. Therefore, the framework should provide the knowledge necessary and available on understand crowd disaster development. Furthermore, the proposed guide should have crowd management measures applicable for a large range of different mass events in the public urban space, which is the function of a framework. On top of that the framework should provide tools to assess risks of crowd disasters. This translation of the research goal in the objective of the framework is stated as follows:

The main goal of the framework is to let crowd management authorities acknowledge crowd disaster development, let them be able to assess risks of crowd disasters and provide them with advice on effective measures for risk mitigation.

The framework proposed here functions as a tool for any actor responsible for crowd management to assess the risk of crowd disaster development and be provided with a list of potential measures to mitigate these risks. Potential clients are the local government departments for mobility, crisis and control, and mass event authorisation, and mass event organisers.

The objective and function of the framework are translated in 5 pillars which form the basis of the framework. The framework (1) combines the knowledge on crowd management practices with a (2) newly designed macroscopic flow model in System Dynamics to (3) identify the areas with a higher risk of crowd disasters in order to (4) provide the user with a set of crowd management measures for mitigating crowd disaster risks and (5) show their relative effectiveness on the performance criteria for crowd management.

The macroscopic flow models are designed for archetypes of mass events based on SAIL 2015 by application of Traffic Flow Theory and System Dynamics methods. The Archetype Macroscopic Flow Models function as the quantitative part of the framework to be adapted for new risk assessments of clients. For these assessments performance criteria are derived from the interviews and literature studies. Performance is measured on the throughput of the event area, risk development and travel times. With these performance criteria it is not only possible to evaluate the measures in effectiveness to risk mitigation but also to provide advice on prioritising the measures for implementation.
Research Questions

The presented research and framework goals provide focus for the research to be conducted. This focus could be translated in 12 research questions. These questions are derived from the problem context, the goal of the framework and research, and narrowed down to the scope of the research in Table 1 below. The research questions are answered while applying the methodology. Why some of the questions are postulated need some extra explanation which is given on the basis of the scope of the research and the definitions of concepts in the next subsections.

Table 1 Overview of Research Questions

<table>
<thead>
<tr>
<th>Research Questions</th>
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<tbody>
<tr>
<td>1 Which factors are relevant in determining the flow of people?</td>
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<tr>
<td>2 Which factors dominate the development of crowd disasters?</td>
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<tr>
<td>3 What is a suitable definition for risk of crowd disasters?</td>
</tr>
<tr>
<td>4 Which measures mitigate risk of crowd disasters?</td>
</tr>
<tr>
<td>5 What is required of the framework for risk mitigation of crowd disasters?</td>
</tr>
<tr>
<td>6 How to design the required framework?</td>
</tr>
<tr>
<td>7 Which performance criteria should be chosen for the framework outcomes of the macroscopic flow model?</td>
</tr>
<tr>
<td>8 What is required of the macroscopic flow model?</td>
</tr>
<tr>
<td>9 How to model a macroscopic flow model?</td>
</tr>
<tr>
<td>10 To what extent can these factors, in determining flow and development of crowd disasters, be incorporated in the macroscopic flow model?</td>
</tr>
<tr>
<td>11 To what extent can the measures to mitigate risk be incorporated in the macroscopic flow model?</td>
</tr>
<tr>
<td>12 What is the effect of risk mitigation measures on the performance criteria for the archetypes of the SAIL 2015 case?</td>
</tr>
</tbody>
</table>

The research goal contains terms asking for more explanation, therefore the definitions within their context are provided here.

Definitions of Concepts

A framework is defined as a fundamental structure. A framework should be applicable to all cases in scope of the framework.

Public urban space refers to cities, towns or conglomerations characterized by relatively high residential density compared to rural areas. Normally these areas are open for the public. Within this area infrastructure is provided to accommodate flows of traffic, see for infrastructural dependencies for pedestrian flow efficiency Appendices B.2 on page 133.

Mass events are crowded events where a large number of people gathers for an occurrence or happening. For the local government of Amsterdam over 2000 people expected at peak period is considered as a mass event (Gemeente Amsterdam, 2014). For the local government of The Hague this number rises to 25,000 visitors. A reason for large differences between governments in The Netherlands could not be provided by the interviewees. Therefore, pedestrian mass events in this research are referred to as pedestrian events within the urban environment and can last for a variable period of time with multi-activities and facilities with an expected peak density at Service Level C* or higher.

*The Level of Service is a determinant for the comfort level for moving through an area. Fruin (1971) separated the Level of Service into 6 segments from A to F. ‘A’ stands for very low density thus a high level of Service and ‘F’ for the highest densities and thus lowest Level of Service. Level of Service ‘C’ is characterized by a density between 0.43 and 0.72 \( p/m^2 \) (Fruin, 1971). The Level of Service differs per functional area, for example at main activity areas Level of Service will be lower than at the private lounge areas.*
“A crowd is a sizeable gathering of people in a given location, who have come together for a specific purpose over a measurable period of time and who, despite being predominantly strangers or in an unfamiliar situation, feel united by a common identity and are, therefore, able to act in a socially coherent manner” (Challenger, et al., 2009).

Crowd management is the science to deal with crowds or: the systematic planning for, and supervision of, the orderly movement and assembly of people (Fruin, 1993). The primary crowd management objective is to avoid critical crowd densities (Fruin, 1993). Although the terms crowd management and crowd control are often used interchangeably, there are important differences. Crowd control is the restriction or limitation of group behaviour. Crowd management involves the assessment of the people handling capabilities of a space prior to use. Next to crowd control a distinction can be made for riot control, which is only involving the action taken by police and safety operators when a situation is out of control. The above is summarized in Figure 2. In this figure the event is pictured in the blue block. This block represents the duration of the event with the start on the left and end on the right. For crowd management no repressive actions are considered, and for crowd control no preventive actions are considered. The small overlap between these two strategies are those prevention measures which can be implemented before total repressive actions are being relied on.

The part of the event where crowd management and crowd control are both involved is the operational crowd management taking place during the event. Operational, Tactical and strategic crowd management takes place in advance of the event. In addition operational crowd management takes also place in the first phases during the event when planning is still possible. The part during the event in which solely crowd control is visualised, is the part in which no planning tasks are being done, but when authorities are in full operation. In the example below, the situation during the event will go out of control (represented by the vertical red dotted line). After this moment only crowd control and riot control can be appealed to, according to definitions found in literature and used in interviews.

Crowd safety is defined by the probability of freedom of being injured or freedom of being in life threatening situations (Roughton & Crutchfield, 2014). Notice that this concept also relates to the definition of safety, which involves only unintentional harming events. Intentional hazards are those hazards resulting in crowd disasters by terrorists. A distinction is given by Ale (2009) who describes safety as the threat being an unwanted side effect of something else. Safety is thus related to accidents and incidents, whereas security deals with malicious acts such as sabotage and terrorism (Ale, 2009). Another distinction is given by Aven (2013), who indicated that safety relates more to unintentional hazardous situations and security to intentional hazardous situations (Aven, 2013).
Crowd disasters are defined as any extreme or catastrophic condition that imperils or results in loss of life and or property (Bishop, et al., 2010). In this research a crowd disaster is therefore defined as a catastrophic occasion where people are injured or caused to death because of unintentional and unmanageable crowd behaviours. Furthermore, a disaster is described as a high-magnitude low-frequency event (Quarantelli, 1991). Examples for recent crowd disasters are the Loveparade in Duisburg in 2010 and during celebrating of the New Year 2015 in Shanghai and 5 more last year in China, Nigeria, Congo and India (Still, 2015). All disasters are socio-technical events in nature with human, organizational and managerial features playing significant roles (Hood & Jones, 1996). See for the analysis of crowd disasters as socio-technical system Appendix A.4 on page 121. This analysis provided the context of the definitions of crowd disasters.

Following theory on Probabilistic Risk Assessment, Risk is determined by the total expected loss which is the sum of the consequences times the probability of frequencies (Stamatelatos, 2000). In this case consequences of mass events are the number of people injured and number of fatalities. The probability of frequencies is defined by the likelihood of these occurrences per unit of time. In this research only the physical level of risk development by means of the density of a crowd is considered by risks. As such risk of crowd disaster is defined by the likelihood on injuries and deaths as function of the density of a crowd over time. How to calculate this is subject of study.

A risk assessment is necessary for supporting decisions upon crowd management measures. This assessment is primarily concerned with mitigating risks, assuming risks in their probabilistic character cannot be prevented. Mitigation aims at diminishing the consequences of risks of crowd disasters and thus to prevent crowd disasters from happening.

SAIL is a nautical pedestrian public mass event organised in the public urban space of Amsterdam every five years. For SAIL 2015 between 1 and 2.5 million visitors are expected over 5 days of festivities in the City Centre of Amsterdam including its harbours. This case study is an example of a mass event in the city centre in line with the scope of the research.

### 1.4 Research Scope

The research is scoped to the pedestrian mass events, which take place in public urban areas. A reason for this is that crowd disasters are often present because of infrastructural bottlenecks and a too high demand. Within the public urban space, infrastructure is a constraint rather than a design variable, which makes these places more vulnerable to crowd disaster developments, as is already been stated in subsection 1.1.

**Focus on Safety**

Both unintentional and intentional hazardous events can be the incentive for a crowd disaster. In this research pure safety related unintentional hazards in the development of crowd disasters are being considered for defining risk of crowd disasters. An example for the intentional hazard resulting in a crowd disaster is the “Damschreeuwer“ in Amsterdam at the commemoration day 4th of May 2010. In this event the intention was clear to cause panic. An example of an unintentional hazard resulting in a crowd disaster is the Loveparade in Duisburg in 2010, which happened due to mismanagement of the regulation of the inflow to the terrain. This research focuses on the latter crowd disaster incentives which are unintentionally hazards. As such the research focuses on mitigation of hazardous crowd dynamic development by the mass of people flowing over the event areas. To put this in other words, no risk assessments will be carried out to find the potential hazards for an event related to security (creating panic, social group frictions, terrorism et cetera). Only the risks concerned with the crowding of people over time on event areas are taken into account.
Focus on Macroscopic Flow Modelling

Macroscopic flow modelling is chosen for assessing risks of crowd disasters by modelling aggregation of people over time per area of an event. An alternative to macroscopic flow modelling is microscopic flow modelling. In microscopic flow modelling trajectories in multiple directions of each pedestrian are subject of modelling. Whereas in macroscopic flow modelling the aggregation of people on a large scale is being modelled. The reason for choosing a macroscopic flow model is threefold. Firstly, to mitigate risks it will be sufficient to assess the aggregation of people over time rather than the trajectories of the individual pedestrians over time. The calculation of these risks by the density accumulation in a certain area suits application of macroscopic modelling. In macroscopic flow models density is used as the state variable for identifying the traffic condition (Daiheng Ni, 2011) from which the risk can be determined. Secondly, more computational time is needed for assessing the risks in the same event area for microscopic modelling vs macroscopic modelling. Thirdly, often (and as is the case for SAIL 2015) no specific data is available on arrival and departure rates and distributions, which makes microscopic flow modelling a too detailed study of the event compared to macroscopic flow modelling for the accuracy of the model given the data available. See for the outline of the main differences between these modelling segments Appendix B.3 on page 140.

Focus on Tactical Planning of Crowd Management

It is important to notice that only crowd management measures, not crowd control nor riot control measures are being included in the scope of research. As is pictured in Figure 3 for crowd management strategies three levels of planning could be distinguished; strategic, tactic and operational. Strategic planning focuses on influencing pedestrian decisions of movement which take place prior to arrival at the event area (off-road). Tactical planning incorporates the major decisions on movement over the event network during the event (on-road) and operational planning focuses on the local decisions on movement for example controlling a crossing (on-road).

These risk mitigation measures needed of crowd management could be in any of the three levels of planning (strategic, tactical and operational). However, for deriving a risk mitigation strategy for mass events in the public urban space the main focus is on the tactical level in this research while incorporating the relation between the strategic and operational measures, see also Figure 3. The first reason for this focus is that for a public mass event organisation strategic decisions of visitors (which take place prior to the event) cannot be influenced because the event is publically open and hence there is a limitation on reaching the visitor population to influence their departure times. However, the results from these decisions taken on strategic level are important to incorporate in the macroscopic flow models. Secondly, this focus is chosen because of higher hierarchical level of tactical vs. operational planning. This means not only that more decisions on behaviour can be influenced at a higher hierarchical level, but also that planning is more effective if applied to the tactical level first. By first determining the tactical strategy on risk mitigation, the operational strategy can follow in line with the tactical mitigation strategy. Thirdly, tactical risk mitigation measures entails the regulation of the inflow, distribution over the event area and maintaining a tolerated level of density in an event area. These measures are matching the level of detail for incorporation the macroscopic flow models. Operational movement is closely linked to decisions on individual trajectories, whereas tactical movement is more related to the average dispersion over a network and hence more applicable to this research. Because trajectories of people are not being modelled, operational crowd management measures cannot be incorporated in the macroscopic flow models. Fourthly, the operational measures do have a large overlap with crowd control measures and hence are less applicable for scope of this research.
The tactical influencing of pedestrian behaviour involves influencing activity scheduling, activity area choice and route choice, as is shown in Figure 3. Tactical crowd management measures are subject of this research, but examples are the regulation of the inflow by grouping people or maintaining a tolerated density level, the information providence for distribution over the available routes, the guidance for on-route routing, the separation of directional streams, the allowance for standstill areas, whether or not to provide sight on landmarks for routing, etc. Further elaboration will follow in chapter 4.

Because strategic decision-making takes place off-road in advance of on-road movement of pedestrians, these decisions form the initial setting for deriving arrival and departure patterns. This is the reason that no arrow exists from tactical planning level to strategic planning level in Figure 3. From tactical to operational level the arrows are placed into both directions. This illustrates that the information from operational pedestrian movement is taken into account, and that these operational decisions on movement are also influenced by the tactical measures taken. This effect is beneficial to accomplish effective risk mitigation strategies. For example, influencing decisions on road crossings and obstacle avoidance are not taken into account, but the existence of road obstacles as well as the effect of road crossing on the flow over a network are considered.

To conclude, effects on the flow are considered from all three levels of pedestrian movement, but for the derivation of crowd management measures, the tactical level is dominating. For more information upon differences in planning according to this hierarchy see Appendix A.1 on page 93.

### 1.5 Applied Research Methodology

A distinction should be made between the research in total and the goal of designing a framework. The research is more extensively than only the research related directly to the framework, because in this way the framework can be developed in its existence of a broader knowledge scope. This allows for designing a framework in the full context of the system of crowds and narrow down without losing the link with the full context of this systems behaviour.

To design a framework a methodology is searched for, however no such methodologies has been found in literature. This gap is due to the fact that frameworks are often established from one science
field of knowledge and fitting a specific purpose. This means that the knowledge field best applicable provides the methods for conducting research. For designing frameworks on the edge of science fields of System Dynamics and Traffic Flow Theory no framework design method exists.

The proposed methodology shown in Figure 4, aims to overcome the lack of methodologies for framework proposals. The methods are derived from two science fields. During this research, methods are applied which are more widely applicable than only for the design of the framework in this research. Therefore, the methodology for designing a framework might be wider applicable than only for the purpose of this research.

Theoretical Lenses

Two theoretical lenses applicable for this research are concealed in the research and framework goals: Traffic Flow Theory and Systems Engineering. Traffic Flow Theory involves the analysis of pedestrian flows, modelling pedestrian flows and crowd management. Traffic Flow Theory has been applied to define crowd disaster development and to model pedestrian flows. System Engineering involves the systematic manner of analysis socio-technical systems and modelling complex systems behaviour to derive solutions to overcome problems and provide advice for stakeholders. In a systematic manner a systems engineer tries to deliver solutions to the analysed problems in line with the organisations’ objectives. Systems Engineering has been applied to analyse the problem context in a socio-technical matter and model pedestrian flows in System Dynamics. The application of two science fields led to a framework for risk mitigation of crowd disasters.

Therefore, two science fields are integrated in the methodology. In order to show which methods are used and which topics are analysed corresponding to either one of these two science fields, a list of applied methods and analyses is provided below. All the listed analyses and methods are needed for conducting the research. These have been deduced from the research and framework goals and the function of the framework. A distinction is being made to quantitative (underlined) vs. qualitative (italic) methods or analyses of topics.

1. **Pedestrian Traffic Flow Theory**
   a. Crowd Dynamics
      - Crowd Phenomena and Behaviour
      - Factors influencing Crowd Behaviour
   b. Fundamental Diagram
      - Macroscopic Fundamental Diagram
      - Factors influencing the fundamental relationship
   c. Pedestrian Flow Modelling
      - Bottleneck Analysis
      - Macroscopic Pedestrian Flow Modelling
      - Queuing Modelling

2. **System Engineering**
   a. Safety & Risk Science
   b. Socio-Technical System Analysing Methods
      - Stakeholder Analysis
      - Object Oriented Modelling & Process Analysis
      - System Analysis:
         o Cause-Effect Diagrams
         o Objective Analysis
         o Multi-Criteria Analysis
         o Means-End Analysis
c. Designing for Complex Multi-Actor Systems
   - Need Analysis
   - Functional Requirement Analysis
   - Morphological Overview

d. System Dynamics
   - Causal Feedback Loops
   - Stock-Flow Structures
   - Modelling System Dynamics

The list is now described in line with the placement of the methods and analyses in the methodology in Figure 4. The subdivision of Pedestrian Traffic Flow Theory into topics 1a to 1c follows the steps from conducting a literature study (a and b) to pedestrian flow modelling (c). The fundamental diagram together with pedestrian flow modelling are the key subjects of this science field and they play a great part in understanding crowd disaster development and finding measures for risk mitigation of crowd disasters. The macroscopic fundamental diagram and factors influencing this diagram need to be studied according to the research scope as stated in the previous subsection. Therefore, macroscopic flow modelling and (macroscopic) queuing modelling are analysed. Next to this, qualitative and quantitative bottleneck analyses are being carried out for identifying risky areas. In addition, crowd dynamics are being studied by literature reviews for the purpose of this research on crowd disaster mitigation. All addressed topics of 1 are translated into key subject of interest in the literature phase in the methodology to ensure information on these subjects is incorporated in the research. These ‘key subjects of interest’ are addressed as follows in Figure 4: Crowd Dynamics & Management, Pedestrian Dynamics & Infrastructure, and Pedestrian Flow Modelling. Together these three topics (1a to 1c) provide the information needed to design both the conceptual part of the framework and the quantitative part (macroscopic flow model).

Topic 1c is needed in the parts ‘system analysis’ and ‘scoping the system’ of the methodology in both the literature phase and design phase. Topics 1a, 1b and 2a, 2b of the list above are especially needed in the ‘conceptualisation’ part of the framework design, but also are present in the system analysis part and in the key subjects of interest in the ‘literature study phase’ of the methodology. They cover the knowledge primarily necessary to develop this concept of the system of crowd disasters and the methods for the conceptualisation process. The topics 1c and 1d are needed in the ‘specification’ part of the methodology and in the conclusion phase in the ‘Implementation of solutions’ part.

For (2) Systems Engineering four subtopics have been defined (2a to 2d). Topic 2a (Safety & Risk Science) is not always present in systems engineering, but in this research suits best here as these definitions form the basis for the systems objectives and scope. This is thus also a ‘key subject of interest’ in the ‘literature study phase’ in the methodology addressed to as ‘Safety and Risks and Regulations & Measures’. The next topic (2b) is on defining the socio-technical system of crowd disasters and the process describing the development of crowd disasters over time. The literature necessary here is called ‘Crowd Dynamics & Management’. Topic 2c refers to designing methods for complex multi-actor systems by performing a need analysis, define requirements and decide on a morphology for the design. ‘Planning & Organizing Mass Events’ and ‘Designing a Framework’ are the ‘key subjects of interest’ in the ‘literature study phase’ related to topic 2c.

The last topic needed in this research is 2d in which the System Dynamics methods are indicated. The first analysis is to identify causal relations in order to construct causal-effect diagrams in topic 2b, but then devoted solely to the conceptual model. With these diagrams the stock-flow structures for modelling flows in System Dynamics can be derived. The knowledge necessary for these methods is provided by all the other topics 1a to 1c and 2a to 2c. On top of that, literature on system dynamics.
and pedestrian flow modelling is needed. This is addressed to by the key subject of interest ‘Pedestrian Flow Modelling’ in the literature study phase of the methodology presented in Figure 4.

**Methodology**

The synthesis of these methods and analyses of the list above provides the methodology for the research. The methodology is divided into 3 parts: Literature Study Phase, Design Phase and Conclusion Phase. These parts aim to structure the research process which is beneficial to plan and organize the research accordingly with the aim to stick to the time schedule. These methods need to be combined and logically ordered in the phases of the research process to which they are most beneficial. For example, the modelling in system dynamics with macroscopic flow specifications cannot start without information on the crowd disaster systems behaviour, macroscopic flow modelling of pedestrians and not without a conceptualisation of the system. Therefore, all presented methods and analysis are assigned to either one of the three parts and subdivided in smaller methodology parts defined on their chronological order in the design for a framework, see Figure 4.

The methodology is carried out in 6 key subjects of interest for this research. These subjects of interest have been derived from the scope of this research, the research goal, the function of the framework and from the need for information given the methods and analyses of the 2 theoretical lenses provided above. These subjects of interest cover the information necessary for this research totally and are named: Crowd Dynamics & Management, Safety and Risks and Regulations & Measures, Planning & Organizing Mass Events, Pedestrian Dynamics & Infrastructure, Pedestrian Flow Modelling, and Designing a Framework. They can be find in Figure 4 under “Key Subjects of Interest” in the Literature Study Phase of the methodology.

The 3 phases of the methodology do follow each other chronologically, but allow also to develop iteratively and partly simultaneously. Within this approach, the first phase is the Literature Study Phase in which the first step is the System Analysis where the need for such framework is being identified together with a thorough study of its system of application by literature reviews and interviews with stakeholders. First of all, the literature study needs to be carried out with the objective to provide the framework with state of the art crowd management strategies, enrich knowledge on crowd dynamics and to discover knowledge gaps and input for designing the framework. The time available for this research phase together with the progress in conceptualising what has been learned, indicates whether or not more literature research is needed or that the design phase can be entered. Therefore, both the literature phase and conceptualisation part of the design phase are entered simultaneously. This means that the literature reviewed is analysed and used in conceptualisation of the system of crowd disasters. While conceptualising the need for more knowledge is the incentive to do more literature research. In this way the research findings from the literature phase are combined to define the problem more concise and to define the system in which this problem exists. This process is referred to by the parts ‘System Analysis’, ‘Scoping System’ and ‘Conceptual Modelling’ and the double arrow between those parts in the methodology presented in Figure 4.

Both ‘scoping system’ and ‘conceptual modelling’ form the conceptualisation part of the design phase. In the ‘scoping system’ the archetypes for the evaluation of the framework are being defined. Usually archetypes are applied to evaluate methods. Archetypes of cases of SAIL 2015 are being modelled to apply the framework to and to evaluate the frameworks’ applicability. To select those archetypes, bottleneck analyses are conducted, which are also used as guide in the framework. The outcomes of the conceptualisation part are (1) conceptual models describing the system of crowd disasters and (2) an analysis of measures together with the derivation of (3) modelling objectives and questions to test the measures effectiveness on the defined (4) performance indicators for the (5) archetypes selected.

Following on the conceptualisation, the ‘Quantitative Modelling’ part is the specification of the design phase in the methodology. Specification can start as soon as the conceptual modelling phase is preliminary finished. In this step the goal is to specify the conceptual model and derive a preliminary
framework design. This can be done iteratively by improving the conceptual model when evaluating the preliminary design. Firstly, one should decide upon the approach for modelling the problem cases, gather data and specify the variables and calculations in the model. Hereafter, verification and behaviour tests of the model show the need for whether or not improving the conceptual model and if amendments in the specification of the model are necessary. This feedback process will narrow down from improvements needed in both concepts and specification, to improvements needed only in the specification of the model, towards a valid model.

When the behaviour of the model is validated, the solutions can be implemented to test their effectiveness. Now the finalizing phase has been entered and this part is called ‘Solution Implementation’. When implementing solutions the models should be verified and validated again. This is represented by the double arrow between ‘Quantitative Modelling’ & ‘Solution Implementation’ parts in Figure 4. After the analysis of the performance by solution scenarios, the ‘Recommendation’ part can start. This last part draws conclusions and discuss them. Here recommendations are derives and further research issues are provided.

With the current interdisciplinary approach, the methodology is rich of both qualitative and quantitative methods for conducting research to design the framework. Firstly, this is highly beneficial for designing the framework in full context of the system of crowd disasters. Secondly, the concealed theoretical lenses in the goals of the research and framework are integrated in this methodology showing that these objectives can be achieved by this methodological approach. Thirdly, the methodology designed by applying the two science fields is proved applicable for designing frameworks by application to this research.

**Reading Guide**

The report is structured into 5 parts (A to E). The first part A covers the introduction chapter in this chapter 1. The second part B provides the theoretical concepts and conceptual models of crowd dynamics and disaster development at mass events in chapters 2 to 4. With these concepts ready, the next part C of this thesis presents the design of the framework in chapters 5 and 6. Following Part D applies the framework to the archetypes derived from SAIL 2015. Part D consists of chapters 7 and 8. Chapter 7 presents all steps from the framework applied to the archetypes. Next to that, the discussion of the macroscopic flow model is provided in chapter 8.

To close, part E concludes on the framework proposed. In chapter 9 the conclusions are provided on the objectives, modelling questions and solutions to risk mitigation of crowd disaster. Furthermore, in this last chapter recommendations for mass event organisers are provided, a reflection on the design process of the framework is given and further research issues are addressed.

Chapters 1 to 4 entail the outcome of the literature study and conceptualisation phase of the methodology. Chapters 6, 7 and 8 refer to the specification part in the Design Phase of the methodology. In these chapters the focus is on the quantification of the macroscopic flow models. Part E thus refers to the last conclusion phase of the methodology and especially to the part called recommendations. All answers to the 12 research questions are provided in the Conclusion Part E of the thesis.
To give an overview which research questions are answered during application of the methodology and in which part of the thesis these are presented, the following Table 2 is provided.

**Table 2 Overview of Research Questions answered by applying methodology and presented in the thesis**

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Methodology Phase</th>
<th>Thesis Part</th>
</tr>
</thead>
<tbody>
<tr>
<td>1       Which factors are relevant in determining the flow of people?</td>
<td>Literature Study</td>
<td>Part B Chapter 2</td>
</tr>
<tr>
<td>2       Which factors dominate the development of crowd disasters?</td>
<td>Literature Study</td>
<td>Part B Chapter 3</td>
</tr>
<tr>
<td>3       What is a suitable definition for risk of crowd disasters?</td>
<td>Literature Study</td>
<td>Part B Chapter 4</td>
</tr>
<tr>
<td>4       Which measures mitigate risk of crowd disasters?</td>
<td>Literature Study</td>
<td>Part B Chapter 4</td>
</tr>
<tr>
<td>5       What is required of the framework for risk mitigation of crowd disasters?</td>
<td>Literature Study</td>
<td>Part C Chapter 5</td>
</tr>
<tr>
<td>6       How to design the required framework?</td>
<td>Literature Study</td>
<td>Part C Chapter 5</td>
</tr>
<tr>
<td>7       Which performance criteria should be chosen for the framework outcomes of the macroscopic flow model?</td>
<td>Literature Study</td>
<td>Part C Chapter 5</td>
</tr>
<tr>
<td>8       What is required of the macroscopic flow model?</td>
<td>Literature Study</td>
<td>Part C Chapter 6</td>
</tr>
<tr>
<td>9       How to model a macroscopic flow model?</td>
<td>Literature Study</td>
<td>Part C Chapter 6</td>
</tr>
<tr>
<td>10      To what extent can these factors, in determining flow and development of crowd disasters, be incorporated in the macroscopic flow model?</td>
<td>Specification</td>
<td>Part C Chapter 6</td>
</tr>
<tr>
<td>11      To what extent can the measures to mitigate risk be incorporated in the macroscopic flow model?</td>
<td>Specification</td>
<td>Part D Chapter 7</td>
</tr>
<tr>
<td>12      What is the effect of risk mitigation measures on the performance criteria for the archetypes of the SAIL 2015 case?</td>
<td>Conclusion</td>
<td>Part D Chapter 7</td>
</tr>
</tbody>
</table>

For definitions, explanation of mathematical variables and units please consult the glossary.
**Literature Study Phase**

- **System Analysis**
  1. Define Problem or Need
  2. Set research objectives and questions
  3. Analyse Stakeholders
  4. Conduct Literature reviewing questions
  5. Perform literature research by Key Subjects of Interest & defined questions
  6. Address Knowledge Gaps

- **Key Subjects of Interest**
  1. Crowd Dynamics & Management
  2. Safety, Risks, Regulations & Measures
  3. Planning & Organizing Mass Events
  4. Pedestrian Dynamics & Infrastructure
  5. Pedestrian Flow Modelling
  6. Designing a Framework

---

**Design Phase**

- **Conceptualisation**
  - Goal is to conduct a preliminary framework design
  - Scoping System
    1. Conduct Framework Needs Interviews
    2. Derive stakeholder objectives
    3. Determine Framework Functional Requirements
    4. Analyse Socio-Technical System
    5. Scope System for Modelling
    6. Define archetypes & Perform bottleneck analysis
    7. Define performance criteria
    8. Brainstorm on knowledge gaps derived from Literature Study

- **Conceptual Modelling**
  - Derive Causal Models for Socio-Tehnical Systems’ Behaviour
  - Derive Class Diagram for object-oriented modelling
  - Define internal and external factors influencing systems behaviour
  - Perform Process flow analysis
  - Derive Measures for influencing causal relations
  - Derive Modelling objectives and questions

- **Specification**
  - Goal is to specify preliminary framework design
  - Quantitative Modelling
    1. Determine software best applicable to conceptual models
    2. Gather data conform Class Diagram
    3. Quantify causal relationships
    4. Specify Quantitative Model by translating process flow models and causal models into mathematical expressions in software for defined archetypes
    5. Calibrate Model
    6. Verify Model
    7. Validate Model
    8. Evaluate Model
    9. Improve Model or continue

---

**Solution Implementation**

- 1. Analyse performance of Archetypes by performance criteria
- 2. Define Solution Scenarios
- 3. Implement Solutions in Models
- 4. Analyse Performance of Solution Scenarios by defined performance criteria

**Conclusion Phase**

- **Goal is to provide client with recommendations, address conclusions and future research issues**

**Recommendations**

- 1. Present relative performance of solution scenarios
- 2. Give advice on solutions implementation
- 3. Address future research issues
- 4. Answer research questions
- 5. Evaluate performance of Framework Design with requirements
- 6. Draw conclusions and reflect on process
**Part B State-of-the-Art Crowd Disaster Mitigation**

Part B covers the understanding of crowd disaster development and provides the first qualitative models to deal with crowd disasters by risk mitigation. The literature study outcomes on the ‘key subjects of interest’ (see Figure 4) are addressed in chapters 2 to 4.

The first chapter 2 provides a theoretical background on Traffic Flow Theory. Traffic Flow Theory provides an understanding and determination of the evolvement of flows of people into crowd disasters. The next chapter 3 combines the analyses on the development of crowd disasters into a conceptual model of crowd disasters. This model is called the Layered Crowd Disaster Model. With the knowledge on the development of crowd disasters, the next chapter 4 elaborates on how to mitigate the risk of crowd disasters. In this chapter measures for mitigating risks of crowd disasters are analysed and combined into two flow charts for implementing them in logical order to mitigate phenomena leading to a crowd disaster. These are called Scenario Measure Charts.

### 2. Traffic Flow Theoretical Background

Crowds are studied in science more extensively since the last 3 decades. Traffic Flow Theory involves analysing pedestrian behaviour, modelling pedestrian flows and advising crowd management. A key theory in Traffic Flow Theory is the fundamental relationship between speed \([m/s]\), density \([p/m^2]\) and flow \([p/m \cdot s]\). The flow is determined by the density multiplied by the speed. The capacity of a system is defined by the maximum possible flow at a capacity density, often referred to as the critical density. When the density exceeds the critical density congestion can set in. Congestion does not only occur because of a high demand compared to the available capacity, but also when oscillatory changes in walking direction and periods of standstill occur for instance when people need to wait for other people to pass. In these situations dynamic patterns in the flow can be observed which often lead to congestion and eventually can trigger a crowd disaster.

Comparing to car traffic dynamics, pedestrian traffic dynamics are considered more complex as people can morph, people tend to have more freedom in choosing walking directions on a walking route and thus for predicting trajectories given an origin and destination people are less predictable than cars. Crowds can thus be viewed as a system with the property to morph to adapt for changes in densities (Miguel, 2013). For example when high pressures occur, the mass becomes denser and by lowering pressures the mass becomes less dense. During crowd disasters, high pressures within the crowd occur for a certain period of time until the pressures can be released, for example when the density decreases. This is why compared to car accidents during congestion, people in crowd disasters are extremely vulnerable. After a car accident occurs, the flow of cars usually stops moving. For this reason the car accident is usually not growing in number of cars involved. When a single person falls after being swept of his feet because of too high densities, a crowd disaster can occur. When it strikes, the flow of people does not stop moving. For this reason pressures within the crowd can still increase. Therefore, after a crowd disaster sets in until the moment that the density decreases the number of people involved in the crowd disaster grows. People are thus extremely vulnerable when a crowd disasters occurs.

#### 2.1 Discussion of Fundamental Diagram Application in this Research

In Figure 5 the fundamental relationship between speed, density and flow is summarized by Daamen et al. (2005) for 6 studies by Fruin, Weidmann (1993), Virkler, Older, Sarkar and Tanariboon. This relationship is plotted in 3 diagrams: speed-density plot, flow-density plot and speed-flow-plot.
The fundamental diagram is used for macroscopic flow modelling to determine the flow from the density and speed of the flow. The fundamental diagram is still subject of study, however for this framework a choice has to be made for the shape of the fundamental diagram.

For those six studies in the figure above, there is no consensus on which fundamental diagram suits best. This is mainly because this is dependent on the width of the infrastructure, walkable space and visitor characteristics like age, physical condition and gender. Furthermore, the more the population is homogeneous in these characteristics, the better the fundamental diagram will fit.

Next to the presented fundamental diagrams in Figure 5, a study by Miguel (2013) implies a critical density of \[ \frac{p}{m^2} \] for unidimensional flows and a critical density of \[ 2 \frac{p}{m^2} \] for multidimensional flows. Lee & Hughes (2006a) also found that a critical density is achieved with \[ 3 \frac{p}{m^2} \]. Next to this, Helbing et al. (2007) found a value of \[ 1.22 \frac{p}{m^2} \] as free flow, a critical density of \[ k_c = 5.4 \frac{p}{m^2} \] and a maximum density \[ k_{max} = 10 \frac{p}{m^2} \] for their study of the Hajj in 1426H in Mekkah. It is remarkable that these latter values are much higher than the values from the studies summarized in Figure 5 and the studies by Lee & Hughes (2006a) and Miguel (2013). It is believed that because of cultural differences in Mekkah people accept a lower Level of Service and thus have a lower desired interpersonal distance compared to the situations present in the other fundamental diagrams. For this reason it might be that the value for a critical density in Mekkah is much higher than the value for the critical density in The Netherlands. Therefore, the fundamental diagram of Helbing et al. (2007) is found not to be best applicable for mass events in The Netherlands. In this research Weidmann Fundamental Diagram (1993) is chosen for the shape of relation between speed, density and flow. The values for Weidmann (1993) unidirectional flow relationships are: a maximum density of \[ k_{max} = 5.4 \frac{p}{m^2} \], a critical density of \[ k_c = 2 \frac{p}{m^2} \] and \[ u_1 = 1.34 \frac{m}{s} \] as initial desired speed for a density of zero \[ k = 0 \frac{p}{m^2} \].

The first reason for choosing the fundamental diagram of Weidmann, is that he reviewed the work of 25 papers and their resulting fundamental diagrams, plotted their results in one graph and took the average over all results. On top of that, he presented the macroscopic flow characteristics for a normal/non-pushy crowd. This makes this fundamental diagram useful for the purpose of this research. At last, this shape and values of the fundamental diagram by Weidmann (1993) are generally accepted by researchers in this field.

Figure 5 Fundamental Diagrams derived from (Daamen, et al., 2005)
2.2 Fundamental Diagram Improvements

Although the presented fundamental diagram by Weidmann will be used for the framework, it is clear that this relationship is prone to improvement by more empirical data in future research.

First of all, the fundamental relationship proposed by Weidmann (1993) of flow as a function of density and speed shows no differences in pedestrian behaviour upstream and downstream of a bottleneck. Upstream of the bottleneck pedestrians seem to be captured by producing information about the approaching bottleneck, whereas downstream of the bottleneck pedestrians seem to be governed by physical restrictions of the current local situation only (Duives, et al., 2014). Next to that, they hypothetically stated that in normal situations the anticipation behaviour of pedestrians upstream of a bottleneck would have a greater effect on the walking behaviour of people than in evacuation situations. These effects are nowadays not incorporated in any fundamental diagram, because first more research is needed (Duives, et al., 2014).

Secondly, due to the fact that jammed flows of pedestrians will not stop moving (Helbing, et al., 2007), the chosen flow is inadequately being zero for a maximum density of $k_{max} = 5.4 \frac{p}{m^2}$. In this research the assumption of Weidmann is applied in order to demonstrate the effect of a stopping flow when a crowd disaster occurs, which is a breakdown of the flowing system.

Thirdly, the faster is slower effect learns that forces applied on each other to pass a certain hallway or door result in a lower speed and therefore lower throughput than may seem from the initial width of the event block (Hoogendoorn, 2012). The flow will probably be higher in case these doors or separations are made for 1 person, and lower than average if they are made for more persons (Helbing, et al., 2000b). The fundamental diagram cannot capture these effects for the specific situations of entrances and exits.

2.3 Factors Influencing the Fundamental Diagram

The higher the walking speed for the same density, the higher the flow becomes. With a higher flow for the same density, a higher throughput can be observed. Therefore, it is important to adapt the fundamental diagram to the desired walking speed of the population to describe. Furthermore, per event area the capacity will differ and thus fundamental diagrams need to be adapted as well.

The walking speed is dependent on over 40 factors related to infrastructure characteristics, directions of flows, crossing characteristics, route choice sets, demographic characteristics, information processing, anticipation behaviour, purpose of walking, desired interpersonal walking space and the weather. These factors have been derived from literature and a brainstorm session with a researcher, see the details in the Appendices B.1 to B.3. Literature provided already a lot of factors influencing the free flow speed with a clear direction (increasing or decreasing the speed). However, their correlation is key to understand before those factors could be quantified and implemented in pedestrian flow modelling. Furthermore, the extent to which the factors influence the free flow speed should be subject for future research. In this subsection the main factors influencing the speed are analysed.

2.3.1 Directional Dependency

Streams are often categorized into unidirectional, bidirectional and multidirectional flows. For bidirectional and multidirectional flows the walking speed is estimated to be lower than for unidirectional flows in the same area. This means that the total throughput will be less with the same demand in case of bidirectional streams or multidirectional streams compared to unidirectional streams. Literature provides a direction for this deficiency, however upon this time no consensus is being derived. For example, Miguel (2013) found a 6% deficiency in free flow walking speed for unidirectional flows versus multidirectional streams (Miguel, 2013). Whereas, according to Hoogendoorn & Bovy (2003b) the efficiency of lane formation reduces the capacity in case of bidirectional flows 4 to 15% (Hoogendoorn & Bovy, 2003b).


2.3.2 Group Size, Age and Gender Dependencies

The walking speed decreases linearly with the group size and density (Moussaïd, et al., 2010). According to Moussaïd et al. (2010) the average interpersonal distances between group members decreases with smaller group sizes for both moderate and low density situations. At a moderate density ($k = 0.25 \text{ [p/m}^2\text{]}$) and with on average a large group size of 4, the walking speed is about 0.9 [m/s]. Whereas at a low density ($k = 0.03 \text{ [p/m}^2\text{]}$) and an equal average group size of 4, the walking speed is on average 1.2 [m/s] (Moussaïd, et al., 2010). Furthermore, they also found that a higher share of small groups does influence the overall speed positively. For perceiving comfort in walking it is observed that larger groups above 5 people tend to split up in smaller groups of 2 or 3 people (Moussaïd, et al., 2010). Next to that, a wider sidewalk does not have to result in higher speeds for different group sizes between 2 and 5 people (Cheng, et al., 2014). This might be because of inhomogeneity in division over the total space for wider sidewalks compared to smaller sidewalks for the same density.

Walking speeds depend also on the physical condition of a person. The maximum average walkable speed found in literature is 1.42 [m/s] (Bohannon, 1997). This value is rather high for average walking speeds. A reason is that in this study only at a very small stretch in total free flow (single person observation) the speeds were being measured. The following can be derived from (Bohannon, 1997) who indicated the speeds of elderly and younger women and men:

- Elderly female average walking speed = 1.29 [m/s]
- Elderly men average walking speed = 1.34 [m/s]
- Younger female average walking speed = 1.40 [m/s]
- Younger men average walking speed = 1.42 [m/s]

Weidmann (1993) also found a relation between the age and the speed, see Figure 6. In this figure more nuances are provided compared to the study by Bohannon (1997).

Next to the findings of Bohannon and Weidmann, Brščić, et al. (2014) found that a higher share of taller people (above 1.45 meters) will result in a higher overall speed under same density conditions in free flow domain. It is possible that this relationship is the same as the relation found between body mass indexes and desired walking speeds. On average the walking speed is higher for male than for female of same age and this is also related to the higher body mass index of males compared to
females (Miguel, 2013), which might also be related to the higher average length of males compared to females. On average the interpersonal distance [m] in one direction is smaller for women than for men at same walking speed and density (Miguel, 2013), this may also be culturally dependent. In the appendix B.1 on page 126 these topics are further emphasized.

Brščić (2014) also showed that speeds of flows may differ related to the moment in the day (tardiness at evenings and hastiness at mornings). In normal conditions without panic or stress, pedestrians tend to walk at a comfortable average speed at the least energy-consuming walking speed (Miguel, 2013), (Helbing, et al., 2000b). Furthermore, complex decisions during walking are stated to influence the walking speed negatively (Li, et al., 2013), (Duives, 2015). Complex decisions involve route choices, avoiding obstacles or opposing pedestrians or traffic, please find Appendices B2 and B3 from page 138 onwards.

### 2.3.3 Summary of Factors Influencing Free Flow Speed

The figure 7 on the next page summarizes all factors influencing the free flow speed are found in literature. The factors are coloured red in case the relationship is non-beneficial, green if the influence in beneficial for the speed and orange if the relationships is unknown or is believed to be non-dominant. An example for the latter category is the sun. The sun might influence the free flow speed negatively because people tend to keep their energy levels low during sunny periods. However, a reason why one would keep their energy level low is because movement takes place out of leisure or because it is too warm. So the sole effect of the sun is assumed to become overshadowed by the factor of purpose or temperature. The latter one is not stated yet by literature, but might also influence the desired walking speed.

In the figure below factors influencing the free flow speed are presented in 4 categories: Infrastructure, Direction of Flow, Demography and Weather.
Free Flow Speed

Negative Gradient

Slope

Multidirectional Crossing vs unidirectional

Roundabout vs Cross Intersection

Share stress

Positive Gradient

Share negative behaviour

Presence of natural light

Short Stairs Up

Long or Short Stairs Down

Presence water channel without fence vs with fence

Sight on landmarks in direction of flow vs sideways

Multidirectional flow vs unidirectional flow

Presence of grassland next to paved area

Density of intersections at Routes

High share Elderly and / or Children and / or Disabled

Sun (+) ? (-)

Large angle (> 90 °) of approaching crossing flows vs small angle (< 90 °)

Cramped Feeling (+) ? (-)

Roundabout with Tree over roundabout without tree

Roundabout with distractional object

Lower interpersonal distance headway than average

Heterogeneity in desired speed

Large route choice set vs lower route choice set

Larger share women than men

Share of small groups over larger groups

Presence of difference in street level

Bad quality of walking paths

Presence of difference in street level

Low space available next to buildings

Leisure Purpose

Hastiness

Tardiness

Infrastructure Factors

Demographic Factors

Weather Factors

Directions of Flow Factors

Figure 7 Speed Influence Diagram deduced from studying literature and by a brainstorm session, see Appendices B.1 and B.2.
3. Crowd Disaster Development

The largest danger for the crowd comes from the crowd dynamics existing at high densities which lead to turbulent flows and in this way can trigger trampling and crushing (Helbing, et al., 2007). In those turbulent situations, the size and directions of forces acting on the bodies move people around in an uncontrolled way. People have difficulties keeping their balance and when people stumble, fall and get injured this can be the start of a crowd disaster (Helbing, et al., 2007). According to Hoogendoorn & Bertini (2012) and Helbing et al. (2007) densities can even rise up to 10 \( \frac{p}{m^2} \) in a very short period of time.

3.1 Crowd Disaster Development Analysis

The question is how these densities can rise up that quickly to this unbearable level of density. Therefore, literature is analysed on how crowd disasters occurred in the past. An example of such crowd disaster is the Loveparade in Duisburg in 2010. This crowd disaster together with the study by Helbing et al. (2007) of a crowd disaster at the Hajj in 1426H in Mekkah on the Jamarat Bridge has been studied thoroughly in this research. Furthermore, literature on crowd dynamics and disasters by Fruin (1993) and Still (1989-2014) help to define the phenomena precedent to a disaster. In this way causal chains of phenomena leading up to these crowd disasters could be discovered.

These phenomena are structured to assess their place in the causal chain leading up to a crowd disaster. For this causal chain Traffic Flow Theory has been applied which distinguishes flow regimes in the fundamental diagram.

Flow Regimes

These flow regimes are derived qualitatively from Traffic Flow Theory on car traffic and by the literature study on crowd disasters. Each flow regime shares a same state of flow, speed range and density range in the fundamental diagram. In total 5 flow regimes could be distinguished from free flow till a crowd disaster: Free Flow Regime, Instable Flow Regime, Crowd Turbulence Regime, Crowd Disaster I and Crowd Disaster II. Because these regimes are derived qualitatively only the regimes will be presented in relation to crowd disaster development and risk of crowd disasters, please find Figure 8 on page 23 and Table 4 on page 27.

The free flow regime is characterized by neat flow patterns in which people can walk their desired speed. When a phase transition occurs from laminar flows in a Free Flow regime (first layer in Figure 8) to jammed flows in a Crowd Turbulence regime, patterns observed go from neat to dynamic. In between the Free Flow state and the Crowd Turbulence state another state could be defined: Instable Flow. The Instable Flow state is characterised by a decrease in walking speed and a higher density compared to the free flow state. The phase transition from a Free Flow state towards an Instable Flow state further to a Crowd Turbulence state is the key to the development of crowd disasters, represented by the red arrow in between the layers of Figure 8. A crowd disaster is characterized by the two regimes of Crowd Disaster I and II. The density accumulates from critical in state I on till its maximum in regime II. These latter two states have been identified to distinguish the total breakdown in regime Crowd Disaster II form the state in between the breakdown and the Crowd Turbulence Regime, named as Crowd Disaster I regime. This latter distinction is useful for stating difference between a breakdown and congestion before the breakdown occurs.

3.2 The Layered Crowd Disaster Model

A conceptual model for crowd disasters could be derived, presented in Figure 8. The Layered Crowd Disaster Model gives the first schematization of crowd disaster development in line with Traffic Flow Theory. In this Layered Crowd Disaster Model the horizontal layers represent the flow regimes. The bottom layer represents a free flow regime and the top layer represents the Crowd Disaster regimes.
I and II. The vertical layers represent the distinction between crowd control and crowd management, stress and panic involvement. The red arrow in between the horizontal layers represent the disastrous development from the first to the last layer. The trend of crowd disaster development (red arrow upwards) should thus be mitigated by preventive management (green arrow downwards). Therefore, this model provides a distinction to which extent mitigation of a crowd disaster is possible given a certain flow regime. It also provides starting points for defining measures for mitigation.

With the qualitative characterisation of states, the phenomena observed by literature should fit into these regimes. To find this match the first step is to address mutual attributes. These attributes can be shared in terms of extent of turbulence, or extent of self-organisation and in time prior to the crowd disaster or in causal chain to other factors. The next check is if (1) these phenomena can be caused by the same factors, (2) if there is a particular same chronological order, or (3) effects are the same in flow patterns and walking speed restrictions. Within the layers 19 different phenomena are showed. In some cases these phenomena show interrelationships which are then also showed by the arrows within the layers in Figure 8. Furthermore, the phenomena are placed in chronological order to a transition to the next flow regime.

Not all phenomena of a layer in the Layered Crowd Disaster Model in Figure 8 have to be present in order to accumulate towards a crowd disaster. The probability of crowd disaster increases as soon as effective self-organised flows are being suppressed. This means that the crowd disaster development can start within the second layer of this model in the Instable Flow Regime by a Slow Moving Bottleneck, the Faster is Slower Effect, Non-Separation, an Interest & Attraction Peak and Inefficient Choice Behaviour. When the density keeps rising these effects could lead to Crowd Turbulence in which Pushing, and/or a Stampede or and/or a Craze which on their turn can lead to a crowd disaster.

The phenomena within the layers can trigger each other, this is indicated by the arrows. This means that a single phenomenon does not have to lead directly into a crowd disaster, but first triggers other phenomena leading to a crowd disaster. Because more than one phenomenon can be triggered, the course of development can differ. Therefore, measures to mitigate the crowd disaster also differ dependent on scenarios of development.

When the effects of the phenomena are mitigated in time, the crowd disaster development can be stopped. Therefore, the phenomena of the top 3 layers in the Layered Crowd Disaster Model should be mitigated in order to maintain self-organisation. This is also indicated by the colour of the layers in this model; the bottom layer is coloured green and the top 3 layers coloured in gradient to red to the Crowd Disaster Regime in the top.
All the phenomena in this model are explained in Table 3 and in more detail in the Appendix B.4 on page 141.

**Table 3 Layered Crowd Disaster Model Phenomena Description**

<table>
<thead>
<tr>
<th>Phenomena Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Congestion/ Jammed Flow</strong></td>
<td>in which people move with low speed or stopped walking because of timely too high demand for the infrastructure supplied. Stop-and-Go waves can occur even as (wide) moving jams or shockwaves.</td>
</tr>
<tr>
<td><strong>Craze</strong></td>
<td>is a competition for a scarce place or item resulting in a run and can cause panic.</td>
</tr>
<tr>
<td><strong>Crush</strong></td>
<td>is the event in which people are moving towards a physical bottleneck and are pressed closely together in front of its narrowest point due to too high densities.</td>
</tr>
<tr>
<td><strong>Diagonal Formation</strong></td>
<td>is a phenomenon observed in Free Flow regime when at a crossing people form lanes to pass each other.</td>
</tr>
<tr>
<td><strong>Disaster</strong></td>
<td>is a catastrophic occasion where people are injured or caused to death because of unmanageable crowd behaviours. According to Ale (2009) an <em>unmanageable scenario</em> can be defined as a case without warning, with a fast dynamic (uncontrolled) development and no stabilization possible within available response times.</td>
</tr>
<tr>
<td><strong>Faster is slower effect</strong></td>
<td>in which the density upstream of a bottleneck is increasing, due to the fact that people keep heading forward while the bottleneck is clogged (Hoogendoorn, et al., 2014). The higher densities cause coordination problems since a large number of individuals is competing for a few small gaps and interaction forces slowing down the total crowd motion (Hoogendoorn, et al., 2014). This effect can lead to a bottleneck.</td>
</tr>
</tbody>
</table>
**Gridlock** is a phenomenon which is best described by network saturation. A few bottlenecks and a higher demand than capacity often lead to a network gridlock in which the feeder routes and the mainstream route both are congested.

**Herding** is described as following behaviour because of panic, evacuation or uncleanness of the situation, and or unwillingness/incapability to assess routes on their own, see also Inefficient Choice Behaviour. Herding can be caused by an interest/attraction peak or by non-separation. See for behaviour during evacuation Appendix B.5 on page 149.

**Inefficient Choice Behaviour** is used to describe the phenomenon in which people tend to walk a route which is not the optimal route considering the actual route capacity and demand. This behaviour can be caused by the lack of information or because people follow the crowd (herding). In contrast to herding in this phenomenon there is a choice for a better route in terms of travel time, but people do not choose this route. Inefficient Choice Behaviour can be caused by an interest/attraction peak or by non-separation.

**Inefficient Self-Organisation** is used as behaviour description for in the stages after free flow regime. In this concept the stage is meant directly after free flow state, because more nuances can be provided. According to Hoogendoorn (2013) there are four phenomena which indicate the reduced throughput in case of inefficient self-organisation: (1) Blockades and grid-lock (spillback), (2) capacity drop, (3) uneven distribution of pedestrians over the available walking space and (4) inefficient choice behaviour of individual travellers.

**Interest & Attraction Peak** is a phenomenon which is referred to as peak in demand because of an attraction or event or departure or arrival of transportation. This phenomenon can lead to inefficient choice behaviour or herding.

**Lane Formation** is a phenomenon which is observed in the Free Flow state in which people form lanes to pass each other in bi-directional flows.

**Laminar Flow** is a neat, smooth self-organised flow in stable conditions within the Free Flow Regime.

**Non-Separation** is the case whenever characteristically different streams of people are not being separated in route. For example when a queueing area is also used for flowing area this will give a problem, because the queueing people have a speed of zero and the flowing people desire to walking their comfortable speed. This phenomenon can lead to inefficient choice behaviour or herding.

**Panic** is a situation where people move considerably faster than normal, have physical interactions for getting somewhere and show uncoordinated passing of bottlenecks. Panic is often observed in threatening situations where a lack of information on the current situation is provided or available (Kinkel, 2015). In some situations high level of stress is observed with panic. Herding is also considered in some situations to exist because of panic and a lack of information.

**Pushing** can occur within all defined phenomena related to (too) high densities and often is intentional when people have to wait long without physiological needs, entertainment or shelter and within the absence of understandable reasons for delays. Unintentional pushing may occur because of shockwaves, or because in high densities people need to increase their individual (walkable) space.

**Quake** is occurring when people are (unintentionally) pushing around and are being pushed by fluctuating forces in the crowd.
**Self-Organisation** is described as the phenomenon of spontaneous occurrence of qualitatively new behaviour through the non-linear interaction of many objects without intervention of external influences (Hoogendoorn, et al., 2014), (Helbing & Johansson, 2010), (Camazine, et al., 2010). Self-organisational movement is characterized by lane formation in bidirectional flows, diagonal stripe formation and the Zipper-Effect in crossing flows.

**Shockwave** can occur during congestion. Shockwaves can be observed which travel at high speed upstream of the bottleneck in which people are being unable to control their body movements and walking is being restricted.

**Slow-Moving Bottleneck** in car flow theory often a car with far lower speed than free flow speed or maximum speed. In pedestrian traffic a slow moving person or a slow moving group. Overtaking takes place and this phenomenon can lead to a bottleneck.

**Stampede** is an occasion when many people suddenly all move quickly and in uncontrolled way in the same direction at the same time.

**Stop-and-Go Waves** are temporarily interrupted longitudinally flows that appear at higher densities in unidirectional flowing crowds. This can lead to a shockwave.

**Trampling** is an occasion where people fallen are being walked over because of too high densities.

**Turbulence** is a flow regime. Due to too high densities chances of self-organisation are excluded. Forces within the crowd add up resulting in uncontrolled movements. Dynamic patterns are being observed in the flows. Turbulence can be caused by pushing, stampedes or crazes, which are often initiated by a bottleneck or gridlock.

**Uneven Distribution over Network** is a phenomenon where the total amount of participants in the network are not occupying the networks capacity in an optimal way. This often leads to a bottleneck in the network where the demand in high and capacity insufficient. This effect can be caused by inefficient choice behaviour or herding.

**Zipper-Effect** Pedestrians allow others within the territorial space diagonally in front of them, as long as the direct space in front of their feet is still empty (Hoogendoorn, et al., 2014). Therefore, narrower lanes are being observed in a bottleneck than expected based on the width of a pedestrian’s territorial zone (Hoogendoorn, et al., 2014).
4. Specification and Mitigation of Risk

In general a risk mitigation strategy consists of five avenues to address risk: risk avoidance, risk spreading, risk transfer, risk acceptance and risk reduction (Peterson, 2010). Applied to this research, risk avoidance is for the visitor to avoid the crowdedness. In risk mitigation strategies the solutions related to risk avoidance are thus to avoid the accumulation of people at a certain place or stop the increase of density at a certain time at certain areas. Risk spreading and risk transfer are occurring as soon as a congestion results in gridlocks or spills back into the network or via shockwaves through the crowd. To mitigate risk transferring through the crowd, gridlocks should be mitigated and in general over critical densities should not be allowed to avoid the occurrences of shockwaves. Risk acceptance is referred to by risk tolerance for consistency of definitions embraced by practitioners. Risk tolerance plays a role in the evaluation of the performance of the risk strategy and the extent to which risks are allowed for an event area. Therefore, in the framework risk tolerance should be included to evaluate risk mitigation strategies. At last, risk reduction aims to diminish the consequences of a crowd disaster. This can be done by mitigating the effects by taking preventive measures. All risk mitigation topics are being addressed in the risk mitigation strategy in this research and framework.

The specification of risk of crowd disaster is elaborated upon in paragraph 4.1 and the risk mitigation measures are derived in paragraph 4.2.

4.1 Specification of Risk of Crowd Disasters

As stated in Chapter 1, risk is determined by the total expected loss which is the sum of the consequences times the probability of frequencies (Stamatelatos, 2000). In this case consequences of mass events are the number of people injured and number of fatalities. The probability of frequencies is defined by the likelihood of these occurrences per unit of time. In this research only the physical level of risk development by means of the density of a crowd is considered by risks. As such risk of crowd disaster is defined by the likelihood on injuries and deaths as function of the density of a crowd over time. How to calculate this is subject of study. The crowdedness is used as an indicator for the risk in an area.

A widely used indication for the crowdedness is the Level of Service (Fruin, 1971). With the Level of Service the comfort for a visitor is expressed in the average share of pedestrians in a square meter. Related to the level of comfort, the level of risk of a crowd disaster is also dependent on the density in an area. However, it is not enough to assess the risk of a crowd disaster only by the density relatively to the maximum density of 5.4 \( \frac{p}{m^2} \), but also by the duration of the density. When peaks of high densities occur but the average density is under a critical value, the flow is stabilising itself. This means that in this case the risk of crowd disasters does not increase. However, when a high density lasts for a longer period of time, the risk of crowd disasters is increasing with the time. For the lower densities, the duration of this density can last longer to obtain an equal level of risk compared to a higher density. The following equation is derived to determine the risk of crowd disasters: density \( \frac{p}{m^2} \) times the duration of the density \( s \) = Risk \( \frac{p}{m^2} \times s \). This means that the integral is taken over the density over time to derive risk.

There is a drawback of this calculation of risk. For example, the risk concerned with a density of 0.1 \( \frac{p}{m^2} \) lasting 120 minutes would be the same as a density of 10 \( \frac{p}{m^2} \) lasting 1.2 [min]. Although the latter case is rather unusual the effect should be compensated, because logically the latter case would imply a much higher risk than the first case. Therefore, the distinction is being made between risk development exceeding the critical density and density development staying under this critical value by risk stages, see Table 4. The risk of a crowd disaster is assumed higher when the critical density is exceeded. The first reason is that the critical density represents the turbulent flow regime; the last flow regime before the Crowd Disaster flow regime I. Secondly, the property of the turbulent
flow regime is that the situation can become unmanageable in a very short period of time, because of dynamic flow patterns.

The fundamental diagram of Weidmann (1993) has been used to match the flow regimes to a risk stage according to a density level. For determining the density regimes, the flow regimes in the fundamental diagram should be clear. However, these are not yet determined, because it is not clear why the phase transitions occur. The conditions under which the flow state transitions occur will be the focus of future research (Hoogendoorn, et al., 2014).

The aim is to overcome this knowledge gap for this research. The phase transitions indicated by literature of pedestrian and car fundamental diagrams are translated to the fundamental diagram of Weidmann (1993) to come to the risk stages described in Table 4. These stages aim to give a first impression of the risk per flow regime. The separation for each density regime should be focus of future research to determine the regimes more precisely with empirical data. For this research this distinction of risk stages improved useful for determining risk of crowd disasters in the flow models on top of the duration of the density. Together the duration of the density and the risk stages defines risk of crowd disasters.

In the table below the assumed density ranges are provided for the risk stages defined. In light blue the flow regimes under the critical density value of \( 2 \ [p/m^2] \) are indicated. The flow regimes above the critical density are presented in dark blue. This distinction between under critical and over critical risk is used in the macroscopic flow models in addition to the duration of the risk. It can be assumed that if the critical density is reached, the risk of crowd disaster is higher than if this density is not reached. Also the time until a crowd disaster will occur is taken into account in this risk stage definition. For the flow regimes beneath the critical density (light blue) the time till a crowd disaster occurs is much greater than for the regimes over the critical density. It is assumed that a crowd disaster has occurred when the maximum density has been reached; in the Crowd Disaster II Regime.

Table 4 Risk Identification Table related to Flow Regimes & Fundamental Diagram of Event blocks

<table>
<thead>
<tr>
<th>Flow Regime</th>
<th>Risk Stages</th>
<th>Assumed Density Regime</th>
<th>Assumed Probability of Crowd Disaster</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free Flow</td>
<td>1</td>
<td>( 0 [p/m^2] &lt; k &lt; 1 [p/m^2] )</td>
<td>Zero - Low</td>
</tr>
<tr>
<td>Instable Flow</td>
<td>2</td>
<td>( 1 [p/m^2] &lt; k &lt; 2 [p/m^2] )</td>
<td>Low - Medium</td>
</tr>
<tr>
<td>Turbulent Flow</td>
<td>3</td>
<td>( 2 [p/m^2] &lt; k &lt; 3 [p/m^2] )</td>
<td>Medium - High</td>
</tr>
<tr>
<td>Crowd Disaster I</td>
<td>4</td>
<td>( 3 [p/m^2] &lt; k &lt; 4 [p/m^2] )</td>
<td>High – Certain</td>
</tr>
<tr>
<td>Crowd Disaster II</td>
<td>5</td>
<td>( 4 [p/m^2] &lt; k &lt; 5.4 [p/m^2] )</td>
<td>Certain</td>
</tr>
</tbody>
</table>

4.2 Risk Mitigation by Crowd Management Measures

The phenomena defined to be part of a crowd disaster development are key to define crowd disaster mitigation strategies. Such strategy should consist of preventive measures to mitigate risks on dangerous accumulations of people, as stated in the objective of the framework. To derive those preventive measures, the phenomena of the Layered Crowd Disaster Model give the first incentive to perform more literature study in this subject.
4.2.1 Literature Findings on Crowd Management Measures

In general crowd management should be able to provide sufficient quality to handle crowds. According to Helbing & Mukjeri (2012) the following should be dealt with sufficiently: the choice of a suitable location, an adequate preparation of the mass event, an appropriate organisation of crowd management and a quick response to early warning signs for which information and communication play a key role. Also Fruin (1993) concludes that real-time information and communication are key factors in preventing crowd disasters. Next to that, he emphasizes that configuration, capacity, and traffic processing capabilities of assembly facilities determine the Level of Service.

Traffic Flow Theory Solutions

Hoogendoorn (2013) provides strategies for solving inefficient self-organisation. According to Hoogendoorn (2013) there are four phenomena indicating the reduced throughput in case of inefficient self-organisation: (1) Blockades and grid-lock (spillback), (2) capacity drop, (3) uneven distribution of traffic over the network and (4) inefficient choice behaviour of individual travellers. These four phenomena relate directly to measures for mitigating crowd disaster development: (1) prevent blockades, (2) increase throughput, (3) distribute traffic effectively and (4) reduce inflow (Hoogendoorn, 2013). All the solutions will be discussed briefly in relation to pedestrian traffic.

The first solution (1) prevents blockades and grid-lock. In car traffic management ramp-metering and intersection control are great implementations to achieve this. However, for pedestrian networks these measures are not being implemented in infrastructure. A reason is probably that in contradiction to vehicle traffic, pedestrians walk freely in public urban space without intervention of intersection control unless they encounter cross flows of other traffic. An example of a measure to control inflow without having to implement a physical control measurement systems is by separating the inflow by batches (groups) and maintain the speed in desired speed conform the tolerated Level of Service by letting people walk with the section keepers. These section keepers separate the flow in groups and let them walk with a defined slow speed for high throughput. In a normal Dutch street with a width of approximately 7 meters, one needs approximately four of them per group. This measure is derived from own-experienced crowd control in Tokyo in Japan during a summer fireworks event. This measure is now to be named ‘create groups upstream of bottleneck’.

Like for car traffic, also pedestrian traffic benefit from a dynamic routing information panel system (DRIP) (Klootsema, 2014). This will influence both the speed at a crossing and the gridlock effect beneficially. Furthermore, by placing the panels in advance of a crossing, people approaching a crossing do not have to slow down in walking speed to choose their routes because they already did. With this system, the gridlock effect can be controlled because routes can be closed or bottlenecks can be showed as such compliance to not choose the preferred route because of a bottleneck might become higher. However, to the compliance for these kind of systems at mass events, more future study is needed. Though, current police practice already entails these kind of systems they indicate also that compliance is often a struggle.

In the research by Lee et al. (2006) is shown that with controlling the variable free flow walking speed the safety of pedestrians could be guaranteed. However, in practice this parameter is not being controlled because peoples’ walking speed cannot be controlled in this detail. Therefore, the design of the complexity of the infrastructure is to be used to control pedestrian free flow speed and their walking speed. As stated in chapter 2, brainstorming on this together with literature reviews resulted in over 40 factors influencing the free flow speed categorised in infrastructural features, demographical features, weather conditions, and directions of walking (see Figure 7 on page 20). By influencing these factors the speed of the flow could be controlled in order to prevent blockades.

Allowance of multiple directions of walking will result in temporally stagnation of the crossing flow. This can result in blockades. A solution could be to maintain unidirectional streams. It should be
noticed that by preventing blockades on the one hand and increasing inflow on the other hand congestion is only being delayed. Therefore, these solutions are timely if no other solutions are implemented instantaneously to control the inflow.

The second solution (2) increase throughput can hypothetically be achieved by setting walking speed limits according to the tolerated Level of Service and increase the available walking space either by physical interventions or by introducing inflow control (ramp metering). However, speed limits as used for car traffic management are not directly applicable for pedestrians. First of all people cannot assess their walking speed unless they are equipped with a special (individual) measurement system. Furthermore, speed limits would vary too small for achieving a determined Level of Service as such these limits are hard to obey even if an individual could measure their speed. On top of that, the walking speed of people largely depends on the comfortable walking speed which is characterized by a persons’ anatomy and their motivation to walk a certain speed. Therefore, the speed limits would be made also individual which is counterproductive seen from macroscopic perspective. For this reason the speed can be influenced by the factors presented above and by ‘create groups upstream of bottlenecks’ measure as is discussed for solution (1) above.

The direction of walking is highly influencing the throughput due to the deficiency of bidirectional and multidirectional flows over unidirectional flows. It is estimated that this is only in small proportions in case of self-organisation with bidirectional flows with less than 16% decrease in efficiency. For a 50-50 proportion in direction this is only 5% (Hoogendoorn, 2012) in case of free flow conditions. Similar to mitigating blockades (1) also throughput can be increased by maintaining unidirectional flows. However, if this is not possible because of intersections, the flow will become more inefficient. This should be taken into account when planning crowd management measures and assessing capacities.

The other solution for increasing throughput is by acquiring more space. This can be done in advance of the event by indicating main routes and bottlenecks and try to redirect people to increase capacity of a route. Furthermore, one can think of allowing extra ‘free’ space as buffer zones in case needed (when reaching or exceeding critical densities). Not mentioned yet is that the throughput is also increased when homogeneous flows of pedestrians is existing walking in same direction at a common desired Level of Service with same walking speeds. This implies that slow moving bottleneck (people moving slower than average) are decreasing the throughput because they form a temporarily blockade. Thus with removing blockades (1) throughput can be increased. It can also argued that solution (4) reduce inflow is also a solution for improving throughput when the demand exceeds the supply and the inflow is reduced to its maximum for the situation.

Thirdly, (3) distribution of people over available routes can improve Level of Service in the system, improve the network capacity utilisation and reduce average travel times. Furthermore, it is stated that minimisation of risk of trampling in a crowd is achieved by distributing the pedestrians uniformly over the event area (Lee & Hughes, 2006a). One way to achieve this is by informing people on the available routes to take with actual information on the Level of Service on each block and the approximate duration for getting to the activity at the end of the route. A more dedicated way is to assign people to a particular route by (temporarily) closing a route (section) or by an inflow controller.

The last solution (4) concerns the reduction of inflow primarily to avoid inefficient pedestrian behaviour of being with too many at the same time at one place to prevent congestion. Reducing inflows can simply be achieved by closing gates, entrees or routes or by allocating slots of entrée for visitors.
Human Needs in relation to Crowd Disaster Mitigation

According to Helbing & Muerji (2012) the ‘laws of nature’ should be respected to succeed in crowd management. These laws refer to the human needs which result from physical, physiological, psychological and social requirements of humans such as sufficient space, food, water, and air, toilet facilities, feeling of safety, perceived progress towards the goal, information, communication, entertainment et cetera. These ‘laws of nature’ are explained by the pyramid of Maslow for a hierarchy in human needs, see Figure 9.

The crucial layer for success of an event; layer 3 love and belonging, can only be achieved when the first two layers are of a perceived satisfactory kind (McLeod, 2007). This means that the perceived crowd safety can be seen as the extent to which the layers 3 or higher can be achieved or not. An insufficient consideration of the human needs can promote disasters, particularly if shortcomings accumulate (Helbing & Mukerji, 2012).

In the pyramid of Maslow (Figure 9) it can be seen that safety belongs to the second layer of priority of human needs after physiological need satisfaction and before acquiring love and belonging. This is a crucial finding for assessing perceived safety and studying evacuation strategies. See for the evacuation strategies Appendix B.5 on page 149.

Experience of Crowd Managers

On top of that, the experience of crowd managers in leading positions is important. The number of productions of the event is not enough, it only counts as experience when people in management positions have experience with the type of event in the selected urban environment(s) or have sufficient insight in crowd dynamics and are able to manage crowds. This conclusion is conducted from the Loveparade disaster in Duisburg in 2010 where the number of productions of this event was numerous, but the new environment of Duisburg was not experienced by the management until that time in 2010. In Duisburg this is one of the causes pointed out by researches which lead to the crowd disaster (Krausz & Bauckhage, 2011). The above is summarized and applied by Helbing & Mukerji (2012), see Table 5 on page 31.

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2 With management in this context is meant all people responsible for crowd safety during the event.
### Table 5: Crowd Criticality Identification Table (Helbing & Mukerji, 2012)

<table>
<thead>
<tr>
<th>Observation</th>
<th>Assessment</th>
<th>Required action</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Densities are below 2-3 persons per square meter.</td>
<td>Normal operation at low risk.</td>
<td>Regularly verify normal operation, watch out for perturbations. Make sure that the flow does not exceed the safe value of 82 persons per minute and meter.</td>
</tr>
<tr>
<td>1 People accumulate. Certain areas become progressively more crowded.</td>
<td>People slow down due to a bottleneck or stop for some reason.</td>
<td>Limit inflows to ensure that the expected extent of accumulation will not be exceeded. Gather information and determine the reasons for the accumulation. Prepare possible counter-measures. Move enough security to the respective area. Inform the responsible police and emergency units.</td>
</tr>
<tr>
<td>2 Jams of people are forming and growing</td>
<td>Insufficient outflows may cause serious problems over time (such as high densities), particularly in constraint spaces.</td>
<td>Communicate with the crowd. Promptly take appropriate flow reduction measures such as re-directing people. (Keep in mind that stopping people causes a growing pressure in the crowd and impatience). Move police and emergency units towards the crowded area(s). In case help will be needed.</td>
</tr>
<tr>
<td>3 Stop-and-go waves occur (this happens only in dense moving crowds). People are pushed.</td>
<td>The continuous flow has broken down. The outflow capacity is considerably reduced. The situation may escalate quickly.</td>
<td>Take suitable counter-measures. Pressure relief strategies (such as opening emergency routes and re-routing inflows) should be taken and people informed about them. Before, any obstacles (such as fences) in the way must be removed. A sufficient number of emergency units and police must be in the critical area and ready to take over control in interaction with the crowd management.</td>
</tr>
<tr>
<td>4 People cannot move freely and are squeezed between others. People are pushed around.</td>
<td>A critical density has built up in the crowd. Injuries can easily happen.</td>
<td>Police should take over control in close consultation with the crowd management. Appropriate contingency plans must be applied. Evacuation is strongly advised. Communication with the crowd is crucial. Emergency forces must be in the most crowded areas, in order to provide first aid whenever needed.</td>
</tr>
<tr>
<td>5 People disrespect fences or try to get out of the area</td>
<td>The situation is critical and likely to get out of control.</td>
<td>Communicate with the crowd and evacuate it. Provide help and first aid. Inform hospitals and additional emergency units about the possibility that the situation may get out of control.</td>
</tr>
<tr>
<td>6 Crowd turbulence occurs. People scream or shout for help.</td>
<td>Injuries and fatalities are likely. A crowd disaster can happen any time.</td>
<td>Calm down the crowd and guide it. Continue to evacuate people. Watch out for the areas with the highest densities and largest crowd movements, to ensure support and first aid. Additional emergency vehicles must be called to ensure sufficient manpower, and hospitals must be informed about likely (and potentially many) injuries.</td>
</tr>
<tr>
<td>7 People are falling to the ground. People raise arms into the air.</td>
<td>People are in big trouble. Many injuries are to be expected. A crowd disaster is (most likely) happening.</td>
<td>Immediate help and first aid are needed, probably for many people. Hospitals must be prepared to shift from routine to large-scale emergency operation.</td>
</tr>
<tr>
<td>8 People crawl over others.</td>
<td>A crowd disaster has probably happened.</td>
<td>Apply rules for a state of serious emergency.</td>
</tr>
</tbody>
</table>
4.2.2 Measure Charts

Preventive crowd management measures are provided by literature, by the provided list by Helbing & Mukerji (2012) on the previous page, the four key strategies to provide a state of Self-Organisation by Hoogendoorn (2013), and the indication that information is also important (Fruin, 1993). Furthermore, measures to take in order to prevent crowd disasters are found and by interviewing practitioners of crowd management and control in the region of Amsterdam, see for stakeholder analysis Appendix A.2 on page 93. To strengthen this set of measures, the phenomena (Figure 8 on page 23) of the Layered Crowd Disaster Model could be assigned to measure scenarios for mitigating crowd disaster development. As stated, not all phenomena in the Layered Crowd Disaster Model have to be present in order to evolve into a crowd disaster. Furthermore, the phenomena are related to each other chronologically. This leads to the decision to draw scenarios of phenomena in a chronological chain leading towards a crowd disaster. For mitigation purposes, mitigation measures are assigned to these scenarios. By coupling the measures to a causal chain leading to a crowd disaster, a measure scenario could be derived.

These measure scenarios are presented in flow charts and called Scenario Measure Charts. The two measure charts are depicted for each one of the two layers (flow regimes) of the Layered Crowd Disaster Model prior to a crowd disaster for which mitigation of risk of crowd disaster is still possible. The first Scenario Measure Chart in Figure 10 is for the Inefficient Self-Organisation layer and the second chart in Figure 11 for the Crowd Turbulence layer. One scenario is represented by the full application of both charts from (one of) the starting point(s) in Figure 10 to the ending point in Figure 11. Because there are more than one starting points in each of the two charts, in multiple ways the measures can be assigned to a case. To give advice on the usability of the chart, the starting points of each scenario is given. In total 6 scenarios are derived for mitigating measures. For full application, all 6 scenarios should be incorporated for planning risk mitigating measures.

In these two charts the starting points for assigning mitigating measures are the phenomena of the second and third layer in the Layered Crowd Disaster Model, as described in subsection 3.2. These starting points for the scenarios 1 to 4 in Scenario Measure Chart in Figure 10 for the Inefficient Self-Organisation layer are: a (1) Slow-Moving Bottleneck, (2) Non-Separation, (3) Faster is Slower Effect and (4) Inefficient Choice Behaviour. The starting points in Figure 11 are (5) craze and (6) stampede. The last phenomenon of the third layer measure chart (Figure 11) is the title of its layer ‘crowd turbulence’. Measures to this phenomenon represent the last measures to take prior to escalation into a crowd disaster. These measures operate at the boundary between crowd control and crowd management, because this is the last phenomenon in the causal chain towards a crowd disaster.

Within the charts, diamonds represent decisions with a question to be answered with yes or no. These answers lead to a following symbol in which a rectangle represents an action or measure. The colours used relate to phenomena of the Layered Crowd Disaster Model. When more than one measure can be applied without a specific order the measures are presented in arced blocks, with the colour corresponding to the phenomenon. Measures applicable for two or more phenomena in the same layer or over the two layers are possible and are therefore also indicated by the same colours. Some measures for phenomena in the second chart in Figure 11 could also be used for phenomena of the first measure chart. This is also indicated by the colour of the phenomenon to which this tactic was first assigned to.

By starting in any one of the 4 scenarios in the first measure chart (see Figure 10), the outcome is to go to the next measure chart for further mitigation of risk of crowd disasters (see Figure 11).
Figure 10 Scenario Measure Chart for Phenomena of Ineffective Self-Organisation Layer of Layered Crowd Disaster Model, derived in Conceptualisation Study
Figure 11 Scenario Measure Chart for Phenomena of Pre-Disaster Layer of Layered Crowd Disaster Model, derived in Conceptualisation Study
Part C Framework Design

This part C presents the framework established for this research. In chapter 5 the introduction to the framework and design of the framework is provided. The following chapter 6 elaborates on the process for modelling pedestrian flows in System Dynamics. This modelling process is necessary for the quantitative part of the framework.

5. Introduction to the Framework

The framework provides both qualitative and quantitative methods for mitigating risks of crowd disasters in which the level detail of advice can be chosen by the client. The framework consists of a qualitative and a quantitative part. The qualitative part provides generic solutions to mitigate risks of crowd disasters. The quantitative part functions as the fulfilment of the need for case-specific advice. Full application of the framework means the application of both the qualitative and quantitative part. The output and input of the framework is thus dependent on its application. The framework should be applied stepwise in which the need for case-specific measures and the available data determines the level of application possible. The application can be done generic or specific. This is why there is a distinction made between general applicable part (GAP) and specific applicable part (SAP). The outcome of the framework for GAP clients is a general qualitative advice on risk mitigation of crowd disasters. SAP will provide the user with both qualitative general (GAP) as quantitative specific advice on risk mitigation of crowd disasters. SAP therefore can be seen as the full application of the framework. The case-specific advice provided by SAP is dedicated to event areas. The non-case-specific advice of GAP is not dedicated to a specific area.

5.1 Framework Requirements

The functional purpose of the framework is to provide crowd management measures which can be implemented in advance of the mass event in order to mitigate risks of crowd disasters. In line with this purpose, more specific requirements can be derived for the design of this framework. These requirements are deduced from the framework objective which in its turn is derived from the research goal and the need statement, see chapter 1. In Table 6 these requirements are presented.

The first four requirements are directly deduced from the frameworks’ objective which is to let crowd management authorities acknowledge crowd disaster development, let them be able to assess risks of crowd disasters and provide them with advice on effective measures for risk mitigation. From interviews with potential clients it became clear that a decision tool towards the implementation of the measures would be beneficial to support collaboration in multi-disciplinary teams of crowd management. Therefore, the risk decision-making tool is also a requirement for the framework. The key stakeholders with interest and power to involve in crowd safety at mass events are the potential clients of the framework. These stakeholder are mass event organisers, governments on crisis control and mobility and the policy department of crowd management. The details and analysis of the key stakeholders is provided Appendix A.2 on page 93.
Table 6 Translation of Framework Objective to Functional Requirements of the Framework and application

<table>
<thead>
<tr>
<th>Functional Requirements derived from framework objective</th>
<th>Functional Application in Framework</th>
<th>Applied in Framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provide information on how crowd disasters develop</td>
<td>A -&gt; Simulation environment of crowd dynamics &lt;br&gt;B -&gt; Crowd Disaster Development &amp; Mitigation</td>
<td>A -&gt; SAP Macroscopic Flow Model &lt;br&gt;B -&gt; GAP &amp; SAP</td>
</tr>
<tr>
<td>Provide preventive measures</td>
<td>Provide hands-on tactical measures for crowd management for risk mitigation</td>
<td>GAP &amp; SAP</td>
</tr>
<tr>
<td>Provide advice on measures</td>
<td>A -&gt; Provide crowd management measures in context of their mitigation for risk of crowd disasters &lt;br&gt;B -&gt; Show relative effectiveness of measures to crowd management performance criteria</td>
<td>A -&gt; GAP &amp; SAP &lt;br&gt;B -&gt; SAP</td>
</tr>
<tr>
<td>Risk estimation of crowd disasters</td>
<td>Provide risk estimation of crowd disaster in macroscopic flow model</td>
<td>SAP Macroscopic Flow Model</td>
</tr>
<tr>
<td>Risk decision-making tool</td>
<td>A -&gt; Provide insights in decisions by simulation of dynamics without subjectivity of stakeholders to measures or risks taken into account &lt;br&gt;B -&gt; Provide decision tool with subjectivity towards risk taken into account</td>
<td>A -&gt; SAP Macroscopic Flow Model &lt;br&gt;B -&gt; SAP</td>
</tr>
</tbody>
</table>

The application column in the table above shows which requirements are applied in which part of the framework GAP or SAP. It can be concluded that for SAP all requirements are incorporated and for GAP half of the requirements could be incorporated. This is due to the fact that for a general application no quantitative part of the framework needs to be considered. Thus for GAP, no quantitative estimations on risk development can be provided.

In addition to the functional requirements, the framework should be understandable and perform in its function as a guide to mitigate risk. Therefore, an example of application of the framework is provided and tools and tables are simplified without losing information. The application of the framework is provided in chapter 7. Symbols and definitions should be understandable with the glossary provided, definitions explained and knowledge of the English language. On top of that, the knowledge in Pedestrian Traffic Flow Theory and System Dynamics is expected to increase within coming years. This implies updates in the conceptual diagrams of crowd disaster development, and changes in the initial parameter set as well as in the stock-flow structures in the macroscopic flow models. Therefore, to keep the framework applicability and performance as high as possible, the state of art knowledge should be updated in line with the science on crowd behaviour and dynamics.

To conclude, the framework combines the knowledge on crowd management practices with a newly designed macroscopic flow model to identify the areas with a higher risk of crowd disasters in order to provide the user with a set of crowd management measures for mitigating crowd disaster risks.

5.2 Framework Application Scope

All stakeholders in need for assessing risks of crowd disasters for an event area can apply the framework. The framework is applicable for those event areas which have the purpose of flowing and are dedicated for unidirectional and bidirectional pedestrian flows. The first reason for choosing flowing areas, is that it is wise to study those parts of the event which function as feeder of the crowd towards activities or along activities to assess their capacities and the risk of crowd disasters. During the Loveparade in Duisburg in 2010, the crowd disaster happened just before the entrance of the event terrain on the main feeder routes. This illustrates that it is interesting to study the crowd disaster risks at the assigned flowing areas on the routes of the event outside the squares and stages.

Secondly, crowd disasters can happen of course in all event areas but the modelling of crowds within squares and in front of stages is very difficult for reasons of predicting (multiple) route trajectories.
where the crowd has no predefined destination. The in- and outflows in these areas next to the behaviour of people within those standing/dancing/sitting areas is highly different from the flowing areas. On top of that, more information on multi-directional fundamental diagrams is needed in order to incorporate these event areas in this research. This means for incorporating them in the quantitative part of the framework a more extensive research is needed than the scope of this graduation project aims.

Aforementioned reason results in considering only the unidirectional and bidirectional flows for macroscopic flow modelling which do not cross flows of modalities or pedestrians. The framework will entail general and qualitative measures on avoiding multidirectional flows and bidirectional flows and on influence of crossings, intersections and roundabout on the flow efficiency, but no modelling of multi-directional flows, crossing, intersections or roundabouts is part of the framework macroscopic flow models. All routes taken into account should be predetermined from origin(s) to destination(s).

Tactical crowd management measures are applied in the framework. This tactical planning level of crowd management deals with on-road behaviour of pedestrians on route and activity choices. Measures involve the regulation of the inflow by grouping people and measuring crowd density, distribute the crowd over the event areas according to capacity, maintain a tolerated level of density in an event area, provide information for distribution over the available routes, guide on-route routing according to actual density, separate directional streams, allow for standstill areas, whether or not to provide sight on landmarks for routing.

### 5.3 Framework Steps

In Figure 12 the framework is presented. In total the framework consists of 6 steps. These steps are derived during the design process of the framework. They capture the total process for a client to fulfil from a need statement on a risk assessment for their event to get advice which measures to implement. These 6 steps are represented by a flow chart in which each step is dedicated to a process in the application. These steps are being verified by the application of the archetypes for mass events to this framework. The numbers in the framework overview in Figure 12 represent the framework application in chronological order.

The 6 steps have been structured into 5 blocks related to the input needed and the order of application. Furthermore, the domains of application are presented by the colours of these blocks. There are 4 domains of application. Green stands for the initialisation, yellow for gathering data, blue for applying the macroscopic flow model and red for selecting risk mitigation measures. The arrows on the left side of the framework figure represent the input needed for the step(s) in the 5 blocks. The arrows on the right side represent the information flows. These arrows show which information is acquired by application of the step(s) in the block and which information is needed for application of next steps. The framework can be applied generic by following f 3 steps for GAP being 1, 2 and 5 and all 6 steps for SAP.

The arrow on top of the figure below represents the client. The framework clients can be all actors with interest in crowd disaster development and risk estimation of crowd disasters and in system dynamics. Especially for event organisers, local government and crowd managers this framework can be applied to support crowd management decision making. The client decides whether or not to apply the framework in step 1.
The green block represents steps 1 and 2 which are needed for the initialisation of application. In the green block the client is first asked to check if the framework is applicable to the case(s). Also in step 1 the client is guided to focus on some probable problematic areas of the event. In step 2 the client is guided to derive specific parts called ‘Event Blocks’ for application of the next steps and select those Event Blocks most interesting for further application. An Event Block is a stretch at an event area with a certain width, length and a direction of flow. These Event Blocks determine the cases for modelling in SAP or to focus on for implementation of measures in GAP. Input for the green block are general mass event characteristics of the infrastructure, walking routes, arrival and departure distributions and main activity distributions over the terrain. The output of both steps 1 and 2 of the green block is a selection of Event Blocks and an indication of application GAP or SAP.

When applying GAP after step 2 follows the next and final step 5. The input for step 5 are both the Layered Crowd Disaster Model and Scenario Measure Charts. The model and charts are derived from state-of-the-art crowd disaster mitigation theories designed for the framework. From these charts the
client can derive scenarios of measures for mitigating risk of crowd disasters. The outcome of application of GAP is general advice on risk mitigation of crowd disasters.

For SAP, after step 2 follows step 3. In this step 3 the client needs to gather data on infrastructure of the walking routes, origin and destination locations, arrival and departure distributions and demography of the crowd. The client also checks if available data is sufficient to continue with SAP. All data needed is expected not to be real-time as is logical for the planning purpose of the framework. The output of step 3 is the decision on continuation with SAP with a data set for each Event Block or otherwise the decision to continue with GAP without data sets. If GAP is chosen the next and final step is step 5.

For SAP after step 3 follows first step 4, then a part of step 5 and finally step 6. In step 4 the client is asked to adapt the Archetype Macroscopic Flow Models with data on the Event Blocks. These models have been derived for archetypes of mass events. These are macroscopic flow models and are needed to assess risks of crowd disasters. The Archetype Macroscopic Flow Models function as example and frame for the application of new cases for either unidirectional, bidirectional flows or queuing areas. After adaptation to new cases they are called Event Blocks Macroscopic Flow Models.

When these Event Macroscopic Flow Models have been derived, the next step is to select measures for implementation in step 5. For the Archetype Macroscopic Flow Models measures have been implemented which are then called Archetype Measures Macroscopic Flow Models. These latter models can be used for implementing measures in the Event Blocks Macroscopic Flow Models in step 6. After implementation of measures in step 6, the last action to be taken in the framework for SAP is to evaluate the performance of the measures implemented. In the evaluation, the relative performance of these solutions is determined. This is done by a multi-criteria analysis. The client needs to assess the tactical crowd management performance criteria. Because the performance relies on risk acceptance or risk tolerance of the client, the users’ opinions are input for the evaluation of the performance of the framework to mitigate risks of crowd disasters. This incorporation is beneficial for decision making on complex issues related to risk tolerance and acceptance. The performance criteria are derived from the framework-need-interviews, from the study on crowd dynamics and disaster development and from general management perspectives. These are presented in the next subsection.

The outcome of application of GAP is general advice on risk mitigation of crowd disasters. With all steps taken, the outcome of SAP is specific advice on risk mitigation measures. All steps for SAP and GAP are explained in detail in Chapter 7, including an example of application to archetypes of mass events deduced from SAIL 2015.

5.4 Archetypes for Mass Events

Archetypes of mass events function both as evaluation in the process of designing the framework and as quantitative part of the framework, as is stated in chapter 1. Furthermore, archetypes function as example of application of the framework and as test for effectiveness of measures. The archetypes of mass events are used for modelling generic macroscopic flow models. It is important that those archetypes are selected well to cover a large part of clients’ cases for functioning of the framework.

For designing the framework SAIL 2015 is used as case study as stated in chapter 1. The archetypes of mass events are therefore derived from SAIL and restricted by the scope of the framework. From the scope it can be derived that the archetypes should have the characteristic to either be a unidirectional flowing area or a bidirectional flowing area. The areas should not have infrastructure like intersections, crossings or a roundabouts. This means that at least two archetypes of mass events are needed; one for unidirectional flows and one for bidirectional flows.
To select those archetypes of mass events, the event terrain from SAIL 2015 has been analysed on bottlenecks due to an infrastructural narrowing and/or demand peaks. This analysis is also part of framework steps 1 and 2. Two of the bottlenecks indicated by this analysis are suitable as archetype for the framework, as will also be discussed in the application of steps 1 and 2 of the framework in chapter 7 in more detail.

For the unidirectional case the Wide Dam has been selected. This is a long (282 m) but narrow (at its narrowest point 5.5 m) stretch of flowing area at the main walking route where people walk from the main land towards the Java Island and back on the other side of the Wide Dam. Because the directions are separated by two car lanes and a tramway, the Wide Dam is a unidirectional flow archetype.

The Bi-Directional archetype is indirectly derived from SAIL. The main reason for this is that at time of designing the framework there was a lack of information which areas would have bidirectional flows. To compensate for this, an archetype is designed for bidirectional flows called Bi-Directional. The Bi-Directional archetype is based on dimensions of the Wide Dam archetype.

The bottleneck analysis in steps 1 and 2 of the framework applied to SAIL, led to a need for an additional archetype for queuing flows. At SAIL, people can choose either to continue on the walking route or choose for departure by boat which leads to queuing in front of the mooring place at the Sumatrakade. Queuing is part of the framework scope and demands additional modelling functions for the unidirectional or bidirectional flow archetype. In addition, when queuing is involved, measures will differ from the other two flow archetypes. At last, because there are two different entries towards the queuing area, entrance choice needed to be included in the model. All extra functions needed in this archetype makes it interesting to be included in the framework in addition to the unidirectional flowing archetype Wide Dam. This latter archetype is called Sumatrakade Mooring.

All three archetypes are presented in Table 7 with the flowing characteristic, length of the event terrain, modelling characteristics and application characteristics.

<table>
<thead>
<tr>
<th>Archetype</th>
<th>Flowing Characteristic</th>
<th>Length</th>
<th>Modelling Characteristic</th>
<th>Application Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide Dam</td>
<td>Unidirectional</td>
<td>282 m</td>
<td>Flow in large unidirectional flowing areas</td>
<td>Measures for unidirectional streams</td>
</tr>
<tr>
<td>Sumatrakade Mooring</td>
<td>Unidirectional</td>
<td>50 m</td>
<td>Flow in small unidirectional flowing areas, Entrance Choice, Separating flows and bundling flows, Queuing, Discrete Departure Function</td>
<td>Measures for unidirectional queuing streams, Capacity Analysis, Effect of upstream archetype (Wide Dam) on downstream archetype</td>
</tr>
<tr>
<td>Bi-Directional</td>
<td>Bidirectional</td>
<td>150 m</td>
<td>Flow in bidirectional flowing areas</td>
<td>Measures for bidirectional streams</td>
</tr>
</tbody>
</table>

5.5 Evaluation of the Framework Concept

The framework concept is proven by its application to archetypes of mass events, described in the previous subsection. The framework has been improved iteratively throughout the design process by evaluating the application of the archetypes for deriving a risk assessment of crowd disaster development for these event situations. By assessing risks of crowd disasters for these archetypes both the framework concepts and the macroscopic flow models could iteratively be improved. When all requirements and the objective of the framework were achieved, the framework design process was finished.
The Archetype (Measure) Macroscopic Flow Models are part of the quantitative part of the framework (SAP). The Archetype (Measure) Macroscopic Flow Models are verified and validated by an extreme value test and a sensitivity analysis and are proven robust to assess risk of crowd disaster development at different event areas with a flowing or queuing purpose, for either unidirectional or bidirectional streams. This is further elaborated upon in the next chapters 6 and 8.

The implementation of measures to the Archetype Macroscopic Flow Models provided more insight in the effectiveness of measures for mitigating risks of crowd disasters in general. This is further elaborated upon in chapter 7.

5.6 Evaluation of Framework Output

The evaluation of the framework to a case can be done quantitatively and qualitatively when SAP is applied or only qualitatively when GAP is applied. This is because with SAP the macroscopic flow model in the framework provides values on the performance criteria’s. Whereas if no model is applied (GAP), no model is applied and thus these values are lacking. Therefore, evaluation by these criteria’s cannot be applied in GAP. For this reason the evaluation of the GAP framework need different criteria only qualitative in content.

5.6.1 Quantitative Performance Criteria for SAP

The performance criteria presented in Table 8 are derived from the framework need interviews, from the study on crowd dynamics and disaster development and from general management perspectives.

<table>
<thead>
<tr>
<th>Number</th>
<th>Performance Criterion [unit]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Average Level of Service ([p/m^2])</td>
</tr>
<tr>
<td>2</td>
<td>Total Travel time ([\text{min}])</td>
</tr>
<tr>
<td>3</td>
<td>Throughput ([p/\text{total run time}])</td>
</tr>
<tr>
<td>4</td>
<td>Risk development over critical ([p/m^2 * s])</td>
</tr>
<tr>
<td>5</td>
<td>Risk development under critical ([p/m^2 * s])</td>
</tr>
<tr>
<td>6</td>
<td>Event continuation without crowd control (\text{yes or no})</td>
</tr>
</tbody>
</table>

The values on criteria 1 to 5 can be directly derived from the model output. The average Level of Service is derived from the average density. This criterion is a widely accepted norm for the extent to which humans can walk freely at comfortable level, as stated in chapter 1 and 4. Therefore, this criterion is a performance criterion for crowd management. The total travel time is used as an indicator for the congestion (delays) at stretches of events with a flowing purpose. Next to that, the throughput is a measure to define the efficiency of the event area. Criteria 4 to 6 are related to the risk of crowd disasters. A distinction has been made for risk development over critical density value and under the critical density value, as is stated in subsection 4.1 to be necessary for compensating the bias of the integral over the density over time. Criterion 6 can be indirectly derived while assuming that crowd control is necessary as soon as a breakdown occurs (when the maximum density of 5.4 \([p/m^2]\) is observed) or the risk stage 4 is entered. The highest risk stages 4 and 5 refer to a crowd disaster regimes I and II in the fundamental diagram, with a density over 3 \([p/m^2]\). Furthermore, a breakdown is assumed as soon as the difference between the arrival rate and the inflow in the first Event Block is equal to or more than 1 \([p/s]\). This would mean that an accumulation occurs in front of the entrance of the first bottleneck of this stretch, which is also a notice for incentive to crowd control.

In step 6 of the framework, evaluation of the solutions is provided in which the simulation results are compared with the null-case. The null-case is the situation for free flow condition with a maximum arrival rate considering the Event Blocks maximum capacity. Solution scenarios which lead to an overall general better performance are taken into account, the other solution scenarios are left out of the comparison. The next step is than to compare the general better performing scenarios into more
detail with the toleration towards the performance criteria taken into account. This is done in the multi-criteria analyses where weights to the performance criteria are given by the user of the framework. All scenarios are given a score in their relative performance on each of those criteria which are then multiplied by the weight for this criterion. This means that if the number of solutions is 5, the total score to divide between the solutions is $5+4+3+2+1 = 15$. When for example 2 solutions score both scoring the best, each will be rewarded with 4.5 points et cetera. For each solution all scores on the criteria are summed and these are then compared. This comparison is on total score and relative total score. Now priority numbers are given to the best scored solution based on the outcome. On top of that, 5 colours indicate the advice for implementation where green is highly recommended, yellow moderately recommended in addition to green, orange might be implemented only in addition to green and yellow solutions and red should not be implemented. Pink is given to those solutions scored lowest relatively, but still might be beneficial in combination with orange or higher preferred solutions. This compensates for the fact that if 4 solutions are all good scored differently, colours indicate how these should be treated in priority of implementation. This provides an overview of the relative performance considering stakeholders tolerance towards their effects with the advice on which solutions to implement at which priority.

5.6.2 Qualitative Performance Criteria for GAP & SAP

The qualitative performance criteria for the framework are presented in Table 9. These criteria are derived from the goal of the framework in line with the application of GAP or SAP and from the requirements of the framework. Therefore, the list below are both requirements of the framework as well as criteria for performance of the framework in general. These criteria should be provided in an evaluation request to the client after application of the framework. This evaluation process is recommended for future research.

The criteria could be measured on a scale of 1 to 5 with the following meaning:

1 = not achieved
2 = moderately achieved
3 = marginal achieved
4 = sufficiently achieved
5 = exceeds expectations in achievement

Table 9 Qualitative Performance Criteria derived from Framework Requirements for GAP

<table>
<thead>
<tr>
<th>Requirement/Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advises on crowd management measures</td>
</tr>
<tr>
<td>Provides information on crowd and pedestrian dynamics</td>
</tr>
<tr>
<td>Provides measures for tactical management of crowds</td>
</tr>
<tr>
<td>Provide risk scenarios of crowd disasters</td>
</tr>
<tr>
<td>Shows effect of crowding on event performance</td>
</tr>
</tbody>
</table>

Additional research was needed for modelling pedestrian flows. Therefore, the process for modelling macroscopic flows, the concepts of these models, specification, assumptions and boundaries are elaborated upon in the next chapter 6.
6. Macroscopic Flow Model

In this chapter the designed macroscopic flow model for the framework is elaborated upon. The macroscopic flow model is the core of the quantitative part of the framework. In the first subsection 6.1 the functional modelling requirements are provided. These requirements are followed by a selection of modelling process for designing the macroscopic flow models. The third subsection 6.3 discusses the evaluation of these models.

6.1 Functional Modelling Requirements & Modelling Approach

The macroscopic flow model functions as a quantitative tool to (1) calculate flows and densities over time to (2) assess the risk development over time and (3) to test solutions on crowd management. The aim is not to model the behaviour of pedestrians as best as possible, but to model flow dynamics of the mass of people in order to quantify the risk of crowd disasters over time, given the initial demand and supply.

The functional model requirements are determined by the above function statement of the model and those functional requirements of the framework related to the model. The following functions are required for the macroscopic flow model in this framework:

1. Calculation of accumulation of people per area over time
2. Calculation of values on performance criteria
3. Application for unidirectional and bidirectional flows and queuing areas
4. Applicable for both discrete and continuous arrival and departure patterns
5. Allowance for simulation of scenarios
6. Adaptable to new cases

For selecting a modelling approach, all above requirements should fit. The modelling of accumulation of people, calculation of performances and the required simulation of risk mitigation scenarios request a modelling environment of macroscopic flows. This is not yet available and should therefore be designed in this research.

For aggregation of people so called stock-flow structures can be used where the stocks represent the integral over the in- and outflows of people. The inflow and outflow rates (flow variables) of a stock are specified as the partial differential equations of this stock. The stock-flow structures allow to model flows over an event area at aggregated level. It is that this stock-flow structure makes system dynamics highly beneficial for deriving the dynamics of crowds at an aggregated level.

A stock-flow structure consists next to stock variables and flow variables also auxiliary variables. The auxiliary variables cover the functions needed for specification of the flow variables, incorporation of parameters and performance indicators derived from the performance criteria. All variables are first analysed in cause-effect relations and then specified with mathematics.

This approach is done in Vensim\(^3\) software version 6.3. Vensim is used often in System Dynamics studies and allows to use both discrete and continuous arrival patterns and both discrete and continuous functions for auxiliary variables. This is especially needed when modelling a queuing part of the event or when visitors arrive in groups at certain moments in time related to the frequency of their modes of arrival. Also delays between causes and effects are easy to implement in Vensim. On top of that no large data sets are needed to run the simulation. For unidirectional flows and

\(^3\) © 2014 Ventana Systems, Inc.
bidirectional flows Traffic Flow Theory has been applied to derive the stock-flow structure in System Dynamics.

At last the models should be adaptable to new cases. As already stated before this is possible in both copying stock-flow structures and auxiliary variables to lengthen a model (increasing the number of Event Blocks) or by removing these parts to shorten the number of Event Blocks. For the unidirectional and bidirectional and queuing flows these structures are provided in the framework. Naturally, the initial parameters and run setup can be changed easily to new standards by changing these values in the initial settings of the models.

### 6.2 System Dynamics Modelling Process

For the modelling process the following methodology is being applied, see Figure 13. First step is to define the problem and corresponding modelling questions. The next step is to derive a conceptual system of crowd dynamics to model. The functions of this conceptual model are then specified in the software. Both the conceptual models and specification are done iteratively. Within this development state, the model is built. Afterwards, the model is verified and validated. When needed, the evaluation can lead to adaptations in the conceptual model and the specification of the model. All steps are provided in the methodology for deriving a System Dynamics model, see Figure 13.

In the methodology presented in Figure 13 the first step is part of the literature study phase in this research. The problem description and need for a System Dynamics model allows to start developing the model in Vensim from step 2 ‘conceptualisation’ onwards. Therefore, the first step and the last step ‘answering the research question’ should be left out for the process of deriving the model in this research. Those steps relate to the methods in doing the research for designing a framework, which is broader than developing the model. However, to give a complete overview of the methodology for deriving a system dynamics model, also the first and last step are showed.

![Figure 13 System Dynamic Model Development Methodology](Slinger, 2014)

All steps of the methodology to develop a system dynamics model are applied and explained in this subsection. The first step is to define the modelling questions and model boundaries. This step is not showed in the methodology provided here, but is found to be very necessary for the development of the model.
6.2.1 Modelling Questions & Scope

The modelling need is to derive a quantitative model for assessing risk development over time for a certain event area in the scope of this research. The model is scoped towards the presented modelling requirements in subsection 6.1. This means that the models are designed for queuing and flowing areas of unidirectional and bidirectional pedestrian streams. Furthermore, measures are incorporated to simulate scenarios which also entails the implementation of performance indicators. The following modelling questions are derived from the functional requirements for modelling.

1. How to model the flow and density developments validly in System Dynamics?
2. How to model a queuing system in System Dynamics validly?
3. How to model bidirectional flows in System Dynamics validly?
4. To what extent can a crowd disaster phenomena be modelled in Vensim?
5. Which solutions to risk mitigation of crowd disasters are applicable for modelling?

All factors, which are stated in chapter 2 to influence the crowd dynamics are being analysed but incorporated only if they are quantifiable and if there is a clear causal link. Uncertainties in these variables and parameters are taken into account by the development of scenarios for sensitivity analysis. Future research is needed before these effects can be incorporated in the framework. An analysis has been done next to a literature study to grasp the causality even more between the infrastructure and speed, please find Appendix B.2 on page 133.

6.2.2 Conceptualisation

For modelling the dynamics of the crowds first a concept of the crowd dynamics system is needed. In this way the main factors and their interrelationships are analysed and the first start is given for the modelling of archetypes. For a uni- and bidirectional flows a separate conceptual model is necessary. The reason for this is that the number of directions in an Event Block determines the share in width of the entrances and exits. This determines also the number of feedback loops in the model. For this reason the number of feedback loops differ for unidirectional and bidirectional flow models. Therefore, one conceptual model is designed for unidirectional flows, see Figure 14, and one for bidirectional flows see Figure 15. A basic rule is: the more feedback loops in a system, the more complex the model becomes. Increasing number of variables and dependencies will make modelling systems behaviour validly harder.

The causal relationships necessary for risk estimations are presented by conceptual models in System Dynamics. These conceptual models are used for defining the stock-flow structure of the macroscopic flow models. The variables and functions in these models are specified in the specification part of the modelling process, here described in the next subsection.

The flow variables are indicated by a circle and the accumulation of these flows in a certain area is represented by a stock variable (rectangle). These stock-flow variables are given in blue, all auxiliary variables and parameters are represented by black text. The parameters are presented italic and the auxiliary variables are presented in bold. The risk estimation variables are presented by the yellow rectangle with red text. The feedback loops are represented by a small loop with a direction and polarity. The polarity of the feedback loops depends on the addition of the polarity of the causal links part of this feedback loop.

For the unidirectional flow systems there are three feedback loops, see numbers 1 to 3 in Figure 14. Two of these loops are negative but they are in opposing direction of each other. This means that this system can become stable in case no external influences disturb this balance. However, there is also one regenerative feedback loop which will disturb the balance internally, this is feedback loop 1 in this figure. Feedback loop number 3 is characterised by the delay function represented by the travel time dependent on the updated speed and the length of the Event Block. The number of visitors entering
per time instance is dependent on their initial desired speed, the updated speed given the density in the Event Block, the width of the entrance and the demand flow at the entrance. When the number of people entering the Event Block increases, the number of visitors in the Event Block increases. The accumulation of people in the Event Block decreases when people exit. However, if people exit and at which rate is dependent on the available number of visitors in the Event Block, the travel time, and the width of the exit and in the number of people in the following Event Block.

The same holds for the conceptual model of bidirectional flows, except for the fact that the width of the entrance or exit is shared between the flows in each direction. Therefore, a lot more auxiliary variables are needed to be able to calculate the share of the width for each direction which in its turn is used to calculate the out- and inflows in and out a stock. For the other bi-directional flow conceptual model 7 feedback loops are discovered, see numbers 1 to 7 in Figure 15. This makes the complexity for modelling this system behaviour validly higher compared to the unidirectional flow conceptual model. The four extra feedback loops are representing the dynamics for sharing the width of an entrance or exit on either one side of the Event Block. The system can become stable if feedback loops numbers 4 to 7 are in balance and the feedback loops 1 to 3 are also in balance. If 1 to 3 are not stable, the system cannot become stable because feedback loops 4 to 7 depend on the feedback loops 1 to 3. If there is an unbalance in the feedback loops 4 to 7 the system can become unstable. Therefore, a breakdown can occur sooner in bidirectional flow models than in unidirectional flow models, which is also expected from theory on decreased flow efficiency for bidirectional flows compared to unidirectional flows.

In Figure 15 the feedback loops 1 to 3 are explained above. The other feedback loops 4 to 7 will be explained here. In case there is a higher demand of people going from left to right than from right to left, the share in visitors left to right at the left side of the Event Block will increase. With increasing this share, the share for right to left on the left side of the Event Block will decrease. This allows for appointing a larger width to entering flows and therefore the number of people entering the Event Block will increase for this left side. Because the width is appointed to the entering people at the left side, the exiting people (right to left) at the left side of the Event Block will be appointed a lower width. Therefore, less people can exit at the left side and the number entering at the left side can increase. The number of people exiting the right side of the Event Block going to the right is therefore becoming larger than the demand of people going from the right to left and entering at the right side of the Event Block. This allows even to decrease the flow of people in the right to left direction. This
continues till the moment the inflow from left to right becomes lower or if the density in the Event Block goes towards its maximum value and flowing is blocked.

Since the concepts of the models could be derived, the next step is to specify the models in Vensim. The specification of the models for the archetypes are presented here.

### 6.2.3 Specification Macroscopic Flow Models for Unidirectional and Bidirectional Flows

Each defined Event Block is assigned an accumulation function, so called stocks in the model, and flow rates. Between these stocks a transfer flow exists. This stock-flow structure is the basis for the macroscopic flow model with System Dynamics. For each different infrastructure (flows combining, separating, or continuous flows) a different structure is needed. This structure differs also for unidirectional, bidirectional flows. The bottom line is that every direction in an Event Block should be assigned its own stock, in- and outflow variables.

In the specification process functions for the identified variables and their interrelationships are defined. Every variable is being defined in terms of type (parameter, auxiliary or stock-flow variable). By specifying the stock-flow structure from the conceptual models for unidirectional and bidirectional flows, the structures for the Archetype Macroscopic Flow Models have been determined. The three different model structures for the archetypes of Wide Dam, Sumatrakade and Bi-Directional are presented in Figure 16, Figure 17 and Figure 18 respectively. The first figure represents a universal model for applying macroscopic flows in system dynamics. Therefore, this first figure shows all auxiliary layers in addition to the stock-flow structure which are also applied in the other Archetype Macroscopic Flow Models. The latter two figures are a very simplified representation of the stock-flow structures for these archetypes.

#### Universal Macroscopic Flow Model Structure

In Figure 16 the universal structure is presented which is incorporated in the Wide Dam and Sumatrakade Mooring and Bi-Directional flow models. The structure for all flow models is defined by
a stock-flow layer on top and a sublayer with auxiliary functions for determining the transfer flows between the stocks. Each direction knows its own stock variables, transfer flow variables and auxiliary variables.

Inflow and outflow variables together influence the stock level which represents the accumulation of people at a certain Event Block. The stock variable is the integral taken over the difference of in- and outflow over the time (step) $|p|$. The inflow and outflow variables are represented by a rate. In this case the unit of the stock variable is people and the flows are in $[p/s]$. The other variables, which are called auxiliaries, influence the rates or are used as lookup (table) functions or are input parameters or performance indicators.

The first and last stocks in the models do not represent an Event Block of the archetype. These stocks function as infinite capacity to define the initial inflow for the system in the first stock and to assess the throughput in the last one. The inflow for the first block in the model is only dependent on the demand flow given an initial density ($1 \text{ p/m}^2$), the initial speed (in this case 1.03 m/s), and the width of the entrance of the block. The desired speed is conform the fundamental diagram of Weidmann (1993) updated regarding the density of the flow inside the next block which can vary over time. This means that the speed of the flow entering a next block depends on the maximum desired speed of the fundamental diagram, the given speed for the outflow of the previous block and the speed of flow in the block following. People will accelerate always towards their desired walking speed in free flow conditions.

The maximum inflow to the next stock is dependent on the speed and density inside this stock, the available width of the entrance and the demand from the previous stock. The maximum outflow of a stock depends on the speed and density inside this stock, the exit width available and the number of people available in this stock for flowing to the next one. For the final outflow no limits are placed by a next stocks’ density.

The travel time is an auxiliary and depends on the length of the block and the speed of the flow inside the block given the actual density in this part. This means that the people inside a block divided by the travel time gives the outflow rate.

The transfer flow one stock (1) to the next stock (2) is the function of the minimum of the maximum outflow of stock 1 and the maximum inflow of the next stock 2. The transfer flow from one stock to
the next one should never become lower than zero. In this way conservation of people is ensured between those blocks.

**Sumatrakade Mooring Macroscopic Flow Model Structure**

For the queuing model in Sumatrakade Mooring archetype, flows needed to be separated and combined. The separation and combination flows can be done easily if the share of the flow over the directions is known and if the exits are separated. In case of sharing exits or entrances, the structure for bidirectional flows is needed in terms of calculating the width share between these two flows, as described below. When this is not the case, the unidirectional structure can be applied with the only adaptation for dividing flows over the exit flows. This is illustrated in Figure 17.

![Figure 17 Example of Archetype Model Unidirectional Queuing with separating and combining flows, applied for Sumatrakade Mooring SAIL 2015. The flow variables are black arrows and stock variables are rectangles.](image)

**Bi-Directional Macroscopic Flow Model Structure**

For bidirectional flows the universal structure presented in Figure 16 is mirrored, as such every direction has a unidirectional flow structure. Furthermore, for bidirectional flow models another layer is necessary which entails the dedication of the available entrance or exit width of an Event Block to each direction. This layer is depicted in the middle between the stocks and flows of each direction in Figure 18. First, the density in each stock and in total per Event Block is determined. Hereafter, the share in density for each direction (stock) per Event Block can be calculated. Thirdly, the share in density is multiplied by total width of the entrance or exit at each side of the stock which thus determines the width dedicated to each direction. Like for the other models, the width is necessary to determine the maximum possible out- and inflows for each stock.
Figure 18 Example of Structure of the Archetype Model for bidirectional flows. Auxiliary variables are connected by blue arrows. The flow variables are black arrows and stock variables are rectangles. The colours represent one Event Block. Each Event Block has a stock variable for each direction.

Parameters of Macroscopic Flow Models

With this in mind the following initial parameters for unidirectional and bidirectional flow models have been determined, see Table 10. In blue the parameters are presented which should be totally adapted towards the case characteristics in case of unidirectional flows. There are a few case specific parameters for Sumatrakade Mooring models (queuing models), these are presented in the colour red. For Bi-Directional archetypes the case-specific parameters are given in purple in this table below. The ones kept black are filled in already with an assumed value, but can also be changed towards new standards if preferable.

Table 10 Parameters of the Macroscopic Flow Models, parameters certainly to be adapted by the user (blue), parameters for Bi-Directional models (purple), parameters for Sumatrakade Mooring model (red), Non case-specific initial parameters (black)

<table>
<thead>
<tr>
<th>Case (Specific) Parameters</th>
<th>Units</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Density</td>
<td>[p/m²]</td>
<td>0.25 [p/m²] Assumption</td>
</tr>
<tr>
<td>Initial Desired Speed</td>
<td>[m/s]</td>
<td>1.31 [m/s] for corresponding initial density of 0.25 [p/m²] in</td>
</tr>
<tr>
<td></td>
<td></td>
<td>fundamental diagram of Weidmann (1993)</td>
</tr>
<tr>
<td>Lookup Speed per stock</td>
<td>Dimensionless</td>
<td>Weidmann Speed-Density table</td>
</tr>
<tr>
<td>Maximum Density</td>
<td>[p/m²]</td>
<td>5.4 [p/m²] Assumption based on Weidmann (1993)</td>
</tr>
<tr>
<td>Arrival Rate</td>
<td>[p/s]</td>
<td>inflowing rate can also be calculated by taking the demand in [p/m/s]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>times the width of the entrance in [m]</td>
</tr>
<tr>
<td>Dimensions per stock</td>
<td>[m²]</td>
<td>Total walkable surface</td>
</tr>
<tr>
<td>Length per stock</td>
<td>[m]</td>
<td>Travel length from entrance to exit stock</td>
</tr>
<tr>
<td>Width Entrance per stock</td>
<td>[m]</td>
<td>Entrance is passing way</td>
</tr>
<tr>
<td>Width Exit per stock</td>
<td>[m]</td>
<td>Exit is passing way</td>
</tr>
<tr>
<td>Arrival Rate for Left to Right and</td>
<td>[p/s]</td>
<td>Continuous Arrival Rate per direction</td>
</tr>
<tr>
<td>Right to Left</td>
<td></td>
<td>For discrete arrival rate use Lookup Arrival or Pulse Arrival</td>
</tr>
<tr>
<td>Bidirectional deficiency</td>
<td>Dimensionless</td>
<td>Factor for deficiency of bidirectional flows compared to unidirectional</td>
</tr>
<tr>
<td></td>
<td></td>
<td>flows. If changing, also change initial desired speed to lower value</td>
</tr>
<tr>
<td></td>
<td></td>
<td>corresponding to deficiency factor</td>
</tr>
<tr>
<td>Total width of left side or right</td>
<td>[m]</td>
<td>Total passing way for both directions</td>
</tr>
<tr>
<td>side of stock</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boat Capacity</td>
<td>[p/boat]</td>
<td>300 [p/boat]</td>
</tr>
<tr>
<td>Boat Frequency</td>
<td>[s]</td>
<td>600 [s]</td>
</tr>
<tr>
<td>Loading Time</td>
<td>[s]</td>
<td>300 [s]</td>
</tr>
<tr>
<td>Share of people going via long route</td>
<td>Dimensionless</td>
<td>0.8</td>
</tr>
</tbody>
</table>
The Weidmann (1993) fundamental diagram for pedestrian flows is being applied with a maximum initial desired speed of 1.34 \([m/s]\) with zero density and critical density of 2 \([p/m^2]\) and maximum density of 5.4 \([p/m^2]\).

The initial desired speed depends on the demographic compilation and the existence of grouping. Hence, the fundamental diagram should be updated towards the visitor population of SAIL. However, because the fundamental diagram is representing average population, it is assumed that this relationship is directly applicable for SAIL demography.

By literature an indication on flow deficiency for bi-directional flows is provided which is included in the Bi-Directional model as deficiency factor. For the model the unidirectional fundamental diagram of Weidmann (1993) will be used with a deficiency factor ranging from 0.95 to 0.85 for bidirectional flows.

**Modelling Assumptions**

During the specification, assumptions have been made for modelling the macroscopic flows.

It is argued that propagation into one direction coexists with diffusion over the available area (Miguel, 2013). This statement is used for assuming that people distribute evenly over the available walking space. On top of that, the pedestrians are assumed to follow the predefined path in the shortest possible way and not stand still but only for a bottleneck occurrence.

The system represents homogeneous flows of people, because no external influences are taken into account which can disturb the internal dynamics. Furthermore, an average population is considered conform the fundamental diagram of Weidmann (1993). Following this fundamental diagram for the initial arriving speed of visitors of 1.03 \([m/s]\) is assumed. On top of that, an average initial desired speed is assumed at 1.31 \([m/s]\).

An accuracy of 0.25 \([p/m^2]\) is used for updating the walking speed by calculating the density in a stock. Furthermore, the function to assign the speed for the density calculated is applied forward. This means that if the calculated density does not match precisely one of the specified densities, the value for speed is returned on the first higher density in the lookup table derived from the fundamental diagram. This will result in a precautious model compared to real case scenarios, because speed is updated towards a maximum of 0.24 \([p/m^2]\) higher density. This will result in a small deficiency for the duration till a breakdown occurs and the travel times. But this specification has no effect on the quality of the model or on any other performance criteria then travel time. It is preferred to have an overestimating model to an underestimating model for risks of crowd disasters.

For Bi-Directional model it is assumed that the share in density in an Event Block for each direction equals the share in the width for an exit or entrance at the left or right side of an Event Block.

**Run Setup of Models**

The model has been ran for the duration of 1 day of the SAIL event; this run is as long as people will walk in. It is assumed that the demand will vary over the day. Because there is no initial demand determined by SAIL, the capacity analysis provides the initial arrival rates for the archetypes. This demand is assumed to be present during the 14 hours of SAIL (from 9 AM to 11 PM).

The running time is over 10 hours for the archetypes derived from SAIL (considering 1 day of SAIL) and 1 hour for the Bi-Directional Archetype Model. This is sufficient to test the Bi-Directional model robustness with the time step of seconds.

The unit of time in the model is seconds. The total run of the model lasts for the duration of 1 day (between 40000 and 50400 seconds). The time step of the model is set at 0.1 \([s]\). The initial time is zero seconds. The calculations are done in seconds, because the flows are given in \([p/s]\) and the speed in \([m/s]\).
The Integration Type is set on Euler. Runge-Kutta 4 is the alternative integration method in Vensim. Euler is considered the simplest one and assumes that the rates computed are constant through the time step. The error by assuming this equals to the square of time step. This means that a decrease in time step is a decrease in the error of integration. However, a too narrow time step can also imply the overestimation of the quality of the integration and therefore $1/10$ of a second is set as time step, as the run is in seconds. While the Runge-Kutta 4 Integration method is more accurate than Euler, it also increases the computation time. Fourth order Runge-Kutta integration performs three intermediate evaluations of the rates of changes and then weights these to give the final result. For computations, the fourth order Runge-Kutta would take four times as long for a given time step as the Euler integration (Vensim, 2015). On top of that, the Runge-Kutta integration assumes a continuous functions which is not preferable when using discrete functions in the simulation like lookup tables, pulse functions and step functions. Next to this, in the models specified for all archetypes a lookup table function is used. For the specification of a solution the pulse function is being applied. For the Sumatrakade Mooring case also a step function is used. Therefore, the Euler method is chosen in this model. The steps of the Euler Integration method are as follows in Vensim:

1. Set $\text{Time}$ to its initial value.
2. Initialize the stocks
3. Compute the rates of change of the stocks at the current value of $\text{Time}$.
4. Use the rates of change in the stock to compute the stocks at $[\text{Time} + \text{TIME STEP}]$ according to the formula: $\text{Stock at Time} + \text{TIME STEP} = \text{Stock at Time} + \text{TIME STEP} \times \text{Rate Time}$
5. Add $\text{TIME STEP}$ to $\text{Time}$.
6. Repeat steps 3-5 until Time is equal to $\text{FINAL TIME}$

### 6.3 Evaluation Process of the Macroscopic Flow Model

The evaluation step in the methodology to design a systems dynamics model is provided with a feedback loop towards the conceptualisation of the system. This means that adaptations can be made in the conceptual model and the specification of the model until the evaluation step is satisfying the purpose and requirements of the model. By iteratively building the model and testing the specific functions and their behaviour on a small scale model, the model can be built efficiently. With the preliminary models improvements are derived by verifying and validating the models. When satisfied, the structure can be broadened with more variables.

The verification is done by correcting input parameters, functions and dimensions. Furthermore, the equations are checked to be consistent in units and names and incorporating of all variables applicable. Also it is verified if these equations are mathematically correct and if they follow a logical or physical law. Furthermore, the system is checked upon conservation of people and positive flows or accumulations of people.

With ‘validation’ in system dynamics is not meant to test the applicability of parameter settings derived from data sets to similar but significantly different simulation environments, but to test the robustness of the model for the parameters on which no data can be obtained and test the behaviour of the models. The validation is done by an extreme value test and sensitivity analysis. In the extreme value test, extreme values for the parameters are being tested to expected behaviour. The sensitivity test is the same, only with small adaptations to the parameters. Furthermore, the model boundaries can be tested.

Thereafter, the model is reflected upon the following modelling criteria: applicability, replicability, accuracy, artistry, parsimony, theoretical sufficiency, usability, understandability, policy significance, and explanatory power. These performance criteria for the model have been provided by the TU Delft J. Slinger (2015) and are used to assess models in system dynamics for the master course Advanced System Dynamics at TPM.
### PART D Framework Application

Part D focuses on the application of the framework. In chapter 7 the framework is step by step applied to the archetypes. In the next chapter 8 the macroscopic flow models are discussed.

#### 7. Application of Framework Steps

The framework has been applied to the archetypes of mass events. Hence, guides for each step of the framework could be derived. These guides are presented in this chapter per step of the framework. See the Figure 19 below for the questions which are answered by application of each step in this chapter.

![Diagram of Framework Application](image)

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**Figure 19 Framework Design**

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7.1 Application of Framework Step 1 Applicability Check

For the first step it is important that the user actually has a potential case for mitigating crowd disaster risks. Otherwise, the framework could be applied while no significant gain is expected to be achieved, meaning time could be wasted. The main questions for this step are:

“Can I apply the framework to my case?”

“What areas of the case should be focused on for risk of crowd disaster development?”

These two main questions are set out into 5 sub-questions in the checklist below. Here the user can check if the framework could be of significant gain to the clients’ cases, see Table 11. With these sub-questions the probability is high that event organisers should apply the framework, because no event is perfect. However, in the rare case it is, the client is informed on the limited expected gain from applying the framework. The choice is left to them to eventually apply it or not.

Table 11 Checklist for crowd disaster risk

<table>
<thead>
<tr>
<th>Number</th>
<th>Question</th>
<th>Continue?</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Are you in organisation of (public) mass events in the urban public space and/or want to do a capacity analysis for the urban infrastructure?</td>
<td>If yes, continue to the next questions. If you are not organising a mass event, but are curious for capacity analysis of the city, the framework can still be applied. If no, consider that this framework is meant to be applicable for all mass events in the public urban space. If your mass event is not in public urban space, you can still continue with general trail of the framework and thus can continue to the next question. If you are not interested in urban capacity analysis, crowd management strategies on tactical level or mass event management, do not continue with applying this framework.</td>
</tr>
<tr>
<td>1</td>
<td>Are any bottlenecks expected because of narrow streets or bidirectional or multidirectional streams?</td>
<td>If yes, these areas under certain circumstances could lead to the development of crowd disasters, hence continue with the application of the framework. If no or ‘do not know’ continue to the next question.</td>
</tr>
<tr>
<td>2</td>
<td>Is there a small time frame in which visitors arrive at the event or depart?</td>
<td>If yes, there is a chance of congestion which in certain circumstances could lead to the development of crowd disasters, hence continue with the application of the framework. If no or ‘do not know’ continue to the next question.</td>
</tr>
<tr>
<td>3</td>
<td>Do visitors walk or follow a certain fixed route?</td>
<td>If yes, a higher chance of congestion is likely under certain circumstances, which could lead to the development of crowd disasters, hence continue with the application of the framework. If no or ‘do not know’ continue to the next question.</td>
</tr>
<tr>
<td>4</td>
<td>Do visitors walk or follow a route at which the availability of alternative routes is limited?</td>
<td>If yes, a higher chance of congestion is likely under certain circumstances, which could lead to the development of crowd disasters, hence continue with the application of the framework. If no or ‘do not know’ continue to the next question.</td>
</tr>
<tr>
<td>5</td>
<td>Regarding the network of the event, is/are there main feeder route(s)</td>
<td>If yes, a higher chance of congestion is likely under certain circumstances, which could lead to the development of crowd disasters, hence continue with the application of the framework.</td>
</tr>
</tbody>
</table>
towards a top activity/show/facility which is/are expected to be too small to accommodate a peak in visitor arrivals?

If no or ‘do not know’, probably the framework would not be highly beneficial towards mitigating risk at your event because you answered all questions with no or do not know. Still an option is to apply the GAP of the framework in which also insight can be gained into crowd management strategies in general.

For SAIL 2015 the checks provided that out of the 5 questions, 4 could be answered with yes (questions 1, 3, 4, 5). Indicating that the framework would be beneficial to apply to this mass event. For SAIL the following Figure 20 presents the above guide applied. In this figure the walking routes at SAIL with the indicated directions and 5 expected bottlenecks. It is likely that there are more bottlenecks, however these 5 are considered major ones on the main walking route (orange) when applying the framework. Each of those bottlenecks are indicated by a red arrow in the figure below. The first ones are at the Central Train Station of Amsterdam exit towards the Ruijterkade. There is a very narrow walking passage out of the exit towards to quay of approximately 3 [m] probably used for bidirectional flows or even multidirectional flows during SAIL. The crossing at the Ruijterkade is the second bottleneck indicated through application of the guide. Here multidirectional streams will occur. Two bottlenecks are expected at the Wide Dam, one at the South to North direction and one at the North to South direction. This is because the dam is at is narrowest point 5.5 [m] wide. The last bottleneck is expected at the Sumatrakade Mooring place where people need to queue before departing by boats to the opposite quay. These 5 bottlenecks represent the Event Blocks which are probably in need for research on risk development of crowd disasters.

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Results on Bottleneck Analysis

In case the client decides to further apply the framework, the next step is to structure the event into Event Blocks and to determine if the framework can be applied specific (SAP) or general (GAP).
7.2 Application of Framework Step 2 Selecting Event Blocks

Since the bottlenecks or other areas of interest have been indicated, now the framework should provide the user with the translation of these areas into study objects (Event Blocks) for the framework application. The reason this is needed is first of all to focus on smaller areas to be able to choose which sections of the event would benefit the most by application of this framework. Secondly, the blocks need to be defined for further application of the model in SAP. Therefore, the main questions answered in this step are:

“How can I derive the Event Blocks for effective application of the framework?”

“Which Event Blocks should be selected for application of the framework?”

“Which kind of detail (SAP or GAP) is applicable for the selected Event Blocks?”

The second step of the framework is supported by one guide for separating sections of the event terrain into Event Blocks, see Table 12. In addition Table 13 is needed to select those Event Blocks for further application which are probably most in favour for risk assessments. Therefore, the first guide entails steps for separating these bottleneck event areas into Event Blocks and the second guide entails a selection tool for selecting critical Event Blocks.

Event Blocks function as design objects for the quantitative model in step 4 and/or as a focus object for the GAP step 6. Furthermore, some of these critical Event Blocks might be out of the scope of the SAP framework, therefore the last column in this guide states the application for either GAP or SAP, see Table 12.

Table 12 Guide for deriving Event Blocks

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
<th>Explanation</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>If there are any intersections or crossing, these are the first separate Event Blocks.</td>
<td>For each intersection the route choices and fundamental relationships between speed and density differ and thus are to be seen as independent blocks. Each crossing or intersection needs to be a separate Event Block.</td>
<td>GAP</td>
</tr>
<tr>
<td>2</td>
<td>Assess the width of the streets and indicate where this changes.</td>
<td>The Event Blocks do not need to have the same width, but the border between those blocks have the same passing width. An inflow entrance can be wider than an outflow exit of a block. Blocks with a buffer space should be seen as unique blocks, although the inflow and outflow of these blocks might have an equal width, because of the possibility for overtaking.</td>
<td>GAP &amp; SAP</td>
</tr>
<tr>
<td>3</td>
<td>If there are any large objects, fountains or bridges in an area these areas should be seen as individual Event Block.</td>
<td>A change in environment can also lead to the distinction of another Event Block, for example when there is a large object on the road or if there is a fountain, channel or bridge.</td>
<td>GAP &amp; SAP</td>
</tr>
<tr>
<td>4</td>
<td>A change in modality is the identification of a new Event Block.</td>
<td>A change in modality, for example from bus to foot, is a change in arrival pattern for a certain area</td>
<td>SAP</td>
</tr>
<tr>
<td>5</td>
<td>If there is a large show/activity or facility,</td>
<td>A show at a square or even an activity/facility on the side-line can lead to change in fundamental diagram in this area and thus is seen as individual Event Block.</td>
<td>GAP &amp; SAP</td>
</tr>
</tbody>
</table>
The need for case-specific advice and the applicability of the derived Event Blocks for specific advice determine the applicability of the framework given the clients need for advice. When the decision is made to continue with SAP, only those Event Blocks applicable for SAP can be applied to the whole framework. The other Event Blocks not applicable for SAP can still be applied in the framework with GAP. For time constraints it is wise to focus on those Event Blocks which are probably most problematic. Therefore, the following guide Table 13 is provided. This guide states whether or not an Event Block should be taken into consideration because of a high probability to become a bottleneck or constraint in the capacity of an event area.

### Table 13 Selection guide for Event Blocks

<table>
<thead>
<tr>
<th>Number</th>
<th>Selection question</th>
<th>Action</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Are any Event Blocks significantly smaller than others? Or are there any bottlenecks?</td>
<td>Take these Event Blocks into account with upstream and downstream blocks</td>
<td>There is a high chance of congestion upstream of a narrowing, so interesting for the framework risk mitigation strategy</td>
</tr>
<tr>
<td>2</td>
<td>Is there a small time frame in which *many visitors arrive and/or depart at/from the Event Block?</td>
<td>Take these Event Blocks into account</td>
<td>*many visitors should be seen within an expected peak period for example a start or ending of a show</td>
</tr>
<tr>
<td>4</td>
<td>Is the object in the Event Block restricting the total capacity of the block regarding the width of the walkable area?</td>
<td>Take these Event Blocks into account</td>
<td>There is a high chance of congestion, so interesting for the framework risk mitigation strategy</td>
</tr>
<tr>
<td>5</td>
<td>Regarding the network of the event, is/are there main feeder route(s) towards a top activity/show/facility?</td>
<td>Take these Event Blocks into account</td>
<td>There is a high chance of congestion during peak period, so interesting for the framework risk mitigation strategy</td>
</tr>
</tbody>
</table>

Next to that, a change of width between those blocks of 0.5 [m] should be taken into account. With 0.5 [m] change at least 0.5 to 1 person can walk extra or less at a cross-section of the Event Block per time unit, which is a significant change in capacity. A slope for over a larger width change is fine for one Event Block, only if the walkable surface is set accordingly.

For SAIL the Event Blocks of the Wide Dam and Sumatrakade Mooring are selected to continue for SAP. These are both for unidirectional streams on the main route passing activities with expected bottlenecks.

When the Event Blocks are selected for further application of SAP with the framework, the next step is gathering more data on all selected Event Blocks. If GAP chosen, the next step is 4b.
7.3 Application of Framework Step 3 Data Gathering

Whether or not to model the selected Event Blocks is advised in the previous step already. For continuation with SAP data is needed for modelling Event Blocks. Therefore, another check is if sufficient data is available on the selected Event Blocks for SAP. The main questions answered in this step are:

“Which data are necessary for continuation?”

“To what extent can the framework SAP or GAP be applied given the available data for each Event Block?”

To guide the acquisition of relevant data for the model, the Class Diagram of Mass Events is conducted. The Class Diagram of Mass Events is an object oriented conceptual study in which the mass event as a system is broken down into smaller classes of objects with similar characteristics and attributes. Also the links between those classes and subclasses are analysed and included. This diagram is thus a breakdown of all information needed for studying mass event systems. Therefore, data for the initial parameters of the model for the Event Blocks will be gathered by this Class Diagram of Mass Events. The Class Diagram of Mass Events is large and is provided in the Appendix C.1 at page 154. A selection of these attributes is used for the variables of the macroscopic flow models in this framework. This selection is provided in Table 14.

### Table 14 Selection of Attributes of Class-Diagram for Macroscopic Flow Model

<table>
<thead>
<tr>
<th>Class</th>
<th>Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route</td>
<td>Direction of flow</td>
</tr>
<tr>
<td></td>
<td>Street Dimensions (width, length)</td>
</tr>
<tr>
<td></td>
<td>Origin</td>
</tr>
<tr>
<td></td>
<td>Destination</td>
</tr>
<tr>
<td></td>
<td>Existence of transportation with predetermined frequency</td>
</tr>
<tr>
<td>Crowd</td>
<td>Average mobility</td>
</tr>
<tr>
<td></td>
<td>Initial Desired Speed (Weidmann (1993) is advised for average populations</td>
</tr>
<tr>
<td></td>
<td>Arrival pattern</td>
</tr>
<tr>
<td></td>
<td>Departure Pattern</td>
</tr>
<tr>
<td></td>
<td>Peak Duration</td>
</tr>
<tr>
<td>Visitor</td>
<td>Route and activity choices to be made</td>
</tr>
<tr>
<td></td>
<td>Age Distribution</td>
</tr>
<tr>
<td></td>
<td>Gender Distribution</td>
</tr>
<tr>
<td></td>
<td>Arrival and Departure mode choice</td>
</tr>
</tbody>
</table>

The user should fill in the data available on each Event Block considering Table 14. With the acquired data, the user can now again check with the Checklist for SAP if there is enough and reliable data provided to continue with SAP. The checklist is provided in Table 15. If this is not the case, the user is advised to continue with GAP.

The crowd attributes on arrival, departure and peak duration patterns can be derived according to a number of strategies. How to define these distributions is in detail explained in Appendix C.2. The average desired speed of the population of visitors is dependent on the visitor attributes of age and gender. How to define these distributions is also in detail explained in Appendix C.2.

The availability of the most relevant data for the input parameters of the model should be checked in order to decide on continuation with SAP. If the results are not valid because of the unreliability of data, SAP cannot provide an adequate contribution to the mitigation of risk of crowd disasters. On the contrary, in this case a user would benefit most by applying GAP. However, if only arrival and departure times and number of visitors are not sure, the application of SAP is still possible with the
notification that the model cannot predict these numbers. Therefore, if this is the case a capacity
assessment can still take place. Please find the elaborated study on how to determine arrival and
distribution patterns, speed, and gender and age distributions in Appendix C.2 on page 155.

Table 15 Checklist for continuation with SAP/GAP

<table>
<thead>
<tr>
<th>Check Item</th>
<th>Question</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Reliability of data on visitor</td>
<td>Are the total numbers reliable for expected number of visitors?</td>
<td>If sure continue with SAP. If they are not so sure; continue with SAP only if it is possible to derive reliable scenarios within SAP step IV, if not continue with SAP for purpose of deriving capacities.</td>
</tr>
<tr>
<td>numbers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Reliability of arrival and/or</td>
<td>Are the distributions reliable for expected arriving number of visitors over time?</td>
<td>If sure continue with SAP. If not so sure, try to derive scenarios on these distributions within SAP step IV otherwise apply SAP for purpose of deriving capacities.</td>
</tr>
<tr>
<td>departure times</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Reliability of dimensions of</td>
<td>Are the dimensions reliable of the width, length of streets</td>
<td>If sure, continue with SAP. If not so sure, try to be sure on 0.5 meters accuracy, if that is not possible continue with GAP. If not being able to, continue with GAP. If totally not sure or not being able to get these data, continue with GAP.</td>
</tr>
<tr>
<td>sections</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If the continuation with SAP is advised and chosen, the next step is to model the Event Blocks in Step 4. If GAP is chosen the next step is 5, which is elaborated upon in section 7.5.

7.4 Application of Framework Step 4 Modelling Event Blocks

The macroscopic flow models for three archetypes are designed so that they could be adapted easily to new cases. In this way not the total structure of the model has to be adapted. The main questions answered in this step is:

“How to adapt the macroscopic flow models for the selected Event Blocks?”

The first check is to check the direct applicability of the stock-flow structure used in the Archetype Macroscopic Flow Model. To what extent the structure needs to be adapted, depends on the Event Blocks selected in step 2 of the framework. The Event Blocks should match one of the three archetypes. Hence, the matching Archetype Macroscopic Flow Model is used to start specifying the Event Block Macroscopic Flow Model. It is advised to start a new plain model sheet and copy paste the stock-flow structures needed from the Archetype Macroscopic Flow Models. The functions defined for these Archetype Macroscopic Flow Models can easily be copied in case more stocks and flows are necessary. Each Event Block should be represented by at least one stock in the model. Furthermore, each direction should be represented by at least one stock.

The second check is if the initial settings of the Event Block model should be adapted. The initial settings refer to the total run time and initial parameters, see Table 16.
60

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrival Rate</td>
<td>( p/s )</td>
<td>Inflowing rate can also be calculated by taking the demand in ( p/m/s ) times the width of the entrance in ( m )</td>
</tr>
<tr>
<td>Dimensions per stock</td>
<td>( m^2 )</td>
<td>Total walkable surface</td>
</tr>
<tr>
<td>Length per stock</td>
<td>( m )</td>
<td>Travel length from entrance to exit stock</td>
</tr>
<tr>
<td>Width Entrance per stock</td>
<td>( m )</td>
<td>Entrance is passing way</td>
</tr>
<tr>
<td>Width Exit per stock</td>
<td>( m )</td>
<td>Exit is passing way</td>
</tr>
</tbody>
</table>

The third check is to verify the fundamental diagram in the models. When another initial desired speed is found applicable for the population than is applied, this should be updated in the fundamental diagram variable for the speed-density function called ‘Lookup Speed’.

The models are designed for unidirectional and bidirectional flows. Queuing can be added to both structures. Also multiple (separate) routes can be added in both structures when applicable. Arrival and departure patterns or rates can be chosen. This means that in case of arriving visitors with public transport or other transport with a fixed schedule, these patterns can be included.

### 7.5 Application of Framework Step 5 Measures Selection

The main questions answered in this step are:

“For SAP & GAP: Which measures can be taken to mitigate risk of crowd disasters for the selected Event Blocks?”

“For SAP, which measures can be implemented in Event Blocks Macroscopic Flow Model?”

“For GAP, how to check if the framework is applied well given its function?”

For the application of GAP this last step entails the application of the Scenario Measure Chart and evaluate the application. These charts show the phenomena in development of a crowd disaster and provide measures to mitigate the risks of these phenomena in scenarios combining the measures following the order of crowd disaster development, see part B of this thesis. The performance criteria for qualitative evaluation are provided in chapter 5.

The extent to which crowd disaster phenomena can be modelled in a macroscopic flow model is limited. This is mainly because the greater share of these phenomena are not quantifiable. This is a pity if one would like to see their effects on the crowd disaster development scenarios. Therefore, in this research an attempt is made to quantify the phenomena in specifying functional adaptations for the macroscopic models applied to archetypes.

A selection is done for which archetypes these scenarios are implemented to be most effective. Furthermore, the implementation of measures is also an evaluation tool for the frameworks’ applicability. This purpose should not be lost in enthusiasm of modelling all scenarios for mitigating crowd disaster risks for all archetypes. When no structural changes to the model are necessary the scenarios are implemented for those archetypes expected to benefit most from these solutions.

Tables to show this selection process from (1) the phenomena of the Layered Crowd disaster Model to (2) the mitigation measures in the Scenario Measure Chart, to (3) the selection of solution scenarios for implementation for each archetype, towards (4) the specification of these scenarios is too extensive to show here. The interested reader is directed to Appendix C.3 on page 163. The summary of this deduction has led to Table 17.

In total 8 solution scenarios for implementation to the SAIL archetypes are being deprived of which 6 are implemented in the models as showed in the table below. While running scenario 7 it became clear that this solution was not beneficial neither disadvantageous for the criteria. Therefore, scenarios 7 and 8 (in which scenario 7 is combined to scenario 6) are excluded from evaluation.
Scenarios 1 to 6 are taken on for further evaluation, where scenarios 5 and 6 are only evaluated for the Wide Dam case because these scenarios are only beneficial if they are implemented upstream. This means that the network function of the Wide Dam archetype respectively to the Sumatrakade Mooring needs to be taken into account. Because the first upstream decision point on flowing into the walking route to Sumatrakade Mooring is the Wide Dam, these solutions scenarios need to be implemented at the Wide Dam.

Table 17 Implementation strategy of solutions to crowd disaster development phenomenon in Macroscopic Flow Model

<table>
<thead>
<tr>
<th>Phenomenon Solution</th>
<th>Scenario</th>
<th>Implementation</th>
<th>Possible in Archetype</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Pushing &amp; No Craze/No Stampede &amp; No Bottleneck &amp; No Gridlock</td>
<td>1</td>
<td>Adapt MAX inflow functions with critical density as maximum density</td>
<td>Wide Dam SN Sumatrakade Mooring B Sumatrakade Mooring A+ Bi-Directional B Sym</td>
</tr>
<tr>
<td>No Crowd Turbulence &amp; No Interest - Attraction Peak</td>
<td>2</td>
<td>Adapt arrival or demand rate</td>
<td>Wide Dam SN Sumatrakade Mooring A+ Sumatrakade Mooring B Bi-Directional B Sym</td>
</tr>
<tr>
<td>No Craze/No Stampede &amp; Increase Throughput &amp; No Bottleneck</td>
<td>3</td>
<td>Adapt width and dimensions of block to create buffer spaces &amp; increase walkable space</td>
<td>Wide Dam SN Sumatrakade Mooring A+ Sumatrakade Mooring B Bi-Directional B Sym</td>
</tr>
<tr>
<td>Efficient Choice Behaviour &amp; Even Distribution over Area &amp; No Interest and Attraction Peak &amp; No Gridlock</td>
<td>4</td>
<td>Adapt inflow, arrival or demand rate on choice distribution and route capacity and allow top attractions with largest supply</td>
<td>Wide Dam NS Wide Dam SN Sumatrakade Mooring A+ Sumatrakade Mooring B Bi-Directional B Sym</td>
</tr>
<tr>
<td>No Interest &amp; Attraction Peak &amp; No Pushing &amp; No Craze No Stampede &amp; No Bottleneck &amp; No Gridlock &amp; Increase Throughput</td>
<td>5</td>
<td>Adapt inflow by pulse function to create groups of people and adapt the function to a critical density as maximum density</td>
<td>Wide Dam SN</td>
</tr>
<tr>
<td>&amp; Increase Throughput &amp; No Bottleneck</td>
<td>6</td>
<td>Adapt inflow by pulse function to create groups of people</td>
<td>Wide Dam SN</td>
</tr>
<tr>
<td>Faster Effect</td>
<td>(7)</td>
<td>Allow adaptation to speed in advance of 1 upstream block</td>
<td>Wide Dam SN</td>
</tr>
<tr>
<td>Faster Effect</td>
<td>(8)</td>
<td>Allow adaptation to speed in advance of 1 upstream block and adapt inflow by pulse function to create groups of people</td>
<td>Wide Dam SN</td>
</tr>
</tbody>
</table>
7.6 Application of Framework to SAIL 2015 Step 6 SAP Solutions

The last step of the framework is step 6. This step is only for SAP. In this step the solutions chosen for the models should now be implemented, simulated and evaluated.

The main questions answered in this step are:

“Given application of SAP, which measures can be implemented in the Macroscopic Flow Models of the Event Blocks?”

“How to implement selected solutions in the macroscopic flow models?”

“How to evaluate solutions?”

In some cases multiple solutions could be applied to mitigate risks on a certain issue, as is shown in the previous step. For this reason, these solution scenarios should be compared and evaluated. The output of the macroscopic flow models is evaluated on the performance criteria by a multi-criteria analysis. One option might be better than another. However what is ‘better’ is exactly the question. The tolerance towards these measures implies the applicability and relevance of the measures for the case in perspective of the user, see also Appendix A2 on page 93 for the tolerance complexity towards risk mitigation. Therefore, the multi-criteria analysis offers the user a tool to include their tolerance towards the performance criteria by assigning weights to each one, please find Table 18.

Because the models have been built up by stocks, for each stock these criteria can be evaluated. However, for the tactical management it will be sufficient to look into the performance of a total stretch. Therefore the archetype with all its defined Event Blocks and corresponding stocks is being evaluated in total.

Application of Step 6 to SAIL archetypes

For the fictive problem owner of the archetypes modelled, it is assumed that the risk development over critical is valued most relevant, therefore given the highest weight 10. Also this client does want the event to continue without crowd control. Though, the client can imagine that in some occasion crowd control is necessary and therefore this criterion is given a high value of 8 but not the maximum of 10. Furthermore, the average Level of Service does not matter for this client, because the client does allow low Level of Service because of the nature of the mass of the event resulting in the value 1 for this criterion. This is presented in the table below.

Table 18 Crowd Management Performance Criteria used for Multi-Criteria Analysis, example weights given to the criteria

<table>
<thead>
<tr>
<th>Number</th>
<th>Performance Criterion [unit]</th>
<th>Weight (Lowest 1 – Highest 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Average Level of Service ([p/m^2])</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Total Travel time ([\text{min}])</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Throughput ([p/\text{total run time}])</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Risk development over critical ([p/m^2 \times s])</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>Risk development under critical ([p/m^2 \times s])</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>Event continuation without crowd control ([\text{yes or no}])</td>
<td>8</td>
</tr>
</tbody>
</table>

Solutions to the Wide Dam are most important for the development of the queue at the downstream located archetype Sumatrakade Mooring. Therefore, the Wide Dam case South to North multi-criteria evaluation is presented here. This evaluation is presented in Table 19 and Table 20 in which for the scenario numbering is referred to Table 17.

In Table 19 the Multi-Criteria Analyses results are presented for the Wide Dam case South to North. In Table 20 the analyses results are presented for those cases which could deal with an over maximum arrival rate of 6.5 \([\text{p/s}]\), which are then being compared to the null case (scenario 2) with 6.27 \([\text{p/s}]\). A maximum inflow is 6.27 \([\text{p/s}]\) derived from a capacity analysis of this archetype. In these tables the
results are presented for weights given as in Table 18 and for equal weights of 1 to show that the tolerance towards these criteria can influence the advice. Furthermore, 5 colours indicate which solution is recommended relatively seen. Green is given to those scenarios performing relatively best, these solutions are highly recommended in this stage of free flow or turbulence. The yellow solutions are moderately recommended or in combination with the green solutions highly recommended. Orange and Pink are scored lowest relatively seen, therefore these solutions are not recommended to implement solely. Only with solutions from the higher preferences the orange might be beneficial. The pink ones should only be implemented next to the orange solutions. Red is given to the solutions which are scoring lower than the null case variant in turbulent flow regimes, which therefore are not being recommended to consider further.

The last evaluation step is to compare the results of the Multi-Criteria Analyses. Scenario 3 and Scenario 4 are scoring highest for the maximum arrival rate, but only work when the inflow rate is kept at its maximum. Scenarios 1 and 6 work second best in the null case environment, and even the best in case of a higher than maximum density of 6.5 \( \frac{p}{s} \). Scenarios 2 and 5 work third best in both cases of initial arrival rate.

To conclude, the advice based on these results for the Wide Dam Case South to North is to try to control the inflow to remain under the critical maximum arrival rate of 6.27 \( \frac{p}{s} \). This can be done either at the entrance of SAIL either by distributing the highest demands for the highest supplies or by influencing decisions on route choice and activity choices. Furthermore, if these measures are not possible to maintain or for any reason fail the risk on crowd disasters could this be mitigated either by maintaining the critical density as maximum density or by creating groups of people to continue over the Wide Dam.

For the Sumatrakade Mooring and Bi-Directional Model the solutions for scenarios 1 to 4 work best if unidirectional flows are being maintained. For the Sumatrakade Mooring, solutions implemented would entail a match with the throughput from the Wide Dam South to North and the available boat capacity and queuing space available. Increasing the walkable space would mean a short period of decreasing the density, which might be beneficial for maintaining the critical density as maximum density. However, the arrival control is always dominating this. Therefore, increasing buffer space is seen as a temporarily measure in this case. Maintaining the critical density as maximum density is not as beneficial in a queueing system as in in a free flowing system, because of the function of waiting areas and higher allowable densities for that reason.

Because the Bi-Directional Model is not considered part of SAIL 2015, the solutions to mitigate risk in this model are not part of the solution evaluation. However, in case bidirectional stretches are being considered by SAIL, the main solution would be to avoid bi-directional streams. The next solution would be to restrict the inflow till the maximum arrival rate and/or control the flow by maintaining the critical density as maximum density. The third solution is to increase the width of the bottleneck, however this does not mean that the throughput might be higher, but only that risk is being reduced.
Table 19 Multi-Criteria Analysis Results for all Solution Scenarios for the Wide Dam Case Study with basis maximum arrival rate of 6.27 [p/s]

<table>
<thead>
<tr>
<th>Case</th>
<th>Performance Criterion</th>
<th>Weight</th>
<th>Scenario 1</th>
<th>Scenario 2 = Null Case</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
<th>Scenario 5</th>
<th>Scenario 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide Dam SN AR 6.27</td>
<td>1 Average Level of Service ([p/m^2])</td>
<td>1</td>
<td>3.5</td>
<td>1.5</td>
<td>5</td>
<td>6</td>
<td>1.5</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>2 Total Travel time ([\text{min}])</td>
<td>4</td>
<td>10</td>
<td>10</td>
<td>20</td>
<td>24</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>3 Throughput ([p/\text{total run time}])</td>
<td>4</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>4</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>4 Risk development over critical ([p/m^2 \cdot s])</td>
<td>10</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>5 Risk development under critical ([p/m^2 \cdot s])</td>
<td>5</td>
<td>17.5</td>
<td>7.5</td>
<td>25</td>
<td>30</td>
<td>7.5</td>
<td>17.5</td>
</tr>
<tr>
<td></td>
<td>6 Event continuation without crowd control ([\text{yes or no}])</td>
<td>8</td>
<td>28</td>
<td>28</td>
<td>28</td>
<td>28</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>Total</td>
<td>Total Score</td>
<td></td>
<td>110</td>
<td>98</td>
<td>129</td>
<td>127</td>
<td>98</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>% of maximum scored(MAX 129)</td>
<td></td>
<td>85%</td>
<td>76%</td>
<td>100%</td>
<td>98%</td>
<td>76%</td>
<td>85%</td>
</tr>
<tr>
<td></td>
<td>Order of preference</td>
<td></td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case</th>
<th>Performance Criterion</th>
<th>Weight</th>
<th>Scenario 1</th>
<th>Scenario 2 = Null Case</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
<th>Scenario 5</th>
<th>Scenario 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide Dam SN AR 6.27</td>
<td>1 Average Level of Service ([p/m^2])</td>
<td>1</td>
<td>3.5</td>
<td>1.5</td>
<td>5</td>
<td>6</td>
<td>1.5</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>2 Total Travel time ([\text{min}])</td>
<td>1</td>
<td>2.5</td>
<td>2.5</td>
<td>5</td>
<td>6</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>3 Throughput ([p/\text{total run time}])</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>4 Risk development over critical ([p/m^2 \cdot s])</td>
<td>1</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>5 Risk development under critical ([p/m^2 \cdot s])</td>
<td>1</td>
<td>3.5</td>
<td>1.5</td>
<td>5</td>
<td>6</td>
<td>1.5</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>6 Event continuation without crowd control ([\text{yes or no}])</td>
<td>1</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Total</td>
<td>Total Score</td>
<td></td>
<td>20.5</td>
<td>16.5</td>
<td>26</td>
<td>26</td>
<td>16.5</td>
<td>20.5</td>
</tr>
<tr>
<td></td>
<td>% of maximum Total Score(MAX 26)</td>
<td></td>
<td>79%</td>
<td>63%</td>
<td>100%</td>
<td>100%</td>
<td>63%</td>
<td>79%</td>
</tr>
<tr>
<td></td>
<td>Order of preference</td>
<td></td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>
Table 20 Multi-Criteria Analysis Results for all Solution Scenarios for the Wide Dam Case Study with basis over maximum arrival rate of 6.5 [p/s]

<table>
<thead>
<tr>
<th>Case</th>
<th>Performance Criterion</th>
<th>Weight</th>
<th>Null Case = Scenario 2</th>
<th>Scenario 1</th>
<th>Scenario 5</th>
<th>Scenario 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide Dam SN Arrival Rate 6.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Average Level of Service ([p/m^2])</td>
<td>1</td>
<td>2</td>
<td>3.5</td>
<td>1</td>
<td>3.5</td>
</tr>
<tr>
<td>2</td>
<td>Total Travel time ([\text{min}])</td>
<td>4</td>
<td>16</td>
<td>10</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Throughput ([p/\text{total run time}])</td>
<td>4</td>
<td>8</td>
<td>14</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>4</td>
<td>Risk development over critical ([p/m^2 \times \text{s}])</td>
<td>10</td>
<td>30</td>
<td>30</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>Risk development under critical ([p/m^2 \times \text{s}])</td>
<td>5</td>
<td>10</td>
<td>17.5</td>
<td>5</td>
<td>17.5</td>
</tr>
<tr>
<td>6</td>
<td>Event continuation without crowd control ([\text{yes or no}])</td>
<td>8</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>Total Score</td>
<td>86</td>
<td>95</td>
<td>44</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td></td>
<td>% of maximum Total Score</td>
<td></td>
<td>MAX 95</td>
<td>91%</td>
<td>100%</td>
<td>46%</td>
</tr>
<tr>
<td></td>
<td>Order of preference</td>
<td></td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

Case Performance Criterion                              | Weight | Null Case = Scenario 2 | Scenario 1 | Scenario 5 | Scenario 6 |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide Dam SN Arrival Rate 6.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3.5</td>
<td>1</td>
<td>3.5</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>4</td>
<td>2.5</td>
<td>1</td>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3.5</td>
<td>1</td>
<td>3.5</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>2</td>
<td>3.5</td>
<td>1</td>
<td>3.5</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>15.5</td>
<td>18.5</td>
<td>7.5</td>
</tr>
<tr>
<td>% of maximum Total Score</td>
<td></td>
<td>MAX 18.5</td>
<td>84%</td>
<td>100%</td>
<td>41%</td>
</tr>
<tr>
<td>Order of preference</td>
<td></td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

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8. Discussion of Archetype Macroscopic Flow Models

In this chapter the Archetype Macroscopic Flow Modes are discussed and evaluated. Each subsection discusses the application results and validation test results per archetype of mass event.

8.1 Introduction to Evaluation Tests

The last step of the methodology is the evaluation of the robustness of the model by testing the model behavioural and numerical outcomes on sensitivity to the chosen parameter sets. The following variables are being considered in these tests: throughput, risk development, density, total arrivals, update speed, travel time per block, total number of visitors in the system, maximum in- and outflows, transfer flows and total number of visitors in a block. The outcomes on these variables are the key in the determining the models behaviour and are also part of the performance indicators of crowd management.

For the evaluation on the sensitivity of the parameters towards the output of the model, test cases are conducted. The following test cases are applied to the Archetype Macroscopic Flow Models, see Table 21. All the tests are being applied for a free flow condition and congestion condition according to the arrival rates. The parameters have unknown uncertainties. In order to test the sensitivity of the model to an uncertainty in the parameter settings, they are changed by 5% or 10% or by another logical value. For the arrival rate, also an arrival pattern is assumed to compare the response of the system towards small and frequent peaks versus a constant peak.

The tests cannot be applied in the same way to all models, therefore a distinction is shown in the table below. Next to the presented parameters in the table below, for the Sumatrakade Mooring and Bi-Directional more case-specific parameters need to be tested. The share in arrivals over the two directions in the Bi-Directional Model and the share in arrivals over the two entrances in Sumatrakade Mooring Model will be varied by [0; 1], [0.2; 0.8], [0.5; 0.5]. In addition, for only the Sumatrakade Mooring case the boat capacity will be varied from [100; 300; 600] p/boat and departure frequencies [300; 600; 900] seconds.

Table 21 Test cases for sensitivity analysis of the Archetype Macroscopic Flow Models

<table>
<thead>
<tr>
<th>Test Case</th>
<th>Wide Dam</th>
<th>Sumatrakade Mooring</th>
<th>Bi-Directional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>+/- 5 and 10%</td>
<td>- 2.5%, 5%, -10% and -15%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Including change in initial desired speed accordingly</td>
<td>Including change in initial desired speed accordingly</td>
<td></td>
</tr>
<tr>
<td>Critical Density</td>
<td>1.5; 2; 2.5 and 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density [p/m²]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Density</td>
<td>5; 5.25 and 5.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density [p/m²]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial demand</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rate</td>
<td>Initial demand rate [p/m/s]</td>
<td>k [p/m²]</td>
<td>u [m/s]</td>
</tr>
<tr>
<td></td>
<td>0.64</td>
<td>0.75</td>
<td>0.855</td>
</tr>
</tbody>
</table>
### Arrival Rate and Pattern
(Vertical axis [p/s])

<table>
<thead>
<tr>
<th>Scenario</th>
<th>W left [m]</th>
<th>W right [m]</th>
<th>Surface [m²]</th>
<th>Bottleneck SN3</th>
<th>Sumatrakade A vs B</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>110</td>
<td>6</td>
<td>660</td>
<td>Normal case</td>
<td>Bi-Directional A vs B &amp; Case B width [m] bottleneck: [6; 6.3; 5.7]</td>
</tr>
<tr>
<td>II</td>
<td>104.76</td>
<td>6.3</td>
<td>660</td>
<td>width 5% increase</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>115.79</td>
<td>5.7</td>
<td>660</td>
<td>width 5% decrease</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>115.5</td>
<td>6</td>
<td>660</td>
<td>width same and 5% increase length</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>104.5</td>
<td>6</td>
<td>693</td>
<td>width same and 5% decrease length</td>
<td></td>
</tr>
<tr>
<td>VI</td>
<td>110</td>
<td>6.3</td>
<td>627</td>
<td>width 5% increase and same length</td>
<td></td>
</tr>
<tr>
<td>VII</td>
<td>110</td>
<td>5.7</td>
<td>693</td>
<td>width 5% decrease and same length</td>
<td></td>
</tr>
</tbody>
</table>

On top of the sensitivity analysis, an extreme values analysis is conducted. This test is only applicable for the arrival rate variable and is applied to all archetypes models. The values for this analysis are always two fold; zero arrivals and a 2 times higher arrival rate than its maximum given the capacity. In the next paragraphs the results on both tests are being presented for each case.

Please find Appendix D.1 on page 170 for more details on the results of these tests. Here only the conclusions are presented per Archetype Macroscopic Flow Model.
8.2 Wide Dam Archetype Macroscopic Flow Model Evaluation

The first archetype discussed is the Wide Dam. First an introduction to this archetype is provided. Hereafter, the results on the tests on sensitivity of parameters and on extreme values are presented. At last the results on implemented solutions are provided.

8.2.1 Introduction to the Wide Dam Archetype

From the bottleneck analysis in step 1 of the framework it is derived that the Wide Dam is a problematic area when a high number of visitors arrive to go to Java Island (Sumatrakade). Two bottlenecks were indicated at the Wide Dam South to North and North to South direction. These cases do not require different structures, but by modelling both cases of the Wide Dam the selected Event Blocks can be analysed and performance can be measured for application evaluation of the framework.

The dam is over its length of 282 [m] varying in width. The narrowest point is 5.5 [m] wide for one direction, see Figure 21. The dam in non-symmetrical. These walking directions are separated by a tramway and two car lanes in between. During SAIL these lanes are dedicated for other traffic than pedestrians. The archetype Wide Dam is thus functioning for unidirectional flows. Therefore, only the walkable space per direction on the Wide Dam is taken into account in the sketch below. This sketch functions as schematisation for deriving the Archetype Macroscopic Flow Models of the Wide Dam.

There is a small separation in height between the cycle and pedestrian lanes which are both used as walkable space on the dam. This can influence the capacity of the stretch. However this is not taken into account in the model. Also there are hanging trees which can block some walking space on the dam which are not considered in the model. The reason for this is that the purpose is to test the models.

For the Wide Dam case South to North the expectation is that the bottleneck will occur at the long stroke of 110 [m] and 6 [m] wide. People are forced to walk into this area via a funnel going from 15

*Not to Scale

Figure 21 Walkable space of the Wide Dam Archetypes with dimensions and Indication of separation of blocks by horizontal arrows, width of the passage ways by vertical arrows, and direction in green arrow.
The second bottleneck will occur due to a narrow part of 5.5 [m] wide with a length of 55 [m]. However, because the first narrowing is already towards this width of 6 [m], the second narrowing to 5.5 [m], will not have a large effect on the flow. Furthermore, a small buffer space is provided just before and after the narrowing of 5.5 [m], giving people the opportunity to overtake or adjust speed. For these reasons only a small increase of the density is observed at the bridge.

For the Wide Dam case North to South the expectation is that the bridge of 5.5 [m] wide will become a bottleneck during high demands. However, what is observed is that in case an arrival rate is chosen above capacity (related to the infrastructural dimensions of the total stretch), the bottleneck is in fact the first stroke of 6 [m] wide so people will accumulate just before entering this stretch. This is seen in the model because an arrival stock is used as accumulation place before entering the first Event Block.

Because the parameters (and structure) are the same for both models of the Wide Dam, their sensitivity only has to be tested in one case, here the Wide Dam South to North is chosen for these tests.

As expected, the initial settings for nearly all parameters do influence the numerical output of the model simulations. References to scenarios in these sections can be found in Table 21 above.

### 8.2.2 Sensitivity of the Wide Dam Models to Uncertainty in Parameter Values

#### Sensitivity to Dimensions Bottleneck block 3 Wide Dam South to North

For the width sensitivity test with an arrival rate above maximum (6.5 [p/s]), the behaviour of the system changes from block 2 onwards if the width is decreased by 5% (comparing scenarios III and VII to the others). For scenarios III and VII a breakdown is shown in block 2, just before the bottleneck block 3. This breakdown results in a blockade of the total wide dam. For a constant width but an increase in walkable surface (comparing scenarios I and V), the model is only numerical sensitive, meaning similar behaviour is shown. Comparing V to I the total travel time is lower for V, because of a smaller length of block 3. This effect is also seen when comparing cases II and IV. However, because in case II the width is 0.3m wider, this effect is balanced. If the cases with increase in width are compared (II and VI) to each other, it can be shown that the total number of visitors in the system is higher for the case in which the length is larger and surface smaller. This is explained by the fact that the density in these scenarios will be higher, thus a lower speed is assigned and therefore more people are in the system. This means that the model is sensitive to the length and walkable surface, but especially to the surface because length is only needed in travel time calculations whereas the surface variable is used directly to calculate the flow.

With an arrival rate at its maximum, the numerical sensitivity is only shown for the so-called internal variable (risk development per block, densities per block, number of visitors walking over the dam), but not for the total throughput of the system. This makes sense, since in free flow conditions the travel time is similar, but very small differences may exist per stock given the changes in length, width and surface. For the risk development at blocks 2 and 3, the relative highest risk development is for cases III & VI & VII followed by cases IV & V & I and the lowest in case II. So the width is dominant here. However with an increased width but decreased surface the density in the block is relatively higher. For this reason next to the width, the surface is dominant. Varying the length is not dominant for the development of risks here, but only dominant for numerical sensitive to travel time calculations.

To conclude, as expected the model is sensitive to changes in the dimensions of the infrastructure, especially for the width of a passage way. For the length and surface only numerical sensitivity is observed in line with the calculations for the flow. Therefore, the model output is valid to the input on width, length and surface.
Sensitivity to Initial Demand Rates, Arrival Rates and Arrival Patterns

The model output shows numerical sensitivity to the initial settings for arrival rate or arrival pattern. The arrival pattern and capacity of the system should be in balance to prevent a breakdown. In this way, the model output is always sensitive to the arrival rates. The arrival pattern of g and h are compared and show in ratio same sensitivity. Furthermore, if arrival pattern g is increased by 40% a breakdown is observed, see the red line not increasing further from 20,000 [s] onwards in Figure 22. For arrival pattern h, with 6 peaks above the maximum arrival rate, no breakdown is observed. Furthermore, as can be seen from Figure 22, the total throughput is lower for arrival pattern h (dark blue) and for arrival patterns of g (various colours) than for the free flow arrival rate maximum of 6.27 [p/s] (the latter in light blue).

![Figure 22 Total Throughput All Arrival Patterns compared to free flow arrival rate 6.27](image)

The initial demand rate is used for calculating the maximum outflow of the arriving visitors. Therefore, the model shows as expected numerical sensitivity to changes in the initial demand rate. The initial demand rate is set to 1.03 [p/s] considering a density of 1 [p/m²] with corresponding speed of 1.03 [m/s], to initiate that this stretch is within the SAIL event area so that an average density is likely to occur. When changing this initial demand rate with densities {0.75, 1, 1.25, 1.5 [p/m²]} the model shows for both conditions (maximum arrival rate and above maximum) numerical sensitivity in throughput and all internal variables. This is likely, as the initial condition of the flow determines the extent to which the flows can still grow before a breakdown occurs.

Sensitivity to Calculation of Flows, Critical and Maximum Density

The flow variables are a function of the determined density and the speed as function of these densities. The function for assigning speeds by the calculated densities is changed by 5%, 10% and 15% in the evaluation test. The increase in lookup efficiency in free flow and congestion condition shows a very small sensitivity. Whereas if all deficiency scenarios are being compared, larger numerical sensitivity is observed in both arrival rates (maximum arrival rate and above maximum). Comparing the same deficiency rate for both arrival rates (arrival rate 6.27 [p/s] and arrival rate 6.28 [p/s]) the sensitivity is very small and behaviour is similar. As expected, all deficiency scenarios with arrival rate above the maximum show a breakdown occurring earlier than for the cases with maximum arrival rate. The more the deficiency the earlier this breakdown sets in.

The model shows no sensitivity to changes in the critical density in case of free flow arrival rates, but a small sensitivity in congestion regimes. This is as expected, since a lower critical density restricts the
transfer flow to the next block earlier in case of demand higher than capacity. This results in the breakdown being delayed. Therefore, the throughput is smaller for a critical density of 3 \text{ [p/m^{2}]}, compared to 2 \text{ [p/m^{2}]}, for an arrival rate above its maximum.

If the maximum density is restricted to 5 \text{ [p/m^{2}]}, it is logical that the total throughput is lower than for the same density of 5.25 or 5.4 \text{ [p/m^{2}]} in case of an arrival rate above its maximum. As expected, this sensitivity is not being observed when the maximum arrival rate is maintained.

\textbf{8.2.3 Extreme Value Sensitivity Results of Wide Dam Model}

The extreme value test is done with zero arrivals (output should be zero) and 2 times the maximum arrival rate, which is 12.54 \text{ [p/s]}. This is also the maximum arrival rate out of a central station exit of 9.5 \text{ [m]} wide with an initial speed of 1.31 \text{ [m/s]} and a density of 0.25 \text{ [p/m^{2}]}. This is a reasonable value to consider, though it is an extreme value compared to the maximum arrival rate of 6.27 \text{ [p/s]} for not letting a breakdown occur in the Wide Dam model. The throughput for 12.54 \text{ [p/s]} arrivals is far lower than for congestion at an arrival rate of 6.5 \text{ [p/s]}, because the breakdown already occurs at the first Event Block within 50 minutes. As expected, the throughput is lower for a higher arrival rate than its maximum. Also a breakdown occurs faster in this situation. Furthermore, no visitor arrives at the wide dam in case of an arrival rate of 0 \text{ [p/s]}.

To conclude, the model output response to the extreme values is in line with the expectations, therefore the model is robust to extreme changes in arrival rates.

\textbf{8.2.4 Results on Solutions Implemented at Wide Dam Model}

For the Wide Dam the most effective solutions are to control the inflow arrival rate (by creating groups, maintain critical density as maximum or by restricting the inflow arrival rate directly). The speed adaptation does not show a beneficial effect in this model nor in other models. The critical density control is very effective in all models. The group size solution needs further specification for each model.

The group creation allows to control the inflow, now the capacity is known. This means that the above maximum arrival rate of 6.5 \text{ [p/s]} can be maintained if groups are created consisting of a maximum of 31 \text{ [p]} every 5 \text{ [s]}. This allows the system to find a balance further downstream, in this way a breakdown is avoided. Variations in group size and waiting time are possible, however the systems output is very sensitive to these parameter settings. Other options discovered are in the same order as the one shown here, so 62 \text{ [p]} every 10 \text{ [s]} or even 186 \text{ [p]} every 30 \text{ [s]}. Although this last formation is rather unlikely to be logistically possible.

\textbf{8.3 Sumatrakade Mooring Archetype Macroscopic Flow Model Evaluation}

This section discusses the Sumatrakade Mooring Archetype Macroscopic Flow Model. Hereafter, the results on the tests on sensitivity of parameters and on extreme values are presented. At last the results on implemented solutions are provided.

\textbf{8.3.1 Introduction Sumatrakade Mooring Archetype}

The Sumatrakade is restricted in space by water (it is on the island), a school and the multidirectional crossing just before entrance ‘A’ to continue on the orange route. The Sumatrakade Mooring is used as queuing place for people waiting for a departure by boat to the green route, see Figure 23. The Sumatrakade Mooring is divided in subcases A and B because it was uncertain if some extra space at the quay can also be used as queuing space. Because space is a dominant factor in deriving a capacity analysis of the queuing case, two subcases have been defined. For modelling no different structures or specifications were necessary. Subcase A includes extra space indicated with red in Figure 23. Subcase B does not include the extra space of A.
The visitors are flowing in from either the far left side (entrance B) or from the bottom (entrance A) towards the quay (following the green arrows). This means people can choose to arrive at these two entry points (A and B) from an upstream decision point. This decision is also sketched above by the two dotted arrows. This separation is considered in the model also to show that separation and combining flows is an application taken into account. Spillback of the flows into this decision point is thus also modelled. As stated before, for every model an additional stock is added to cope with spillback of the congestion further upstream than the stretch modelled.

The underlying question is now when this queue is overflowing to the upstream blocks. To assess this, it is necessary to know the arrival rate of visitors (and distribution over time), the separation of flows over the two entrances, the boat capacity and departure frequency and the available queuing space at the quay. These parameters have been presented in chapter 6 and are here further explained.

Usually choice distributions follow from choice processes in which attractiveness of the route and characteristics of decision makers are included. Therefore, first is looked at the attractiveness of route A versus route B. Next to the fact that route B is the main walking route of SAIL and thus here activities can be visited whereas at route A no activities can be visited, the invisibility of the entrance of route A is high. To go to entrance on route A two narrow and long stairs are available on each side of the street towards entrance A. Because of the large difference in attractiveness of the routes the separation of flows over the two entrances follows probably the Pareto distribution, which dedicates 20% of the arrivals via entrance A and the other 80% via entrance B.

The boat departure is assumed for every 10 [min] with 2 boats in stock. Each has a capacity of 300 \([p/\text{boat}]\). A loading and mooring time of 5 [min] at each quay is assumed and a roundtrip sailing time of 10 [min] is assumed. The sailing and mooring times are derived from the public schedules of regular public transport ferries of the GVB in this area of Amsterdam.

In order to test if this model is validly modelled, the initial parameters are subject to the sensitivity test, presented in section 9.1. Conclusions derived from these tests are presented here.
8.3.2 Sensitivity of the Sumatrakade Mooring Model to Uncertainty in Parameter Values

As expected the model is numerical sensitive to the boat capacity and frequency, loading time, arrival rate and share of visitors choosing one of the two routes. The fluctuation in the transfer flow from the entrance blocks to the quay block due to the discrete departure function (i.e. the boat departure function) is seen in all scenarios. If the maximum arrival rate of the wide dam is considered, the extra space is needed as well as a boat capacity of 600 [p/boat] and a frequency of departure every 300 [s]. Fort these conditions an ‘overcritical risk’ is observed at the end of the first hour in the run. This means, that the Sumatrakade mooring is very likely to become a bottleneck because the boat capacity and frequency are unlikely to increase even more than the case presented. The arrival rate might be lower than is assumed here, but it is a matter of time before the breakdown occurs. Especially taken into consideration that the assumed arrival rate of 2 [p/s] is very low compared to the maximum arrival rate of 6.27 [p/s] at the upstream Event Block of archetype Wide Dam South to North.

8.3.3 Extreme Value Sensitivity Results of Sumatrakade Mooring Model

For subcases A and B the extreme values of zero arrivals and an arrival rate of for 12.54 [p/s] are simulated. In both cases the system output is numerical sensitive to the extreme arrival rates, which is in line with the expected output. For subcase B vs subcase A the breakdown of the system occurs earlier so the total number of people departing per boat is higher for subcase A as can be expected.

8.3.4 Results on Solutions Implemented at Sumatrakade Mooring Model

The Sumatrakade Mooring Archetype Macroscopic Flow Model is valid to use in the framework. For SAIL the solutions to restrict the inflow for the Wide Dam case will mainly influence the performance of Sumatrakade Mooring because the quay is located downstream of the Wide Dam. As could be observed the maximum arrival rate of the Sumatrakade is 2 [p/s] whereas for the Wide Dam the maximum arrival rate is 6.27 [p/s]. To increase the performance of the Sumatrakade without changing the dimensions, boat capacity nor the boat departure frequency, an upstream solution to decrease the inflow seems the only solution. The other solutions (grouping people or restricting the critical density) will be less effective for this case because of the queuing function of the Sumatrakade Mooring compared to the flowing purpose of the Wide Dam. The queuing will occur in congestion state. Consequently, restricting critical density as maximum or grouping people will not be a solution in the queuing areas because here a higher density is allowed.

8.4 Bi-Directional Archetype Macroscopic Flow Model Evaluation

The last archetype to discuss is the Bi-Directional case. First an introduction is given. Hereafter, the results on the tests on sensitivity of parameters and on extreme values are presented. At last the results on implemented solutions are provided.

8.4.1 Introduction Bi-Directional Archetype

For the Bi-Directional Archetype two subcases have been designed of which the sketches are presented in Figure 24. The flow comes in from both directions indicated by the green arrows. The width is indicated by the vertical dotted arrows and the length of each Event Block by the horizontal dotted arrows.

A distinction is made between a non-symmetrical case A and symmetrical case B. In both cases the walkable surface is kept the same for the Event Block on the right side in the sketches below, only in

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4 Overcritical risk is a function of the duration of a density above the critical density of 2 \([p/m^2]\)
case A and B the right hand side of the block differs in width of the exit/entrance. This is to test if cases A and B are indifferent because the walkable surface is kept the same. This one requirement of a valid macroscopic bidirectional flow model. This will be tested first.

![Diagram of Bi-Directional Archetypes Dimensions and separation of blocks by horizontal arrows and width of the blocks by vertical arrows, direction of flows indicated by green arrows.](image)

### 8.4.2 Behavioural Expectancy Tests of Bi-Directional Model

The first tests executed for this model evaluation are on the behaviour of the system. In macroscopic flow modelling, the walkable surface is the key parameter for determining the density in a stock. Therefore, the microscopic flow effect of a higher efficiency for a funnel versus a square, cannot be considered to have an effect on macroscopic flow modelling. As this is the difference between the cases A and B, only a small numerical difference between these cases may be expected because of a difference in length of the stock.

Furthermore, it is stated that bi-directional flows are less efficient than unidirectional flows in the same infrastructure for the same demand. Therefore, the second check is to evaluate if a unidirectional flow in this model is more efficient than a bidirectional situation. To check this, comparison is done between the first case, with maximum arrival rates from the two directions, and the second case, with a unidirectional flow for a higher arrival rate than this maximum arrival rate.

The last behavioural effect is that a very high arrival rate from one direction should dominate the other direction. Therefore, the third behavioural validation test is upon determining if no direction is dominating in equal flows, or if this dominance is shown when unequal arrivals are the case.

**Results on the Behavioural Expectancy Tests of the Bi-Directional Archetype Macroscopic Flow Model**

On the first test, the model shows valid behaviour. Indeed no behavioural or efficiency differences between subcase A and B are being observed. However, there is a very small difference between subcases A and B when comparing them for an arrival rate above maximum (1.59 \([p/s]\)). For this arrival rate subcase B has a slightly higher throughput than subcase A. Comparing the maximum arrival rates for subcases A and B (1.57 \([p/s]\)), this difference is also found but less significant. This difference is due to the fact that the travel time for the right Event Block of this archetype is longer in case A than...
in B. This means that the travel time for equal density is larger in case A than in B. This determines the throughput slightly.

As expected, a unidirectional flow through these Event Blocks results in a higher throughput than a bidirectional flow. Furthermore, for both subcases A and B the maximum arrival rate is 1.57 [p/s], showing that the capacity of these systems is similar. To conclude, the behaviour of the model is valid to use in application and the sensitivity and extreme value tests are pursued with case B only.

8.4.3 Sensitivity of the Bi-Directional Models to Uncertainty in Parameter Values

The conclusions on the sensitivity tests are presented here. First the deficiency, arrival rate and critical and maximum density tests are discussed. Following an elaboration on the infrastructural sensitivity is provided.

What is expected is also observed namely that the capacity of the stretch becomes less if the flow efficiency is lower for the same density. Although in deficiency scenarios a breakdown occurs, a higher throughput for a lower deficiency is seen. However, for both arrival rates the difference between 0% deficiency and -2.5% efficiency is remarkable large compared to the difference in -2.5% efficiency and -5%, -10% and -15% efficiency. This may be due to the fact that the initial desired speed in free flow stage is also changed in accordance with the change of the flow efficiency in the fundamental diagram. Therefore, the total throughput for an arrival rate of 1.59 [p/s] (above maximum) cannot be as high for 2.5% deficiency as is for 0% deficiency as the maximum speed is also 2.5% higher in the latter case. To conclude, the model outcomes are very sensitive to the fundamental diagram and the deficiency values chosen for bidirectional flows.

When changing the arrival rates by 5% or 10% a maximum sensitivity of 1% compared to the change in arrival rates is observed. The estimation procedure is therefore reliable for handling changes in arrival rates. An extreme case would be that the arrival rate is as constant as considered here. Therefore, two distributions are being applied to observe the systems behaviour for arrival distribution with peaks above this maximum arrival rate. It can be concluded that the model outcomes are proportionally sensitive to the arrival distributions. The extent to which the sensitivity is changing the model outcomes is small given a small difference in arrival pattern.

The critical density is the parameter for indicating the under and overcritical risk. Logically, by changing the value for the critical density a proportional change in risk development is being observed for both under and overcritical risk. Next to this, the maximum density is subject to discussion among scientist. For this reason, it can be assumed that the maximum density for the bidirectional fundamental diagram will be lower than for the unidirectional fundamental diagrams. A change in this fundamental diagram does result in a change in the risk development over time for an arrival rate of 1.59 [p/s] or higher. It can be observed that with this arrival rate for the maximum density kept at 5 [p/m²] the bottleneck in stock 2 is reached earlier than for the higher maximum density cases (5.25 [p/m²] and 5.4 [p/m²]). The sensitivity to the maximum density is as expected.

On top of the fundamental diagram parameters, also the bottleneck width adaptations have a large effect on the total performance in throughput and risk development of the system and the blocks. A breakdown occurs for a narrowing of the bottleneck from 6 [m] to 5.3 [m] (including narrowing the walkable surface) at the same arrival rate of 1.57 [p/s]. An increase in bottleneck width by 5% (and increase in walkable surface) was expected to result in a higher throughput. However, a higher throughput is only observed for the first 30 [min], afterwards the same throughput is encountered as for the normal bottleneck width of 6 [m]. An explanation might be that the density in the bottleneck returns to a stable value for this arrival rate because of the dynamics in determining the flows per direction. The stabilizing process is faster for the case of a higher width (6.3 [m]). The risk in this block
is lowest for the higher walkable surface and higher width passage. Therefore, increasing the bottleneck width is considered part of a solution to increase the throughput and mitigate risks.

### 8.4.4 Extreme Value Sensitivity Results of Bi-Directional Model

The arrival rate is doubled for both directions and for the direction Left to Right with zero arrivals at Right to Left and with a maximum arrival rate of 1.57 [p/s]. As expected, in all cases a breakdown occurs. This breakdown occurs the fastest in case both directions have an extreme arrival rate of 3.14 [p/s] and slowest for the unidirectional case with this extreme arrival rate.

### 8.4.5 Results on Solutions Implemented in Bi-Directional Model

Because this model is not considered part of SAIL 2015, the solutions to mitigate risk in this model are not part of the solution evaluation. However, the main solution would be to avoid bidirectional streams. The next solution would be to restrict the inflow till the maximum arrival rate and/or control the flow by maintaining the critical density as maximum density. The third solution is to increase the width of the bottleneck, however this does not mean that the throughput might be higher, but only that risk is being reduced.

### 8.5 Discussion of the Macroscopic Flow Models

In these macroscopic flow models all people walk continuously and are considered a mass, which might create too optimistic estimations of the capacity of a stretch. Therefore, these absolute numbers for the archetypes of SAIL may not be encountered for as maximum capacities by the authorities directly, only as indication. This can be solved as stated in the previous chapter by adapting the inflow rate by arrival patterns.

The attempt is made to use the lowest number of variables, stocks and parameters that will assure the necessary systems behaviour. To illustrate the model structure clearly despite of the amount of variables (and also arrows) necessary, colours and shape indicate different types of variables. The explanatory power of the model is large as the performance criteria are incorporated and the model therefore these Archetype (Measure) Macroscopic Flow Models functions also as dashboard.

The model is replicable in its specification, provided that one has some basic knowledge in mathematics and has Vensim software 6.3. The models are relatively easy to adapt for new infrastructures and arrival rates or distributions by only changing the parameters. To replicate the variables specifically the interested reader can find an indication of the most important variables specified in Appendix C.3 on page 163. If necessary, the author will provide the models upon request.
**Part E Conclusions**

This part provides the conclusions on the research. In the last chapter 9 the research questions are answered, recommendations are provided, future research issues are addressed and the research is reflected upon.

**9. Concluding Remarks**

This chapter concludes on the achievement of the research goal in subsection 10.1 and answers the research and modelling questions in subsection 10.2. The next subsection 10.3 recommends on risk mitigation for mass events. In subsection 10.4 the issues are addressed for future research and in the last subsection 10.5 the reflection is provided on the research accomplished.

**9.1 Conclusions on the Accomplishments Regarding Research Goal**

The purpose of this research is to propose a crowd management framework for mitigating risks of crowd disasters at mass events in the public urban space, by studying cases of SAIL 2015. The main aim of the framework is to let crowd management authorities acknowledge crowd disaster development, let them be able to assess risks of crowd disasters and provide them with advice on effective measures for risk mitigation.

The functional requirements are all met in the proposed framework. The knowledge on crowd disaster development is provided with the Layered Crowd Disaster Model, the Scenario Measure Charts and the design of macroscopic flow models. The preventive measures are provided in the Scenario Measure Charts and Archetype Measure Macroscopic Flow Models. Risk of crowd disaster estimation is provided in all Macroscopic Flow Models. Advice on measures is provided by the Scenario Measure Charts and the Layered Crowd Disaster Model, in the macroscopic flow models and by an evaluation tool. The advice provided in this evaluation tool incorporates stakeholders’ tolerance towards risks. For the complex task on deciding on risk tolerance, this tool is believed highly beneficial to effective multidisciplinary decision-making.

In conclusion, the output of the framework is suitable for tactical decision-making upon risk mitigation for mass events. Options to overcome different crowd disaster development issues are provided as well as specific advice. As illustrated by the application of the framework to the archetypes of mass events, the output of the framework is suitable for deciding upon risk mitigation strategies for mass events in the public urban space. The goal of this research, proposing a risk mitigation framework for tactical crowd management at mass events in the public urban space, has been achieved.

**9.2 Answers to Research Questions**

From the goal of the framework 12 research questions could be deduced which are answered here.  
*What is required of the framework (1) & How to design the required framework (2)?*

From the frameworks’ objective and interviews with potential clients the functional framework requirements have been derived which are to provide information on crowd disaster development, provide advice on measures to mitigate risk of crowd disasters, and provide an estimation tool for calculating the risks.

To fulfil the goals and all that is required in the framework, the research approach was to study literature and simultaneously conceptualise the system of crowd disasters. This resulted in a preliminary conceptual design of the framework. Hereafter, the macroscopic flow models could be
specified. The preliminary design could be improved by the application of archetypes of mass events derived from SAIL 2015. By applying archetypes of mass events to the framework, the design could be iteratively improved. This also provided insight in the effectiveness of some measures for mitigating risks of crowd disasters related to the two cases of SAIL 2015 and in general. The latter phase in the research approach was to implement the risk mitigation measures in the Archetype Macroscopic Flow Models and to draw conclusions and state recommendations.

By bundling conceptual models and quantitative models the core of the framework could be established by satisfying all requirements. However, support was needed to apply this core to different mass event cases. Guides are designed to support the steps the client needs to take from the acknowledgement of crowd disaster risks towards obtaining GAP (general) or SAP (specific) advice on mitigating risk of crowd disasters. This resulted in the 6 steps of the framework which are:

1] Check Applicability of the Framework to clients cases (SAP & GAP)
2] Select Event Blocks for Application (SAP & GAP)
3] Gather Data on Selected Event Blocks (SAP)
4] Adapt Macroscopic Flow Models to match Event Blocks (SAP)
5] Select Measures for Risk Mitigation (SAP & GAP) & Finish GAP
6] Implement Selection of Measures in Event Blocks Macroscopic Flow Models (SAP) & Finish SAP

For each step questions, guides and checklists are provided to accompany the use of the framework effectively.

*Which factors dominate the development of crowd disasters (3)?*

The phenomena (factors) dominating the development of crowd disasters have been derived by literature studies. Their interrelationships are analysed which led to a new conceptual model for crowd disaster development called the Layered Crowd Disaster Model presented in Figure 25 below.
What is a suitable definition for risk of crowd disasters (4)?

Risk is determined by the total expected loss which is the sum of the consequences times the probability of frequencies (Stamatelatos, 2000). In this case consequences of mass events are the number of people injured and number of fatalities. The probability of frequencies is defined by the likelihood of these occurrences per unit of time. In this research only the physical level of risk development by means of the density of a crowd is considered by risks. As such risk of crowd disaster is defined by the likelihood on injuries and deaths as function of the density of a crowd over time.

Risk of crowd disasters in this research is determined by 2 elements. The first element is risk defined by the duration of the density. Here risk is calculated by the integral of the density over time. The second element is to define risk stages by the level of density corresponding to derived flow regimes in the fundamental diagram of Weidmann (1993). There are 5 levels stages of risk from low to certain risk of crowd disaster. Together, these two elements define the risk development of a crowd disaster.

Which measures mitigate risk of crowd disasters (5)?

To mitigate risk, the phenomena causing a crowd disaster should be prevented or consequences should be diminished. There are over 20 measures indicated to mitigate specific hazardous events. In the Scenario Measure Charts in Chapter 4. The measures influence on-road behaviour of pedestrians on route and activity choices. They aim to prevent blockades, gridlocks and crowd turbulence and increase throughput, i.e. regulation of the inflow by grouping people, distribute the crowd over the event areas matching capacity and demand, maintain a tolerated level of density in an event area, provide information for distribution over the available routes, guide on-route routing according to actual density, separate bi- or multidirectional streams, allow for standstill areas or buffer areas, provide sight on landmarks for routing, provide information on routing before intersections, and maintain the inflow under its maximum.

What is required of the macroscopic flow model (6) & How to model it (7)?

The macroscopic flow model functions as a quantitative tool to (1) calculate flows and densities over time to (2) assess the risk development over time and (3) to test solutions on crowd management. The following requirements for the modelling in System Dynamics have been derived from this function statement:

- Calculation of accumulation of people per area over time
- Calculation of values on performance criteria
- Application for unidirectional and bidirectional flows and queuing areas
- Applicable for both discrete and continuous arrival and departure patterns
- Allowance for simulation of scenarios
- Adaptable to new cases

For estimating risk of crowd disasters a macroscopic flow model was needed. To model this the following modelling questions have been deduced.

1. How to model the flow and density developments validly in System Dynamics?
2. How to model a queuing system in System Dynamics validly?
3. How to model bidirectional flows in System Dynamics validly?
4. To what extent can a crowd disaster phenomena be modelled in Vensim?
5. Which solutions to risk mitigation of crowd disasters are applicable for modelling?

These models have been designed in System Dynamics. In System Dynamics software Vensim a simulation environment could be designed for calculation of accumulation of people per Event Block over time. The specification of these models have been derived from methods of Traffic Flow Theory and System Dynamics. The Traffic Flow Theory could be applied to system dynamics macroscopic flow.
models validly to the extent for which the fundamental diagram of pedestrians could be derived. One stock-flow structure is necessary per direction of flow. The macroscopic flow models are all proved valid to use for risk estimation of crowd disasters. For the answers to the last two questions see research question 9 below.

Which factors are relevant in determining the flow of people (8) & To what extent can these factors in determining flow and development of crowd disasters be incorporated in the macroscopic flow models (9)?

To determine the flow of people the basic function is used to calculate the flow by multiplying the density with the speed. On top of that, the width of the entrance or exit should be taken into account. There are at least 40 factors found in literature which influence the desired walking speed. Influencing factors relate to infrastructure, demography, weather and directions of flow. The quantifiable factors have been incorporated in the macroscopic flow models, the non-quantifiable factors have been incorporated in the Scenario Measure Charts in chapter 4 for the GAP framework.

The phenomena leading to a crowd disaster could not all be modelled specifically due to a lack of data. However, the most important phenomena could be modelled which are the occurrence of congestion, delays, bottlenecks, gridlocks and spillback. Therefore, the solutions related to these phenomena could be incorporated in the models.

To what extent can the measures to mitigate risk be incorporated in the model (10)?

The quantifiable mitigation measures could be implemented in the Archetype Measure Macroscopic Flow Models (AM-MFM). To the AM-MFM of the Wide Dam all quantifiable measures could be implemented. For the Sumatrakade Mooring AM-MFM the main solution is to maintain the inflow under its maximum and maintain a tolerated level of density by finding a balance in supply and demand. Therefore, less measures could be incorporated in this model as well as for the latter archetype. For the Bi-Directional model the main solution would be the same as for the queuing model, however with the annotation that a bidirectional flow is in itself a bottleneck, thus preventing these would be more effective.

Which performance criteria should be chosen for the framework outcomes of the macroscopic flow model (11)?

The performance criteria presented in this research have been derived from the framework need interviews, from the study on crowd dynamics and disaster development and from general management perspectives. They include the Level of Service, total travel time, throughput, risk development and breakdown occurrence.

What is the effect of risk mitigation measures on the performance criteria for the archetypes of the SAIL 2015 case (12)?

The performance criteria in this research relate to the throughput, risk development, occurrence of a breakdown and travel times. In Table 22 the solution scenarios are presented. The scenarios showed here relate to measures for the solutions to mitigate risks. Because of overlap between the effects of the measures assigned to a single phenomenon, more than one solution could be achieved in a single scenario by a single measure or a few measures. These scenarios below have been derived from the flow chart called Scenario Measure Chart and are translated for implementation into the AM-MFM.
Table 22 Overview of Solution Scenarios and implementation in the Archetype Measures Macroscopic Flow Models

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No Pushing, No Craze &amp; No Stampede, No Bottleneck &amp; No Gridlock</td>
</tr>
<tr>
<td>2</td>
<td>No Crowd Turbulence, No Interest/Attraction Peak</td>
</tr>
<tr>
<td>3</td>
<td>No Craze &amp; No Stampede, Increase Throughput, No Bottleneck</td>
</tr>
<tr>
<td>4</td>
<td>Efficient Choice Behaviour, Even Distribution over Area, No Interest/Attraction Peak, No Gridlock</td>
</tr>
<tr>
<td>5</td>
<td>No Interest/Attraction Peak, No Pushing, No Craze &amp; No Stampede, No Bottleneck &amp; No Gridlock, Increase Throughput</td>
</tr>
<tr>
<td>6</td>
<td>Increase Throughput, No Bottleneck</td>
</tr>
</tbody>
</table>

Scenario 3 and Scenario 4 score the highest on the performance criteria, but only when the inflow rate is kept at its maximum. Scenarios 1 and Scenario 6 work second best when the arrival rate is kept at its maximum, but the best in case of a higher than maximum arrival rate. Scenarios 2 and 5 work third best in both cases of arrival rates.

In general, the most beneficial solutions are those which maintain the arrival rate while tolerating the critical density as maximum. The throughput is always higher for those cases where the maximum density is never reached. This also diminishes the probability of a breakdown. This can be achieved by either controlling the inflow using discrete units to not allow a peak in arrivals or control the inflow as such that any densities higher than the critical (tolerated) density is prevented and/or controlling the inflow to remain below the maximum arrival rate.

To conclude, the advice based on these results for the Wide Dam archetype is to control the inflow to remain under the critical maximum arrival rate. This can be done by distributing the highest demands to the highest supplies or by influencing decisions on route choice and activity choices. If these measures are not possible to maintain, the risk on crowd disasters could be mitigated either by maintaining the critical density as maximum density or by controlling the inflow by creating groups of people in upstream locations of the bottleneck. The latter solution, might be counterproductive because of the chance for spillback of congestion in the network. Therefore, creating groups of people to discretise the inflow is only possible when infrastructure (buffer space) is available at the entrance of the Event Block and when the Event Block is of a short length (approximately < 300 [m]). Due to the fact that accumulation cannot be controlled by this measure, the effect of the measure will diminish if length increases because the groups are not separated anymore, unless groups are maintained by walking with them to keep them separated. The size of the groups depend on the archetype and especially on the width of the bottleneck(s). This means that for the Wide Dam archetype an arrival rate exceeding its maximum can be maintained if groups are created consisting of a maximum of 31 [p] every 5 [s] or 62 [p] every 10 [s] or even 186 [p] every 30 [s]. Although this last formation is rather unlikely to be logistically possible.

For the Sumatrakade Mooring and Bi-Directional archetypes the solutions for scenarios 1 to 4 work best if unidirectional flows are being maintained. For the Sumatrakade Mooring, solutions implemented should match with the throughput from the upstream located Wide Dam Archetype and the available boat capacity and queuing space available at the Sumatrakade during SAIL 2015. For the Bi-Directional archetype the inflow should be controlled to maintain under its maximum.

9.3 Recommendations for Mass Event Organisations

It is recommended for mass event organisations and other potential clients for risk mitigations strategy to do such risk assessment of crowd disaster prior to the moment the event takes place for improving preventive crowd disaster management. This will support decision-making on complex subject of risk of crowd disasters and provides more insight in crowd disaster development.
A main solution for improving the flow is to avoid bidirectional streams. If this is not possible, the next option would be to restrict the inflow till the maximum arrival rate and/or control the flow by maintaining the critical density as maximum density. The third solution is to increase the width of the bottleneck, however this does not necessarily result in a higher throughput, but only that risk is being reduced for the same inflow of visitors. Increasing the queuing space or bottleneck space is seen as a temporarily measure when not maintaining the inflow below its maximum rate. Maintaining the critical density as maximum density is not as beneficial in a queueing system as in a free flowing system for the reason that the function of waiting allows for a higher densities.

**Recommendations for SAIL**

Next to the solutions provided in the results of the application of the framework, additional recommendations can be done for SAIL. The first is to only allow the maximum arrival rate to continue to the green route (and thus taking the boats) via the biggest entrance only (there are two entrances). The flow continuing the orange route at SAIL should be allowed to pass the entrances to the queuing at Sumatrakade Mooring to avoid the occurrence of multidirectional flows and also be allowed to take the short cut.

To model every part of the event is outside the time scope of this research, but would possibly be very interesting for SAIL. Next to the two archetypes addressed in this framework, it is likely that more bottlenecks need attention for risk development of crowd disasters.

### 9.4 Issues Addressed for Further Research

The evaluation of the framework would beneficially by enlarged with face evaluation of clients. As stated in chapter 5, the qualitative criteria for performance of the framework need to be assessed by the clients to further improve the framework. These criteria should be provided in an evaluation request to the client after application of the framework for either GAP or SAP purposes.

**Risk Mitigation**

The mitigation scenarios provide tactical measures. However, as is shown in the first chapter of this research, the tactical level of management is the link between operational and strategic management. Therefore, future research should be done to determine measures for these other levels of planning. It would be very interesting to analyse the possibilities for risk mitigation on strategic level as this is the dominating level in the hierarchy. A strategic measure to analyse would be a decentralised departure (mode and time) and arrival location choice system for a public mass event.

The phenomena which could lead to a crowd disaster are part of a causality chain which is hard to discover. A first attempt for deriving this has been achieved by conducting scenarios for which measures could be assigned to mitigate those phenomena leading to a crowd disaster. The extent to which crowd disaster phenomena can be modelled in a macroscopic flow model is limited. This is mainly because the greater share of these phenomena are not quantifiable. More research is needed to quantify the measures. Also these phenomena should be tested for correlation among them. In this research a qualitative attempt is made to define the causal relationships between those parameters. This resulted in hypotheses for future quantitative research by further specifying the factors.

In the research by Lee et al. (2006) is stated that with controlling the parameter for free flow walking speed the safety of pedestrians could be guaranteed. However, in practice this parameter is not being controlled because peoples’ walking speed cannot be controlled in such detail. Therefore, the design of the complexity of the infrastructure is to be used to control pedestrian free flow speed and their walking speed. However, with the simulation results of the archetypes in this research the implementation of speed regulation for pedestrians seemed less effective than the other solutions on the performance criteria for crowd management. Therefore, more research is needed on controlling walking speeds in relation to other crowd management measures.
Furthermore, future studies upon the innovations for measures is necessary to design and implement state-of-the-art risk mitigation measures for crowd management. In addition, it would be nice to expand the model with GIS & GPS data to make the simulation less abstract and even real-time. In this way potential risk could be assessed real-time. This should be incorporated in addition to the current framework by including operational crowd management measures as well.

To improve planning of evacuation procedures, the categorization of the police for people in a crowd disaster is interesting for further research to determine if the share in the types of escaping behaviour (freezing, flying and helping) is also found by experimental studies. On top of that, more research needs to be done in order to define panic in relation to the flow efficiency during the impact phase.

For as far as the researcher is aware, no crowd control measures are part of simulation yet. Authorities do rely on these categories of measures. Therefore, they might benefit from insight by simulation with incorporating also crowd control measures.

**Modelling & Fundamental Diagram**

During the literature review the first finding for future research is the fundamental diagram for pedestrians. The phase transitions in all flow direction categories are the key to the first step in the development of crowd disasters. Today, it is still not clear where exactly these transitions occur in the fundamental diagram of pedestrian traffic. The conditions under which the flow state transitions occur will be the focus of future research (Hoogendoorn, et al., 2014). The phenomena related to these phase transitions could be derived qualitatively in the Layered Crowd Disaster Model. More empirical data is needed to derive quantitative descriptions of the phase transitions related to the existence of these phenomena.

Even for modelling unidirectional flows, literature does not provide a solid answer yet for which situations and environments which distributions for flow and densities can be applied. For bidirectional and multidirectional flows even more research is needed upon defining such fundamental relationship. Furthermore, for bidirectional flows the instable regime and turbulent regime will start earlier compared to unidirectional stream for the same track. In this case the critical density and maximum density would be less than for unidirectional flows, however here no literature is provided yet to underlie this assumption. Therefore, more research is needed to test this hypothesis.

Next to this, the separation for each density regime for definition of risks should be focus of future research to determine the regimes more precisely with empirical data. This would help to improve the model robustness.

There are at least 40 other factors assumed to influence the fundamental diagram but are in this stage of science only qualitatively known. Future research is needed before these factors can be incorporated in the framework quantitatively. These factors related to infrastructure, demography, weather and direction of flows before quantification of these factors.

System Dynamics is applied in this research. For future research into microscopic or mesoscopic modelling, it would be interesting to define the behaviour of the flow within a stock variable. In this way a more accurate prediction of density accumulation within an Event Block could be done.

**9.5 Reflection on the Design Process**

The process for designing the framework has started in December 2014 and ended in May 2015. The first finding was that there is no methodology on designing a framework and secondly, that literature of mass event and data on crowd disasters was lacking. This emphasizes the need for the framework even more. By combining system engineering with Traffic Flow Theory I tried to close this gap between knowledge in science and practice. I have applied over 15 different methods from both science fields to come to the presented framework. This process helped to shape a methodology for designing a framework, which might be broader applicable to design other frameworks. Since this methodology
is presented for crowd management purposes, a wider application of the framework or another application, (more) different design disciplines would be needed in the literature study phase. The research outcomes function as a confirmation that with the current methodology, such a complex system could be structured in a framework design.

No cost-benefit analyses of measures are conducted. A reason for this is that during the interviews with potential customers of the framework, when asked the budget was never mentioned a constraint. In The Netherlands, safety is top priority for which apparently no strict budget limits exists. However, the budget is not unlimited but assigned effectively as only those management tools are implemented which are trusted to be reliable. Therefore the measures discussed in this research are implementable of which technological risks are low. A future study upon the innovations for measures is necessary on designing and implementing state of the art measures.

The media in general is often named as a contributor to the crowd chaos. However, the media is not seen as part of the preventive management process and therefore left out of this research. Information on the other hand is something provided by media and this is taken into account in the measures of prevention.

**Reflection on Framework Applicability**

The framework is especially useful whenever risk identification is needed in addition to or for any capacity analysis of an infrastructure for bidirectional and unidirectional flows. This does not have to be an event, it can also be a shopping street for example during a peak moment in December. The measures advised for crowd management are more applicable when a mass stream of people is expected, but this does not have to be during an organised mass event. The framework can be used for assessing risks in any walking area which is functioning as flowing or queuing area for either unidirectional or bidirectional streams.

Furthermore, with this framework the science of crowd dynamics is made available for a wider public who do not have to be familiar with it, but can now apply it for risk mitigation. With the framework, improving mobility in the public urban space is made easier and better available for non-engineers because of the simulation environment provided in the quantitative part of the framework. On top of that, in the qualitative part of this framework the mass event organiser can improve its mitigation strategy without data available in a limited amount of time.
Bibliography


Kloostyteama, M., 2014. *Crisis Control in Amsterdam City Centre; Head Police Department Crisis & Control* [Interview] (20 11 2014).


Lee, R. S. C. & Hughes, R. L., 2006a. *Minimisation of the risk of trampling in a crowd, Melbourne, Australia: IMACS; Elsevier B. V.*


Temme, B., 2014. *Crisis Control in Public Space of Amsterdam Safety Region* [Interview] (9 12 2014).


Appendix A

A.1 What are the levels of planning?

Planning levels in chronological order towards the moment the event takes places are: operational, tactical and strategic. The boundaries between those levels are a bit vague and depend on the subject of planning. However, a distinction is made by reviewing various sources of literature. The following categorization can be made, see Table 23. The focus in this research is on the tactical planning level.

Table 23 Distinction between operational, tactical and strategic planning (McNair & Vangermeersch, 1998) & (Griffin, 2012) (DuBrin, 2012)

<table>
<thead>
<tr>
<th>Subject &amp; Source</th>
<th>Operational</th>
<th>Tactical</th>
<th>Strategic</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUSINESS (DUBRIN, 2012)</td>
<td>Day-to-day operations and specific procedures required at lower organisational levels</td>
<td>Provide details of how the company or business unit will compete within its chosen business area</td>
<td>Establish master plans that shape destiny of the firm</td>
</tr>
<tr>
<td>PLANS (GRiffin, 2012)</td>
<td>Carrying out tactical plans to achieve operational goals</td>
<td>Implement parts of strategic plans to achieve tactical goals</td>
<td>Resource allocation, priorities and action steps necessary to reach strategic goals</td>
</tr>
<tr>
<td>TASKS (GRiffin, 2012)</td>
<td>Small set of activities narrow in scope</td>
<td>Answers the questions on how to implement the decided paths in the strategic plan</td>
<td></td>
</tr>
<tr>
<td>TIME FRAME (MCNAIR &amp; VANGERMEERSCH, 1998)</td>
<td>Short term</td>
<td>Intermediate term</td>
<td>Long term</td>
</tr>
<tr>
<td>RANGE OF DECISION FREEDOM (MCNAIR &amp; VANGERMEERSCH, 1998)</td>
<td>Highly constrained</td>
<td>Moderate constrained</td>
<td>Minimal constrained</td>
</tr>
<tr>
<td>MANAGEMENT LEVEL INVOLVED (MCNAIR &amp; VANGERMEERSCH, 1998)</td>
<td>Low and Middle Management</td>
<td>Upper and Middle Management</td>
<td>Top Management &amp; Board of Directors</td>
</tr>
<tr>
<td>PEDESTRIAN BEHAVIOUR LEVELS (HOOGENDOORN &amp; BOVY, 2003A)</td>
<td>Walking behaviours</td>
<td>Activity scheduling, activity area choice and route-choice to reach activity areas</td>
<td>Departure time choice and activity pattern choice</td>
</tr>
</tbody>
</table>

A.2 A detailed analysis of current crowd management practice in Amsterdam

For obtaining a license for producing a mass events, both a safety plan and mobility plan are being conducted. It is the impression given from these interviews that this safety plan is not sufficient to function also as framework for planning mass events. However, the attributes in this plan could help to set up the initial context of the framework (event description). Within these plans scenario based risk assessments are being carried out in which the detail stops at the hazard identification of ‘crowded’. The impression is given that because there is a lack of knowledge on overcrowding, flowing
pedestrians and distribution over networks, there is not more to say on the risks related to it within these safety plans. What is strongly incorporated in the risk assessments is the security of people related to cultural and social developments and the expected hazards related to these encounters of social groups.

**Actors Involved in Amsterdam**

For obtaining a license for a mass event in the Safety Region of Amsterdam, the application should be done prior to the event and no later than 3 months prior to the event. Most mass event organisers need help from the DIVV (Dienst Infrastructuur Verkeer en Vervoer or in English Service for Infrastructure, Traffic and Transportation) to calculate flows and keep the city accessible by dealing with mobility issues. It is said that most mass events start around 11 months (annual mass events) or 1.5 years (non-yearly mass events) with planning their events, but this is a rough assumption rather than a rule. The government is involved via this license application procedure in which several plans about safety of the visitor, the population and the environment together with a mobility plan need to be conducted. If the police department finds the plans insufficient for safety and DIVV for mobility than the plans need to be revised in order to obtain the licence. This procedure is a play of the stakeholders involved where there is always a trade-off between tolerance of risks and the budget to mitigate risks. Different parties all have responsibilities in executing these plans, but the City Council or Mayor is end-responsible in all cases. This also means that the mayor has the veto in the end to let the event continue or not. However, the mayor is also fully aware on the benefits of such mass event for the Public Relations of his city/region. This places the mayor often for a dilemma and this is why the police department only advises and not decides on toleration of risks concerning public safety and security and the mayor the full responsibility takes. The following chart pictures the stakeholders involved in this planning process.

![Pentagram Stakeholders of a Safety Region in The Netherlands](image)

In Figure 26 the hierarchical diagram of stakeholders is presented. For each safety region the Mayor is end-responsible for the public security and safety. This responsibility is organised in the so called pentagram in which five main stakeholders participate to work together in case of mass events or public crises. These are the fire department, the (GHOR) Health Service Department of the Region, the Crisis Control Department of the government (CCB) with belonging the Department for Traffic and Infrastructure (DIVV), the Police Department (SGBO) with related the departments of public safety during mass events (Crowd Management) and the riot police for crowd control and the latter stakeholder is the operator concerning Terrorism in The Netherlands (NCTV). The NCTV is only
involved in the pentagram if the issue is of terrorism is applicable. The DIVV is placed outside the pentagram because its role concerns only monitoring of traffic flows during a mass event or incident and their main responsibilities lie in planning the mobility in advance. The same counts for the crowd management and crowd control departments which perform during the event but have also a large share in planning the event.

The seriousness of the situation determines the level of GRIP. Grip is a coordinating system which implies certain actions for the police department and the Crisis Control Department related to a certain level of regional impact of the situation.

A.3 Summary of Interviews with Key Stakeholders

It became clear after some interviews with key players in the mass event organisation in Amsterdam, that no standard procedure on crowd management is available yet. Crowd management is executed based on logical thinking. Within this process the DIVV (Dienst Infrastructuur Verkeer en Vervoer or in English: Service for Infrastructure, Traffic and Transportation), event producer, security operators (private and public) and the police and fire department are involved. The following findings were provided through these interviews, which can be found in the next appendix A.3.

It was commonly accepted that the amount of people present at a mass event is no indicator for the risk of crowd disasters. The risk of crowd disasters differs for each situation and in this way it was argued that no distinction could be made between a crowd disasters due to overcrowding versus crowd disasters due to panic or due to a (local) threat in security.

There is currently no monitoring system available which provides quantities on the number of people at a certain area. The idea that these numbers of people would make the crowd management task at least easier is not shared by the most of them, because, that is the reasoning, a hazard could also come from something else than overcrowding. However, in the ideal case that such monitoring system existed, then they would probably make use of it. They argued that often the information is lacking on origin-destination information of people and the distribution which follows over the network. If they knew this distribution then they could take actions properly.

Aforementioned findings are conflicting for obtaining consensus on the framework. Within this framework, the densities are an indicator for the risk of crowd disasters. Furthermore, it is argued within this concept that by prevention risk could be mitigated. On top of that, the identified risks could be mitigated preventively by crowd management rather than by crowd control (repressive action).

Another worrying finding was that the seriousness of the situation in crowding is often neglected or even defended with the opinion that the organisational party was being prepared on the most extreme cases. Meaning that with crowd control reliance every crowd disaster could be dealt with. Questions on what makes crowd management a success or a failure resulted most of the times in the following: success is determined by the absent need for control and the failure cannot be determined. If then the question was related to worst cases experiences, a lot of failures in crowd management were addressed. This gives the impression that crowd management is an immune department and because crowd control is often necessary when crowd management has failed, all the blame or approval goes to the crowd control responsible. Which in their case are also immune because every action taken is better than no action taken. They cannot be possibly blamed for the threat disrupting public order. The impression is given that crowd management is more seen as a predictive study on whether or not some crowding will occur, and by lack of ability to perform these studies, is seen as something one cannot possibly ever know. Because of this perceived unknowable state of crowd management, the system organised around it is only based on experience. This results in a crowd management practice of which its parameters are not defined and not measured and therefore not improved on quantified criteria, but improved only by evaluation and experience sharing of the
participants within the workforces of safety and security. However, experience comes only from cases where situations went (badly) wrong and thus where repressive actions were necessary.

Within these workforces a strong hierarchical organisation is developed in which there is the impression that more experience counts for a higher position in the workforce and therefore operating in a higher appearance. Because these experiences come from crowd control, the reliance on crowd control is higher than on crowd management.

The minutes of all 7 interviews are presented chronologically in Table 24, Table 25, Table 26, Table 27, Table 28, Table 29, Table 30.

Table 24 Interview Bart van Arem Operational Director Stichting SAIL Amsterdam in Dutch

<table>
<thead>
<tr>
<th>Introductie Bert Aben Deze meeting vond plaats op 7-10-2014 om 13:30u</th>
<th>1975 eerste sail meegevaren. Toen was het nog klein geen sprake van massa. Bert was marinier en werkte vervolgens voor afdeling logistiek transport waarna hij sinds 2000 bij SAIL betrokken is in het management. Hij is operationeel verantwoordelijk. Deze meeting vond plaats in de Marine Basis van Amsterdam.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aantal bezoekers Totaal</td>
<td>Meer dan 2,5 miljoen bezoekers over de 5 dagen</td>
</tr>
<tr>
<td>Zwaartepunt bezoekers SAIL-IN dag</td>
<td>19 augustus sail in zwaartepunt eerste dag</td>
</tr>
<tr>
<td>Nog nooit onderzoek naar gedaan verdeling bezoekers, herkomst en bestemming. Geen gedetailleerde getallen over mogelijk.</td>
<td>Niets te maken met bezoekers langs het noordzeekanaal</td>
</tr>
<tr>
<td>Aantal bezoekers per dag</td>
<td>Per dag tussen de 400 en 50000 bezoekers</td>
</tr>
<tr>
<td>Wat is terrein van Stichting SAIL?</td>
<td>Vergunningen &amp; crowd control van oranje oceaan bij stichting Sail</td>
</tr>
<tr>
<td>Sail Event partners BV</td>
<td>Erwin van lambart hoofd</td>
</tr>
<tr>
<td>Sail Event partners BV</td>
<td>Sail event partners BV</td>
</tr>
<tr>
<td>Onderverdeling van SAIL evenementen terreinen</td>
<td>Stichting Sail oranje ocean (ijhaven)</td>
</tr>
<tr>
<td>Wat is terrein van SAIL evenementen terreinen</td>
<td></td>
</tr>
<tr>
<td>Sail Event partners BV</td>
<td>Port of Amsterdam, Nihea media Ivo</td>
</tr>
<tr>
<td>Sail Event partners BV terreinen</td>
<td>Partners voor orga witte en groene oceaan</td>
</tr>
<tr>
<td>Sail Event partners BV terreinen</td>
<td>Scheepvaart museum gebied is blauw -&gt; hospitality ook voor partners</td>
</tr>
<tr>
<td>SAIL pont verbinding java eiland met noorder eiland</td>
<td>Kop java eiland naar links boven pont (soms bottleneck) 200 man per keer, alleen van java eiland naar noord, geen terugweg mogelijk behalve voor geaccrediteerden</td>
</tr>
<tr>
<td>Vrijwilligers</td>
<td>700 vrijwilligers in expertise gebied</td>
</tr>
<tr>
<td>Mobiliteitsprobleem op het water</td>
<td>Mobiliteitsprobleem ingang ijhaven is dicht</td>
</tr>
<tr>
<td>Calamiteiten routes in veiligheidsplan in overleg met gemeente. Bij borneo eiland komt tijdelijke oever verbinding.</td>
<td></td>
</tr>
<tr>
<td>Vergunningen maken de studies naar calamiteitenplan en scenario’s te doen ontstaan</td>
<td></td>
</tr>
<tr>
<td>Infrastructurele aanpassing 2</td>
<td></td>
</tr>
<tr>
<td>Brug naar Java Eiland verdwijnt voor een gedeelte. Er mogen geen mensen meer over de brug (middelste gedeelte wordt eruit gehaald). Dit is de enige toegang tot de IJhaven. Voor boten is dit altijd een knelpunt.</td>
<td></td>
</tr>
<tr>
<td>Need</td>
<td>Hoeveel personen komen via trein, boot of voet of fietsers? Hoeveel uit omgeving Amsterdam?</td>
</tr>
<tr>
<td>Wat te doen uit station logisch verdelen over de oceanen?</td>
<td>Komen aantal optredens en lopende optredens chanti koren</td>
</tr>
<tr>
<td>Hoe valrepen plaatsen, waar rijen?</td>
<td>Ontspannen publiek, karakter is vredelievend</td>
</tr>
<tr>
<td>Foto’s van dichtheid krij ik misschien opgestuurd</td>
<td>Planning &amp; logistiek zijn zeer verweven en is hier genoemd de operationele zaken. Organisatie wordt groter naarmate het event nadert.</td>
</tr>
<tr>
<td>Veiligheidsplan krij ik misschien opgestuurd</td>
<td>Ze hebben veel stagiares in dienst vanuit horeca tourisme branche (MBO-HBO) via SAIL Academy</td>
</tr>
<tr>
<td>Planning budget</td>
<td>Veiligheid voorop, dus wat daarmee te maken heeft moet gebeuren dus in die zin oneindig budget. Deel onkosten voor uitvoerend producent (kaarten en plattegronden voor vergunningen). Miljoen euro?</td>
</tr>
<tr>
<td>Infrastructurale aanpassing 1</td>
<td>Overbrugging ook voor java bewoners, en bereikbaarheid veiligheidsdiensten.</td>
</tr>
<tr>
<td>Beleidsaanpassing</td>
<td>Autos worden geweerd vanaf CS achter naar ruiter en piethein kade volledig gestremd van 10 – 23u, half-kwart voor 11 vuurwerk.</td>
</tr>
<tr>
<td>Control</td>
<td>Monitor systeem wordt uitgebreid (gemeente) doet politie. Samen met openbare veiligheidsdiensten in 1 ruimte operationeel commando centrum in pta terminal centrum</td>
</tr>
<tr>
<td>Ggd = gor</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>50 man in centrum</td>
</tr>
<tr>
<td>Logistiek tall ships bevoorrading</td>
<td>Na 23u bevoorrading tot 9 uur ’s ochtends</td>
</tr>
<tr>
<td>OV aanpassing</td>
<td>Tram keert om op knmi eiland, weet niet of dat verandert tijdens Sail. Maar in principe rijden er dan geen trams</td>
</tr>
<tr>
<td>Infrastructurale aanpassing 2</td>
<td>Loopbrug tussen knmi en vaste land verspert verder ingang van haventje naar brug met tram</td>
</tr>
<tr>
<td>Control</td>
<td>Crises team besluit tot evacuatie</td>
</tr>
<tr>
<td>Samenwerking Gemeente Amsterdam</td>
<td>90 miljoen spin off voor stad amsterdam, dus gemeente heeft baat bij SAIL, dus vergunningstaken gaan in samenwerking</td>
</tr>
<tr>
<td>Overheids inlichtingen diensten</td>
<td>Dreigingsanalyses worden van te voren gemaakt. Verzoek via inlichtingen diensten.</td>
</tr>
<tr>
<td>Fietsbeleid</td>
<td>Te bepalen a.d.h.v. uitvoerende productenten waar ingangen van activiteiten zijn en dus waar fietsen moeten worden geplaatst. In principe worden fietsers niet geweerd uit de</td>
</tr>
<tr>
<td>Betrokkenheid Gemeente Amsterdam</td>
<td>Groot vanwege grote spin-off en eindverantwoordelijkheid</td>
</tr>
<tr>
<td>Mogelijke knelpunt</td>
<td>Doorstroom route naar het IJ op 9 augustus</td>
</tr>
<tr>
<td>Doorstroom route naar het IJ op 9 augustus</td>
<td>De dam tussen KNMI eiland en vaste land</td>
</tr>
<tr>
<td>De plek waar de tram omkeert vertrekken grote marineschepen van 400 man capaciteit in geval van overbelasting van het eiland</td>
<td></td>
</tr>
<tr>
<td>Überhaupt het eiland op zich is 1 groot knelpunt want het is beperkt in oppervlakte en beperkt in uitstroom wegen.</td>
<td></td>
</tr>
<tr>
<td>Data</td>
<td>Als de plek tussen KNMI eiland en vaste land</td>
</tr>
<tr>
<td>Is nog niet beschikbaar. Tot nu toe geen onderzoek gedaan naar stromen voetgangers</td>
<td></td>
</tr>
<tr>
<td>Oceaan ondergedeeld in secties</td>
<td>6 secties, ecco delta bravo charlie alfa</td>
</tr>
<tr>
<td>Succes</td>
<td>Alles loopt volgens planning</td>
</tr>
<tr>
<td>Ongeschonden uit de strijd, alles te handelen</td>
<td>Wordt echt vervelend als t de openbare veiligheid handelt</td>
</tr>
<tr>
<td>Metingen hoeveelheid mensen en schepen die ijhaven ingaan. Vlaggetje met chip</td>
<td></td>
</tr>
<tr>
<td>Tas met goodies, chip voor voetgangers?</td>
<td></td>
</tr>
<tr>
<td>Sail app</td>
<td>80% komt via CS</td>
</tr>
<tr>
<td>Anders soort mensen per type schip</td>
<td>NDSM werf groot jongeren feest</td>
</tr>
<tr>
<td>Uur per km niet gek, 2,5 uur minimaal</td>
<td>6 secties, ecco delta bravo charlie alfa</td>
</tr>
<tr>
<td>Te maken met aantal en type schepen</td>
<td>Allemaal even groot</td>
</tr>
<tr>
<td>Organisatie van secties voor veiligheid en monitors voor operationeel centrum</td>
<td></td>
</tr>
<tr>
<td>Tekst karren vast opgesteld</td>
<td></td>
</tr>
<tr>
<td>Zaken</td>
<td>Beschikking, Acties en Medewerking</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------------------------------------------------------------</td>
</tr>
<tr>
<td>Mogelijkheid app wordt ook gebruikt</td>
<td>Niet anders dan met vrijwilligers Wellicht App in toekomst</td>
</tr>
<tr>
<td>In hoeverre houden jullie rekening met grote voetgangersstromen?</td>
<td>'t Is altijd goed gegaan' plannen wel, maar t wordt wel erg krap op de kades.</td>
</tr>
<tr>
<td>Verder contact en medewerking?</td>
<td>Geen probleem, kan altijd bellen en zijn benieuwd naar de uitkomsten van mijn onderzoek.</td>
</tr>
<tr>
<td>Plattegronden</td>
<td>Aantal plattegronden van activiteitsplanning heb ik meegekregen en op de foto gezet. De map heet foto’s plattegronden activiteiten planning SAIL 2010</td>
</tr>
<tr>
<td>1</td>
<td>Introductie</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>2</td>
<td>Planning</td>
</tr>
<tr>
<td>3</td>
<td>Planning tools</td>
</tr>
<tr>
<td>6</td>
<td>Planning vs Logistiek</td>
</tr>
<tr>
<td>7</td>
<td>Voetgangersstromen bekeken?</td>
</tr>
<tr>
<td>8</td>
<td>Organisatie en verantwoordelijkheden (veiligheid)</td>
</tr>
<tr>
<td>10</td>
<td>Risico analyses</td>
</tr>
<tr>
<td>11</td>
<td>Evacuatie strategieën</td>
</tr>
<tr>
<td>12</td>
<td>Behoefte kennis?</td>
</tr>
<tr>
<td>13</td>
<td>Kennis nodig voor plannen</td>
</tr>
<tr>
<td>14</td>
<td>Eisen voor framework functioneel</td>
</tr>
<tr>
<td>19</td>
<td>Evenement performance</td>
</tr>
</tbody>
</table>
### Tips

<table>
<thead>
<tr>
<th></th>
<th>Tips</th>
<th>Volg een vergunningverlening</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Praat met nog meer hierover en vooral met mensen die grote evenementen hebben georganiseerd</td>
<td>Media is determining the impact of the hazard.</td>
</tr>
<tr>
<td></td>
<td>Human life risks are negligible compared to material losses for the media especially.</td>
<td></td>
</tr>
</tbody>
</table>
## Introductie

Martin is chef crisisbeheersing bij de politie eenheid Amsterdam. Hij zorgt voor risico en scenario inschattingen voorafgaand aan grote en kleine evenementen (of confrontaties) in de veiligheidsregio Amsterdam. Hij is ook veel bezig met opleidingen voor zijn staf en modellen en technieken om de gebruikte methodes te verbeteren of aan te vullen.

Amsterdam heeft meeste ervaring met crisisbeheersing van alle politie eenheden. Daarmee hebben ze lange tijd trots uitgestraald. Nu probeert Martin trots om te zetten in samenwerking om zo ook de andere te laten profiteren van wat Amsterdam weet met minder arrogantie en meer oog voor andere gemeenten.

| 0 | Introductie | M.L. (Martin) Klootsema
Specialist Grootschalig en Bijzonder Politie Optreden
Senior Beleidsadviseur
Accent Multidisciplinair
Politie | Amsterdam | DROS | Regionaal Bureau Conflict- en Crisisbeheersing | Team Crisis
Johan Huizingalaan 757, 1066 VH
Amsterdam
Postbus 2287, 1000 CG Amsterdam
M 06 - 20625015
T (020) 559 4322
Deze meeting vond plaats op het kantoor van de ME in Amsterdam op 20-11-2014 om 09:00u. |
|---|---|---|
| 1 | Organisatie en verantwoordelijkheden? | Politie is verantwoordelijk voor de openbare orde maar de Burgemeester is eindverantwoordelijke, dit vanwege vingertje wijzen als er iets misgaat.
Als burgemeester toch iets toe staat wat politie afkeurt, heeft de politie er maar mee te dealen als het misgaat. | De Algemeen Commandant is eindverantwoordelijk voor de politie eenheid. |
| 3 | Safety (openbare veiligheid) vs Security? | Openbare veiligheid is niet erg gedefinieerd. Wel worden daaronder 3 beleidswaarden gekoppeld: Veilig
Waardig
Ongestoord
De toleranties hiervoor zijn te bepalen door de gemeente in overleg met politie en volgende de wet openbare manifestaties. | In het 5 fasen model is fase 1 platte petten fase waarin de politie aanwezig is maar niet hoeft in te grijpen; alles verloopt dus ordelijk. |
| 5 | Crowd control/ mgmt? | Of het nou 1 demon of 100000 demonen zijn, maakt voor crisisbeheersing niet uit want effect is bereikt en daar moet op worden ingespeeld. | Gedefinieerd als kans maal effect met elk 3 levels gerelateerd aan de openbare orde dus zowel voor politie inzet als de omgeving als burgers als sociale impact als maatschappelijke impact. De tolerantiegrenzen worden uitermate bepaald door de Burgemeester in het geval van Amsterdam. Dit kan echter verschillen per gemeente. In Amsterdam heeft de politie adviserende rol zonder besluitvorming over |
| Risico |

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101
<p>| <strong>6</strong> Planning methode en tools? | IRS (Risico Inschatten en scenario’s schetsen) | Er was een landelijk multidisciplinair (ik denk dat multi actoren wordt bedoeld) knoppenmodel ontwikkeld in 2009 na het monodisciplinair knoppen model van 2005 dat door alle sub 5-hoek gebruikt zou moeten worden. Maar door cultuur verschillen en weigering om zaken aan te nemen van de meer arrogant geziene Amsterdammers is dit model nooit gebruikt. Bovendien vraagt dit nieuwe model veel kennis en hoog opleidingsniveau van de gebruikers. De enige andere acteur die hier ook mee werken is GHOR op sommige onderdelen. Ongeveer 2 keer per maand worden deze methoden gebruikt ten behoeve van een evenement of incident. Een half jaar van tevoren vanwege vergader processen en planning daarvan. |
| IRS | IRS met risico als kans * effect in 3 niveaus) en prioritering (H H = 1) Elke dag wordt er gemonitord om de Informatie up to date gehouden. Als nodig dan nog vaker of minder vaak wel of niet met een rapport. Er worden maximaal 3 prioriteiten geidentificeerd. In de scenario’s wordt een onderscheid gemaakt tussen voorziene en onvoorziene situaties. Bij voorziene situatie wordt nog een worst case, realistic case en basic case uitgewerkt. Bij onvoorziene situaties wordt alleen realistic case behandeld. | Wat de burgemeester verwacht van de politie is ook de tolerantie die wordt doorgewezen t.a.v. scenarios van risico’s: Uitsluiting of Beperking. Maatregelen worden vervolgens uitgewerkt per risico prioriteit. Per evenement wordt dit opnieuw gedaan, zodoende wordt maatwerk afgeleverd. Dit is nodig vanwege de aanname dat historie van een evenement geen gegeven is voor toekomst. Zodoende gelooft Martin niet in een landelijke berekening die soms wordt toegepast voor het inschatten van politiepersoneel nodig voor een evenement (oppervlakte * mensen = aantal agenten o.i.d.), dit is heel erg cultuurafhankelijk. |
| <strong>Gripstructuur</strong> | 1 t/m 6 1 = multidisciplinair 2 = escalerend 3 = burgemeester crisisstructuur 4 = binnen 1 veiligheidsregio 5 = buiten 1 veiligheidsregio 6 = rijksniveau | Zie voor specificatie stukken crisisbeheersing die hij heeft gemaild. |
| <strong>Knoppenmodel</strong> | Het knoppenmodel heeft een aantal knoppen ten behoeve van het reguleren van de openbare orde. Er zijn 2 randvoorwaardelijke knoppen, namelijk informatie en ondersteuning. Daarnaast zijn er 2 prioriteitsknoppen Mobiliteit en Recherche. Naar gelang het evenement en de geschatte risico’s en scenario’s worden er meerdere knoppen bijgevoegd | Obama’s komst zorgde voor 10 knoppen (max) inclusief dus sluischutters met bevoegdheid tot doden en een 3D scan van de omgeving plus volledige screening voorafgaand aan het evenement. |
| <strong>7 Methoden voor incident of risico van veiligheid analyses?</strong> | Brainstorm en ervaring. Altijd in overleg. IRS en LOODS | Voordelen is dat iedereen zelfde methodes hanteert en dat communicatie makkelijker en geeft uniform kwaliteitsniveau (likelihood) van de uitvoerenden. |
| <strong>Problemen met methodes?</strong> | Er zijn geen problemen geconstateerd met de huidige gang van zaken en methodes, wel kleine prestatie fouten van individuen. |</p>
<table>
<thead>
<tr>
<th></th>
<th>Planning gebaseerd op fasen crisis?</th>
<th>Er is wettelijk bepaald dat er beveiligde routes moeten zijn bij bijvoorbeeld VIP.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Valkuilen planning bij plannen van velige grote evenementen?</td>
<td>90% van mass event risico’s kan gedekt worden met de voorbereidingen getroffen door deze modellen. De overige 10% niet, maar dat is niet erg want het is tot nu toe altijd opgevangen.</td>
</tr>
<tr>
<td></td>
<td>Allocatie van politie gebaseerd op wat?</td>
<td>Er zijn 2 kanten, aan de ene kant wordt risico uitgesloten en dan wordt er alles aan gedaan. Andere kant is risico beperking waardoor niet alles uit de kast wordt getrokken, maar alleen wat nodig is.</td>
</tr>
<tr>
<td></td>
<td>Budgettering van veiligheidsmaatregelen?</td>
<td>Budget voor de Nationale Politie is gehalveerd bijna, maar prioriteit is gegeven aan politie crisisbeheersing, dus hier wordt niet op bezuinigd. Er is discussie over budget, maar crisisbeheersing wordt eigenlijk nooit over gesproken.</td>
</tr>
<tr>
<td></td>
<td>Providers</td>
<td>Niet te doen qua verschillende technieken en overbelasting.</td>
</tr>
<tr>
<td></td>
<td>SAIL</td>
<td>Moet zorgen voor beveiliging Wettelijk verantwoordelijk voor deel veiligheid. Annemarie Langeveld is contact met Politie en SAIL. Heb ik contact van gekregen via de mail.</td>
</tr>
<tr>
<td></td>
<td>Training</td>
<td>Crisissen worden eens per jaar geoefend in NL, Zweden of Duitsland.</td>
</tr>
<tr>
<td></td>
<td>Welke indicaties voor onveilige situaties?</td>
<td>Geschatte risico’s en gemelde alarmeringen van zowel burgers als politie ter plaatse.</td>
</tr>
<tr>
<td></td>
<td>Voetgangersstromen bekeken tot in welk detail?</td>
<td>Niet. Als indicator gebruiken ze kennis van capaciteiten van pleinen en zodra er wordt geschat dat t vol is, is dat de aannemelijke hoeveelheid mensen op de plein. Museumplein is 25000 Dit is voldoende om te weten hoe je chaos kan voorkomen en welke maatregelen je dient te nemen.</td>
</tr>
<tr>
<td></td>
<td>Dynamiek van voetgangersstromen meegenomen</td>
<td>Paniek wordt als scenario meegenomen. Echter is de aanname dat dit scenario niet gecontroleerd kan worden. Dynamiek van voetgangersstromen voor zover van belang dat er 3 typen vluchtgedrag zijn:</td>
</tr>
</tbody>
</table>
### In de plannen?

Mensen kijken niet omhoog maar naar beneden tijdens paniek en vluchtgedrag. Dit is iets om rekening mee te houden t.b.v. informatie verstrekking (borden zijn meestal hoger dan mensenmassa).

(2/3) of people in crowd: Vluchten van de plek des onheils. (terwijl ik dit type enorme knal in dit gebouw)

(1/11 of people in crowd) Vechtgedrag (redden en naar incident toe)

(1/4 of people in crowd) Freeze

### Crowd control maatregelen?

Systeem wat ooit werd gebruikt CurrentCity wordt niet meer gebruikt vanwege dat de telefoonpalen werden ingezet en die waren altijd overbelast ten tijde van grote evenementen. Plus de verschillende technieken tussen providers en dekkingen van steden werkte ook ten nadele van dit systeem.

Nu worden alle stadscamara’s gebruikt evenals de camera’s van politiewagens. Wat dat betreft is bluetooth een beter middel.

Ook wordt een app ingezet, maar of er iets met die data (gps tracking) wordt gedaan is niet geheel duidelijk.

Hoe lager de tolerantiegrenzen hoe meer er wordt uitgesloten, uitgewerkt en gedefinieerd.

### Historie van evenement is bijna te negeren, elk evenement wordt op maat bekeken voor het bepalen van risico’s, scenario’s en maatregelen.

Maatregelen ter beter informeren van publiek is een wens om uit te breiden naar bijvoorbeeld SKELTEN naast de matrixborden, apps en gedefineerde looproutes (flyer en app en sites).

### In hoeverre plannen jullie evacuatie van openbare ruimten?

Evacuatie is wat anders dan ontruiming. Over evacuatie wordt gesproken als een gebied voor langere tijd ontruimd dient te worden, zeg langer dan 24 uur waardoor er maatregelen genomen moeten worden door de gemeente ter verzorging van deze gedupeerden. Een ontruiming is voor korte periode, zeg 2 tot 3 uur.

### Evacuatie maatregelen?

Deze maatregelen zijn dus ter verzorging van de gedupeerden; fysiologische middelen en wellicht trauma hulp.

Rond 14/14:30u altijd eerste melding van incident. Zeker in binnenstad kunnen de hulpdiensten niet altijd tot op de plek van het incident komen. Dan brengt soms politie hulpbehoevende naar afvoerplaats. Aan de andere kant als indicent dreigend is dan wordt gewoon de ME ingezet en die hebben pantserbussen en voertuigen om het incident hardhandig aan te pakken en ze wijken in de binnenstad niet voor een terras. De ervaring is dat mensen wel aan de kant gaan voor zo’n voertuig. Ik heb een rondleiding gehad door de garage waar ik de pantservoertuigen van binnen heb gezien. Ze hebben hiernaast ook een drone.

### Qday

800000 inwoners + 1 miljoen bezoekers

Het is heel goed om de evenementen te verspreiden over heel Amsterdam inclusief de buitenarea’s. Er wordt een maximum aan activiteiten/evenementen gesteld t.b.v. aantal alarmeringen.

Rond 14/14:30u altijd eerste melding van incident. Zeker in binnenstad kunnen de hulpdiensten niet altijd tot op de plek van het incident komen. Dan brengt soms politie hulpbehoevende naar afvoerplaats. Aan de andere kant als indicent dreigend is dan wordt gewoon de ME ingezet en die hebben pantserbussen en voertuigen om het incident hardhandig aan te pakken en ze wijken in de binnenstad niet voor een terras. De ervaring is dat mensen wel aan de kant gaan voor zo’n voertuig. Ik heb een rondleiding gehad door de garage waar ik de pantservoertuigen van binnen heb gezien. Ze hebben hiernaast ook een drone.

### Behoefte aan meer kennis crowd management?

Overcrowding: Kunnen mensen nog wekgomen in de goede richting en is zelfredzaamheid mogelijk. Politie schetst hiervoor randvoorwaarde.

Hoe moet de politie omgaan met die mensen, zijn ze bevoegd? Daar is op dat moment geen tijd voor om te checken, dus samenwerken.

### Looproutes hulpverlening

Commercialiteit vs Veiligheidsmaatregelen.

Looproutes door evenemententerrein zou enorm helpen t.b.v. veiligheid maar dit is niet altijd gewenst doordat ruimte = geld.
<p>| | | |</p>
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</table>
| 20 | **Kennis nodig voor plannen of inschatten risico’s?** | Dit wordt gedaan op basis van bruisstorm en ervaring en training via gestandaardiseerde modellen: IRS (Informatie, Risico, Scenario) En LOODS (locatie, Omstandigheden, Object, Daders, Slachtoffers).  
Paniek is een scenario  
Mojo hekken worden gebruikt bij concerten.  
Standaard hekken vallen allemaal aaneengeschakeld.  
-bescherming, tegenhouden, informeren  

|   | **Hekken** | Studies naar hoe plaatsen van hekken. Hekken hebben verschillende eigenschappen (uit elkaar vallen, in 1 vallen, doorheen kijken of niet etc.). Hek heeft verschillende functies tijdens het evenement, het kan dienen ter bescherming, ter afbakening, ter controle, ter tegenhouding of als obstakel.  

|   | **Hoe defineer je succes van politie ingrijpen of crowd control?** | Openbare orde:  
Veilig  
Waardevol  
Ongestoord  

|   | **Vergunning** | Bepaalt criteria voor veiligheidsplannen  
Wet van Pleuris wordt ook meegenomen voor media aandacht. Dit is heel belangrijk voor crisis response. Macht 3 met social media wordt gehanteerd in elk event.  
In de commando kamer is altijd facebook en twitter open.  

|   | **MQRT** | Multi Quick Response Team  
Monitoren en kunnen snel logistiek regelen t.b.v. hulp of versterking.  
In zo’n team zit 1 iemand van brandweer, 1 iemand van politie en 1 iemand van GHOR  
Ze coördineren incidenten  
Direct gekoppeld aan Hoofd Orde en Handhaving  

|   | **Wat zijn grote lessen uit de praktijk bij crowd control/management?** | Discipline bij crisisen en training.  

|   | **Tips?** | Bekijk aspect zowel van mono als multi actoren perspectief  
Ik krijg minimaal nog:  
Contact Annemarie van SAIL – Politie 2009 knoppen model  
Grip structuur  
Scenario voorbeelden  
Voor verdere vragen altijd te bereiken.  

<p>| | | |</p>
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</table>
| 538 is de enige organisatie die hiervoor wil betalen en dus geautoriseerd is om grote evenementen in de binnenstad te draaien.  
Goeie banden met 5-sub hoek. Ook goede afvalprocedures.  
Ze hebben hoog gevoel voor eigen verantwoordelijkheid voor veiligheid.  

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</table>
### Table 27 Interview Eric Seleky Event Manager Museumnacht Amsterdam

<table>
<thead>
<tr>
<th>1</th>
<th>Introductie</th>
<th>Eric Seleky is event manager van Museumnacht Amsterdam en heeft diverse grote evenementen georganiseerd. Deze meeting vond plaats op 18-11-2014 om 14:00u in het Concertgebouw aan t IJ. De gedachte is voornamelijk om een community in Amsterdam te versterken welke niet snel in aanraking komt met kunst en nu in een efficiënte en toegankelijke manier naar veel populaire en nieuwe tentoonstellingen kan gaan. Afgelopen Museumnacht was de 15e editie en loopt sinds 2000. 39 musea deden mee en hiernaast nog 11 exposities in de diverse stadsdelen. Deze exposities hebben een functie voor dit stadsdeel namelijk om mensen te binden aan elkaar en aan de kunst in die wijk die meestal ook tekent voor de wijkcultuur. Zuid-Oost wordt een broedplaats van nieuwe kunstenaar genoemd (CBK).</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Budget is geheim</td>
<td>Ongeveer een halve ton waarvan 80% wordt opgebracht door musea. Alles draait om museumbeleving.</td>
</tr>
<tr>
<td>3</td>
<td>Bezoekers</td>
<td>Er zijn in totaal 32000 bezoekers verwelkomd via ticketing waarvan 30000 klanten waren. 80% komt direct uit omgeving Amsterdam, de overige 20% komt uit Randstad of Utrecht, NH, ZH. Vorig jaar waren het in totaal 28000 en deze stijgende lijn wordt graag voortgezet. Dit aantal wordt vastgelegd a.d.h.v. capaciteiten van musea, programmering en commercieel inzicht. Het aantal tickets wordt altijd vastgelegd van tevoren.</td>
</tr>
<tr>
<td>4</td>
<td>Museemplein</td>
<td>De 3 musea zetten de grootste bezoekersaantallen weg en bepalen daarmee ook de minimale toelatingscapaciteit in aantal kaartjes. Het Rijksmuseum alleen al kan 11000 bezoekers kwijt.</td>
</tr>
<tr>
<td>5</td>
<td>GVB</td>
<td>Wordt vooral gebruikt door mensen van buiten Amsterdam (deze hebben natuurlijk geen fiets in Amsterdam, en fiets is toch wel handiger soms.) Maar bij slecht weer is vooral de angst dat als deze service niet wordt aangeboden dat er dan ook minder museumbezoeken worden geboekt.</td>
</tr>
<tr>
<td>6</td>
<td>Definities</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>Planning gebaseerd op fasen?</td>
<td>Begint 11 maanden van te voren met het bepalen van de doelen, strategie, activiteiten, projecten en sponsors en partners. Meestal is GVB daarbij (ook kostenpost) want er wordt met een kaartje ook gratis binnenstedelijk vervoer geregeld via GVB (bus en trams). Museumkaart is ook altijd van de partij en dit jaar was als mediapartner METRO aangeschreven.</td>
</tr>
<tr>
<td>8</td>
<td>9 maanden van tevoren wordt de begroting definitief gemaakt</td>
<td>9 maanden tot 7 maanden van tevoren wordt de programmering als advies aan het bestuur gepresenteerd.</td>
</tr>
<tr>
<td>9</td>
<td>6 maanden van tevoren wordt de programmering definitief gemaakt en wordt de kick-off gehouden</td>
<td>5 maanden van tevoren begint de campagne (in dit geval met centercom) en wordt er aan programmering gewerkt en worden de vergunning aangetekend. Museumnacht moest dit jaar een (extra?) vergunning aanvragen voor lichtobjecten verspreid over de ingangen van de musea, dit helpt ter identificatie van de ingang in het donker. Dit object bestond uit pallets met TL buizen en werkte goed.</td>
</tr>
<tr>
<td>10</td>
<td>4 Programmering</td>
<td>Thema van de N8 programmering wordt aangepast aan de thema’s van de musea. De headlines en breed programma aanbod worden als indicatoren gezien. Een breed programma trekt sowieso meer mensen.</td>
</tr>
<tr>
<td>11</td>
<td>Wat zijn de valkuilen tijdens het plannen?</td>
<td>Alle musea hebben eigen beveiligingsprotocollen waar rekening mee moet worden gehouden in informatieveoorziening naar vrijwilligers en bezoekers, om nadelige verrassingen tegen te gaan. Hiernaast wisselen contactpersonen gedurende het project vaak en ook zijn de verantwoordelijkheid niet de uitvoerende waardoor soms informatie verloren gaat. Distributie is soms lastig (wordt adhoc gedaan). Inschatten van deelnemers verdeling over aanbod is lastig en wordt gezien als vrijwel onmogelijk. Van alle deelnemers is een grote groep reactief en een groep niet reactief. Dit wordt</td>
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</tr>
<tr>
<td><strong>Gemis in planningsprocessen?</strong></td>
<td>Verdeling van programmeringstoppers over area en over tijd is heel belangrijk maar zou meer meegenomen kunnen worden.</td>
<td></td>
</tr>
<tr>
<td><strong>Planning management vs draaiboek logistiek</strong></td>
<td>Draaiboeken worden in overleg met alle betrokkenen gemaakt. Het distributieplan van marketingmateriaal is eigenlijk de grootste logistieke opdracht die ze hebben. De logistiek en beveiliging regelen musea zelf. De ticket organisatie regelt de toegangststromen in de musea en adviseert op service rates. Voor de kleinere exposities adviseert N8 op logistiek en is bemiddelaar hierin.</td>
<td></td>
</tr>
<tr>
<td><strong>Factoren</strong></td>
<td>Goede verspreiding en lage wachtstijden zijn belangrijk Het weer is van invloed op aantal bezoekers.</td>
<td></td>
</tr>
<tr>
<td><strong>Voetgangersstroom bekijken?</strong></td>
<td>Nee Worden wel koppen geteld door het beveiligingsbureau. Toen de grote Oude Kerk opening was waar 1000 mensen op af moesten komen maar kreeg meer belangstelling hebben ze ervoor gezorgd dat de omliggende cafés de show ook zouden uitzenden.</td>
<td></td>
</tr>
<tr>
<td><strong>Organisatie en verantwoordelijkheden (veiligheid)</strong></td>
<td>Geen verantwoordelijkheid voor veiligheid, ligt in zijn geheel bij gemeente, politie en musea. Deze app wordt nog toegelicht met blogs. De informatie voor de app komt weer van koppentellen in rondrijdende units langs de drukste plekken. Voordeel van deze app is dat dit onderdeel was van Museumnacht app waarin dus alles over programma werd gecommuniceerd en up to date werd gehouden. Dat is een groot nadeel van het programmaboekje. Het programmaboekje wordt al 2 maanden van te voren bij alle plekken neergelegd waardoor het zijn accurate informatie verliet. Het is niet erg nodig als campagne materiaal blijkt. En mensen kunnen meestal op de dag zelf toch niet meer participeren omdat het altijd een dag of 2 van te voren is uitverkocht. Waarschijnlijk gaat deze app het boekje compleet vervangen.</td>
<td></td>
</tr>
<tr>
<td><strong>Budgettering van veiligheidsmaatregelen</strong></td>
<td>Druktmeter app is ontwikkeld in samenwerking met festina lente waarin wordt aangetoond waar het druk is en wat je kan doen om te voorkomen dat je in lange wachtlij lijkt terecht komt. Ook kan je je favoriete route bepalen en kan je feedback geven. Uit publieksonderzoek kwam naar voren dat deze app goed gebruikt werkt (gebruik is sinds 2012 toegenomen) en mensen tevreden waren. Deze app wordt nog toegelicht met blogs. De informatie voor de app komt weer van koppentellen in rondrijdende units langs de drukste plekken. Voordeel van deze app is dat dit onderdeel was van Museumnacht app waarin dus alles over programma werd gecommuniceerd en up to date werd gehouden. Dat is een groot nadeel van het programmaboekje. Het programmaboekje wordt al 2 maanden van te voren bij alle plekken neergelegd waardoor het zijn accurate informatie verliet. Het is niet erg nodig als campagne materiaal blijkt. En mensen kunnen meestal op de dag zelf toch niet meer participeren omdat het altijd een dag of 2 van te voren is uitverkocht. Waarschijnlijk gaat deze app het boekje compleet vervangen.</td>
<td></td>
</tr>
<tr>
<td><strong>Risicovoorlichting strategieën</strong></td>
<td>Worden niet per se uitgevoerd, wel op campagne. Er worden geen scenario’s van onverwachte nadelige gebeurtenissen gemaakt. Alhoewel het wel raar was dat er tijdens Museumnacht 2014 een halloween optocht plaatsvond. Dit veroorzaakte een OV opstopping die eerst maar 40 minuten zou duren en uiteindelijk door onverwachte grote opkomst veel langdurige drukte wat weer tot onvrede leidde bij het bestuur van N8 en haar deelnemers. De gemeente is verantwoordelijk voor vergunningverlening en had dit dus kunnen voorzien en voorkomen. De gemeente heeft toegezegd dat dit niet meer zal gebeuren.</td>
<td></td>
</tr>
<tr>
<td><strong>Evacuatie strategieën</strong></td>
<td>Mensen zijn voortdurend onderweg. Alleen bij de opening was het even druk op 1 plek en bij de afsluiting. Type bezoekers leent zich nooit voor incidenten en dat is ook zo met jongeren die drinken. Drinkbeleid wordt aangepast binnen musea, geeft nooit problemen.</td>
<td></td>
</tr>
<tr>
<td><strong>Communicatie</strong></td>
<td>Er waren teams puur gefocust op opstoppingen, dat wil zeggen dat er Er was dus geen zeker monitorsysteem aanwezig maar hierbij werd puur vertrouwd op het inzicht van beveiligingsstaf</td>
<td></td>
</tr>
<tr>
<td>Subject</td>
<td>Question</td>
<td>Reaction</td>
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</tr>
<tr>
<td>Intro</td>
<td>Who are you and what are your current involvements with crowd management?</td>
<td>Kwantitatief maken van voetgangers gedragingen. Afgestudeerd op Lowlands voetgangersstromen en hoe crowd sensing? Antwoord hierop was negatief, dit is er nog niet of kan ook niet direct. Dorine heeft mijn onderzoek als research gap geïntroduceerd. Wat gebeurt er op kruisingen, welke effecten zijn er en hoe stuur je deze effecten?</td>
</tr>
<tr>
<td>Crowd</td>
<td>What is meant with a crowd?</td>
<td>Control -&gt; wanneer macht over crowd kwijt. Control is al als fout is gegaan, mag niet in thesis voorkomen. Control als ME ingrijpt voor herstel openbare orde. Verstoring van openbare orde. Wij (organisatie en politie) vs hun (Massa), macht over menigte kwijt -&gt; control politie</td>
</tr>
<tr>
<td>Crowd</td>
<td>What is meant with crowd control</td>
<td>Management, dynamics movement is primair. Management gaat over prior tot evenement zowel mensen, beveiliging, infrastructuur etc. Alle voorbereidende stappen te nemen vooraf aan evenement.</td>
</tr>
<tr>
<td>Crowd</td>
<td>What is meant by crowd management?</td>
<td>Kan niet kwantitatief, soms 1 per 10 m² managen even managen. Vanwege herding.</td>
</tr>
<tr>
<td>Mass Event</td>
<td>What is meant with a mass event?</td>
<td>Mass -&gt; massa Large Scale Events is ook goed te gebruiken. Evenement meer dan x aantal mensen samen komen in beperkte ruimte en tijdstromen boven 1 persoon per vierkante meter. Gereferereerd naar Level of Service. Eigenschappen noemen is een goed idee. Zoek thesis Dorine, is in database</td>
</tr>
<tr>
<td>Planning &amp; Organisatie</td>
<td>I am aiming for a framework on planning of crowd management. Should I call is rather framework for crowd management?</td>
<td>Belangrijkste er moet taken worden gesteld. Veiligheids handleiding is menu voor vergunning is nu functionerend als checklist. Grote evenementen hebben eigen handleiding (langdurig opereren) draaiboek. Mojo walst gemeente plat. Wat gemeente nu doet is advies inwinnen, dus 5hoek, Uiteindelijk komt het bij OVV Politieke verantwoordelijkheid ligt bij burgemeester. Tolerantiebeleid wordt door de 5hoek bepaald en is niet onderhevig aan standaarden. Dit is een subjectief verhaal. Gripstructuur opschalen is falen van systeem en niet falen van evenementen organisator, en falen van alles terloops naar evenement crisis is toe t wijten aan alle betrokken partijen. Trek uit elkaar management</td>
</tr>
</tbody>
</table>

Table 28 Interview with Dorine Duives PhD Student TU Delft in Dutch
<table>
<thead>
<tr>
<th>Safety</th>
<th>Did you encounter safety issues or risk issues during your studies in crowd management? Which safety indicators would be applicable for a mass event, or SAIL?</th>
<th>Level of service, tijd (essentieel en niet alleen in congestie), emotie. De tijd waarin de Level of Service aanwezig is is zeer belangrijk en dat wordt nog niet gevangen in het begrip Level of Service. Belangrijk wat gebeurt er waar en specificeren. Voorkom het aanbevelen van maatregelen voor speciale actoren en houdt het objectief. Betrek niet het politieke spel erin. Bekijk het vanuit gemeentelijk perspectief want hierin ligt eindverantwoordelijkheid voor veiligheid en dat is mijn doel voor het evenement.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAIL</td>
<td>What do you think are the bottlenecks at SAIL?</td>
<td>Evacuatie kan voorbereid zijn dus voor crowd management.</td>
</tr>
<tr>
<td>Crowd Dynamics</td>
<td>Are the following phenomenon all related hazards in crowd dynamics? Turbulence Self-Efficiency Herding Zipping Crushing Shockwave Congestion Death Injured</td>
<td>Gevaar perceptie, (eigen waarneming), bronnen van informatie rangschikken naar prioriteit of betrouwbaarheid. Capaciteit van een doorsnee of oppervlakte is groot verschil. Vanuit evenementen organisator gezien is het laatste wat je wil de input verminderen: 4 punten hoog naar laag; Verspreiden stromen over network, geen blokkades, capaciteit benutten input minder. Infrastructurele aspecten nog mee te nemen. Dit zou ik kunnen doen samen met Dorine, heeft zij voorgesteld. Sowieso van belang zijn de volgende aspecten: Vrouwen procenten Hoeken Doorgang breedte</td>
</tr>
<tr>
<td>Framework</td>
<td>Do you agree there is a need for a framework on planning crowd management measures?</td>
<td>Yes Wanneer evenement aan de gang is kan je niet meer managen, want alles wat er gepland is moet dan in actie treden. Till best of its ability. Groepen sturen kan dan niet meer, behalve met control maar dat wil je eigenlijk niet. Alles moet klaar staan voor de scenario’s die er zijn gesteld. En dit is een need die met mijn framework kan worden getackeld. Gelooft niet dat een framework product het eindproduct is van dit onderzoek, wel een goed doel maar wellicht te groot. Dit framework heeft ontwerpmaatregelen en niet control of human resource maatregelen. Perspectief is strategisch vanuit gemeente te bevliegen i.p.v. organisator. Checklist voor komende 20 jaar research zowel door overheid, politie en wetenschap.</td>
</tr>
<tr>
<td>Tips</td>
<td>Do you have tips how to fulfill a successful graduation project?</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>FD nu zeer algemeen, maar eigenlijk past het niet bij voetgangers wel bij auto’s. Nu wordt het niet meer zoveel gebruikt omdat relatie tussen snelheid en dichtheid niet opgaat voor voetgangersstromen. Stromen, demografie en indrukbaarheid van mensen alles speelt mee in FD. Dit wordt dus niet zo veel gebruikt. Dichtheid en snelheid verkennen niet totaal het fenomeen van fundamenteel diagram. Er is een invloed (kwalitatief) maar niet hoe groot, niet deterministisch. Aannames over snelheid mannen vrouwen is puur aanname omdat context waaronder dit onderzoek heeft plaatsgevonden niet duidelijk was (crossing flows etc?) Invloed factoren zijn heel onduidelijk. Deterministisch model is er niet.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q day</td>
<td>30 experts kroningsdag hoe veilig 4 miljoen</td>
<td></td>
</tr>
<tr>
<td>Zorg dat doelgroepen worden gescheiden om massa te spreiden Huidige beleid is verspreiding over evenementen, dit komt vanuit de Kroningsdag.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risico in kaart brengen grote evenementen voor politie</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HEEF huidige procedure geschreven en heeft de IRS en LOODS methode geanalyseerd. Hij zat niet in politie academie maar het rapport ligt daar wel.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Samen organiseren grootschalige feestjes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Berend Temme hoofd (directive) Daniel schipper (project leider SAIL 2015)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brandweer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amersfoort wellicht wel evacuatie berekeningen.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Politie</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rol binnen organisatie is belangrijk, maar rollen binnen politie niet heel gestructureerd. Knoppenmodel is eerste poging, maar niet erg kwantitatief. Pinkpop biddinghuizen (1 keer per maand hebben zij een evenement en Amsterdam 2 keer per week waarschijnlijk). Risico uitsluiten (LOCATIE OF CANCELEN)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beveilig</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Draaiboeken maken en zitten bij evenementen aan tafel. Framework zou indicaties hebben voor beveiligingstaken.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dorine samenwerken effecten van infrastructurele aspecten op</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Je kan matrix bouwen met welke effecten er spelen bij welke infrastructurele aspecten er zijn Stedelijke openbare ruimte is het goede begrip Indicator hier heel moeilijk te kwantificeren.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 29 Interview Berend Temme Crisis Manager Local Government of Amsterdam in Dutch**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Question</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>Purpose of this interview is to get a broader perception on crowd management of the City Council of Amsterdam.</td>
<td>Berend Temme is crisismanager en draait piket in warme tijden (tijdens crises) voor de Burgemeester van Amsterdam. Adviseur in koude perioden. Alle soorten crises m.b.t. gripstructuur en hoeken structuur. Praktijk en niet theoretisch. Team van Berend is ook en team van helpen voorbereiden grootschalig politieoptreden</td>
</tr>
<tr>
<td><strong>Openbare Orde en Veiligheid Gemeente Amsterdam (Veiligheidsregio Amsterdam en Amstelland) 9-12-2014 15:00-16:00u</strong></td>
<td><strong>Werkgroep</strong></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>Lauw is aankomen van risicovolle situaties en voorbereidend hierop. Warm is acute crisis. Projectleider en eerste adviseur openbare orde en veiligheid SAIL.</td>
<td>Nautische veiligheid, veiligheid, communicatie, crowd management, mobility. Veiligheid werkgroep (voorbereiding op grote calamiteiten) en begeleiden scenario proces en kijken per scenario om te voorkomen, mitigating of beheersing en formuleren sleutelbesluiten maken en feest werkgroep (Daniel Schippers)</td>
<td></td>
</tr>
<tr>
<td>Scenarios (20) uiteenlopend en werken helemaal uit. Hiervoor alles wordt gebrainstormd.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Introduction</strong></th>
<th><strong>Who are you?</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Veiligheidsbestuur van de 6 gemeenten zonder veiligheidsdirectie wel werkgroepen per dienst en kleine ondersteunende bureaus</td>
<td>What are your current involvements with crowd management at mass events?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Goal</strong></th>
<th><strong>What is the primary goal of Crisis management at the City Council?</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Meer feestjes organiseren met minder mensen per feestje plus feestjes gespreid over locatie, tijd en doelgroep.</td>
<td>Als ze vinden dat het een crisis is, waarom geen antwoord. Waarschijnlijk als er een gevaar voor openbare orde en veiligheid is als het het feestje verpest (beide takken werkgroepen)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Crisis</strong></th>
<th><strong>Hoekenaanpak en gripstructuur</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bepalen samen crisislevel</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Qday</strong></th>
<th><strong>What is meant by crowd management?</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Er nemen 700-800 K mensen nemen deel en er komen 250-300 K mensen aan en vertrekken weer met NS.</td>
<td>Maatregelen spreading</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Mass Event – Council difference</strong></th>
<th><strong>Why is there a large difference between criteria for mass events based on visitors numbers (Amsterdam 2000 vs Den Haag 25000)?</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wanneer crisisgevoelig? Verwijst naar handleiding evenementen: situatie; activiteit; doelgroep en hierop wordt gebaseerd i</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Safety</strong></th>
<th><strong>What is safety?</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Security is moedwillige verstoring. Safety niet moedwillig. Bevoegdheden verschillen hiervoor. Security heft met rechtsorde te maken en spelt opsporing een rol.</td>
<td>What is Openbare Orde?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Safety – Disaster</strong></th>
<th><strong>What is a crisis, disaster?</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Niet duidelijk, alles wat grote gevolgen heft of kleine gevolgen en vaak voorkomt en risico’s meedraagt voor openbare orde en veiligheid. Wordt niet zozeer gekeken naar crises in voetgangersstromen zelf.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Safety - Responsibility</strong></th>
<th><strong>Who is responsible for safety during mass events?</strong></th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th><strong>Safety – Responsibility &amp; Task Seperation</strong></th>
<th><strong>What are the responsibilities and tasks for event producer, city council (OVV) and pentagram safety operators?</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tolerance Level</strong></td>
<td>How is determined at which tolerance level risks of safety hazards will be minimized or excluded?</td>
</tr>
<tr>
<td><strong>Safety Plan</strong></td>
<td>What involved this safety plan? Is that all there is in the vergunningaanvraag (license)?</td>
</tr>
<tr>
<td><strong>Risk Assessment – Tasks</strong></td>
<td>What are risks, how are they assessed? Which risks assessments are being carried out?</td>
</tr>
<tr>
<td><strong>Risk Assessment - Case</strong></td>
<td>Is there an example of a case in which this is done?</td>
</tr>
<tr>
<td><strong>Crowd Management-Policy</strong></td>
<td>Where is policy on crowd management measures currently based on?</td>
</tr>
<tr>
<td><strong>Crowd Management – Knowledge</strong></td>
<td>To what extend is knowledge on crowds based on experience vs scientific literature?</td>
</tr>
<tr>
<td><strong>Crowd Management- Crowds</strong></td>
<td>To what extent are flows of people taken care of?</td>
</tr>
<tr>
<td><strong>Crowd Management - Evacuation</strong></td>
<td>In which sense in taken care of evacuation strategies, are they set for Amsterdam in general or made specific for mass events?</td>
</tr>
<tr>
<td><strong>Data</strong></td>
<td>Vooral platform nodig met kennis uitwisseling landelijk en real-time rekenprogramma. Er is op dit moment iets in onwikkeling op initiatief van Gemeente Amsterdam om data rondom publieksstromen 356 dagen per jaar + evenementen op systematische manier te verdelen. Nu is dit in een brainstromfase en geen concreet beeld. Er moet eens oort informatie dashboard komen Instroom, toezichthouders, monitoring. Dorine probeert empirisch te beschrijven hoe doelgroepen anders gedragen voor Amsterdam. Wat is er nou voor nodig voor dit platform?</td>
</tr>
</tbody>
</table>

**Crowd Management - Knowledge**

To what extend is knowledge on crowds based on experience vs scientific literature?

Alle kennis is gebaseerd op ervaring en judgements maar empirische kennis ontbreekt volledig. Er zijn een aantal plekken gemodelleerd zoals Jordaan, bruggen in binnenstad en Centraal Station hoe groot capaciteit is etc. Dat vindt hij heel goed want dan weet je waar je aan toe bent.

**Crowd Management- Crowds**

To what extent are flows of people taken care of?

INControl modeleert aantal punten voor Gemeente Amsterdam, heel bruikzaam gevonden.

**Crowd Management - Evacuation**

In which sense in taken care of evacuation strategies, are they set for Amsterdam in general or made specific for mass events?

Evacuatie wordt niet meegenomen gaat vooral vooraf aan evenement en achteraf en er wordt gerekend op capaciteit van horeca. Evacuatie principe. Instroom wordt wel naar gekeken, hier wordt grip op gehouden. Terreinen worden ontworpen (ook in hoeveelheid mensen) dus evacuatie is een scenario waarin een organisator zich op voorbereidt maar niet wat bij de Gemeente. Rondom centraal station is een hekkenplan en hierin kan gedoseerd worden. Voor de rest wordt er geïnformeerd via matrix borden en dit wordt of NS of horeca centrum. Er worden geen extra locaties gereserveerd voor geavanceerde mensen. Bommeliding op de Bijenkorf is heel serieus genomen en verliep soepel. Voor hem is paniek voorkomen hoofddoel van evacuatie. Damschreeuwer heeft geen extra maatregelen veroorzaakt, wordt als zeer incidenteel gezien.

**Data**

Vooral platform nodig met kennis uitwisseling landelijk en real-time rekenprogramma. Er is op dit moment iets in onwikkeling op initiatief van Gemeente Amsterdam om data rondom publieksstromen 356 dagen per jaar + evenementen op systematische manier te verdelen. Nu is dit in een brainstormfase en geen concreet beeld. Er moet eens oort informatie dashboard komen Instroom, toezichthouders, monitoring. Dorine probeert empirisch te beschrijven hoe doelgroepen anders gedragen voor Amsterdam. Wat is er nou voor nodig voor dit platform?
Voor Sail is Berend opdracht geven de partij. Toeristen zijn ook een issue. Stefan in de gaten houden met data platform.

Inrichting terrain Vergunnign wordt hierop beoordeeld end it doet politie

Waarom verantwoordelijkheid Aaleen bedacht ter beersing van risico’s. En gemeente levert projectleider voor vergunning. GHOR en politie zijn eerste adviseurs.

Resources / Spel Zeker spel, maar budget en veiligheid wordt strikt gescheiden

Verdrukking Komt niet erg vaak voor want maatregelen worden daartegen genomen zoals compartimentering en fencing and barriers. Discussie over welke maatregelen, vol is vol. Preventie door geen shockwave, distributie en

Sources Who do I have to spoke with for this topic next to you? Praat met evenementen organisatoren over maatregelen op terrien zelf.

Which topics can be helpful or which documents? Vraag Martin Klootsema over Q inhuldiging en 2014. Shockwave beelden ajax huldiging 2011 waargenomen voorste vak museumplein vraag bij Martin Klootsema en via Jan Pronk. Vraag mobiliteitsplan Q day 2014 en troonswisseling in fysieke ruimte. (vraag ook naar communicatiemaatregelen.)

What would you like to recommend me for achieving this framework? Anne Frankhuis rijen probleem 538, mogen ook andere evenementenboeren om museumplein draaien. Daniel van Motman vragen om mobiliteitsplannen. Daniel Schipper mocht niet contact mee opnemen van Berend, wellicht telefonisch wel mogelijk voor gerichte vraag.

---

Table 30 Interview Daniel Motman Mobility Manager Local Government of Amsterdam DIVV

<table>
<thead>
<tr>
<th>Subject</th>
<th>Question</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Introduction</strong></td>
<td>Purpose of this interview is to get a broader perception on crowd management of the DIVV (Dienst Infrastructuur Verkeer en Vervoer) of the local government of Amsterdam.</td>
<td>DIVV is responsible for accessibility of the city in regional and local perspectives. The department of traffic management is seen as the director of crowd management measures for Amsterdam urban public space.</td>
</tr>
<tr>
<td><strong>Interview</strong></td>
<td>Who are you? What are your current involvements with crowd management at mass events?</td>
<td>Daniel van Motman is advisor in planning crowd measures (crowd management) and advising in traffic management situations for the government of Amsterdam. During mass events he directs the crowds and traffic. With his team he is the one for achieving consensus about mobility for all stakeholders. They provide the mobility and crowd management plan for all mass events which is seen as the leading document for accessibility issues in Amsterdam during regular situations and mass events. They do not provide advice for the event producer. They see the event terrain as a black box and take into consideration all that affects the in and outflow of this blackbox and how the visitors of the event affect the accessibility of the city centre.</td>
</tr>
<tr>
<td><strong>Indicators</strong></td>
<td></td>
<td>Indicators for crowds are the flow (doorstroom) efficiency and no injuries or deaths because of crowdedness. They want to have the party going on without delays of people on their way to access the ‘blackbox’.</td>
</tr>
<tr>
<td>Section</td>
<td>Question</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>----------</td>
<td>-------------</td>
</tr>
<tr>
<td>When do we talk about crowdiness?</td>
<td>This entity is hardly described by all stakeholders, even though everyone talks about a certain criticality of the crowd. Here is need for a good quantified measure or statement about what a critical density is for a crowd. He emphasizes that one crowd is not the other if the situation is taken into account and the infrastructure.</td>
<td></td>
</tr>
<tr>
<td>Crowd Management - Crowds</td>
<td>To what extent are flows of people managed?</td>
<td>All people flowing in and out of the event terrain is of issue. No crowd management measures are being discussed in the plans of DIVV of flows on the terrain itself. The flows are categorized as corridors (in vehicle traffic, not in pedestrian traffic although he agrees the same methodology could be applied), ontsluitingswegen, calamiteitenroutes. He also says that nowadays the whole city centre of Amsterdam can be seen as a mass event.</td>
</tr>
<tr>
<td>Safety</td>
<td>What is safety? What is Openbare Orde?</td>
<td>Safety for the individual is if he can continue walking without concerns or disruptions in its perceived safety. For event if all people can go in and out at any time and in the public order is maintained.</td>
</tr>
<tr>
<td>Safety – Disaster</td>
<td>What is a crisis, disaster in crowd management?</td>
<td>Disaster is if people get injured or are caused to death.</td>
</tr>
<tr>
<td>Safety - Responsibility</td>
<td>Who is responsible for safety during mass events?</td>
<td>I argued that event producers usually do not seem to care that much about crowd management because they do not seem to agree on their full responsibility of the crowd. He says that he thought they were responsible. This is the same as Berend Temme of Openbare Orde en Veiligheid of the government of Amsterdam told me.</td>
</tr>
<tr>
<td>Safety – Responsibility &amp; Task Separation</td>
<td>What are the responsibilities and tasks for event producer, city council (OVV) and pentagram safety operators?</td>
<td>DIVV advises and takes part in seeking consensus about mobility of the city. Furthermore they take part in monitoring mass events in providing data from NS and GVB to the ‘bunker’ of the 5-hoek.</td>
</tr>
<tr>
<td>Traffic Management</td>
<td>In which ways are pedestrians incorporated in traffic management?</td>
<td>Separated mobility and crowd management plans for pedestrians and for regular vehicle traffic.</td>
</tr>
<tr>
<td>Traffic mgmt. - Risk Assessment</td>
<td>Are risks assessments part of traffic management?</td>
<td>Not as such. Crowd disasters are taboo. Scenarios are not developed. The only way they assess the situation is advance is by simulation in cooperation with INControl (Alexander van Hees works here).</td>
</tr>
<tr>
<td>Risk Assessment - Case</td>
<td>What are risks, how are they assessed? Which risks assessments are being carried out? Which software is used? Is there an example of a case in which this is done?</td>
<td>How to deal with risk control at Stations and available space for the expected demand? Where do people come from? Where do they go and in which degrees? How much space is needed and how much is provided? Which walking routes are corridors and where are additional measures needed to increase capacity? Are these measures used or not? How come there is a gap between simulation and practice?</td>
</tr>
<tr>
<td>People</td>
<td></td>
<td>Are far more vulnerable than cars. In panic situations everything can happen. Control is harder and has its boundaries.</td>
</tr>
<tr>
<td>Crowd Management - Planning</td>
<td>Which tasks are involved in planning of mass events in Amsterdam Public Urban Space?</td>
<td>In the mobility plan all walking routes, communications intern and with visitors, closing down of traffic and Public Transport redirecting are elaborated needed for the event to take place. Spreading and programming are seen as important measurement options even as ticketing and O&amp;D matrices as data input.</td>
</tr>
<tr>
<td>Crowd Management – Knowledge</td>
<td>To what extend is knowledge on crowds based on experience vs scientific literature? Are psychological factors taken into account?</td>
<td>This is gathered, no knowledge is based in this department yet but since they exists only for two year they are waiting for studies on psychological factors influencing crowd behaviour, infrastructural and traffic flow also via Serge Hoogendoorns’ consultancy agency.</td>
</tr>
<tr>
<td><strong>Crowd Management</strong></td>
<td>Are infrastructural factors taken into account? Are traffic flow factors taken into account?</td>
<td>They say spreading event locations over Amsterdam is a good option together with programming of events and increasing throughput of corridors towards the event locations or closing down public transport facilities to segment the inflow.</td>
</tr>
<tr>
<td>----------------------</td>
<td>---------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Crowd Management - Evacuation</strong></td>
<td>Is there currently a used classification of crowd management measures? Which classification of measures can be applied (prior, during, after or something else)?</td>
<td>No evacuation policies as such are being incorporated. He calls it ‘interface’ with GRIP structure if evacuation is needed the fire department arranges this on the event terrain self. The 5-hoek is traditional in its work process and bureaucratic and hierarchic and static in their work process. The department Openbare Orde &amp; Veiligheid need to get used to the idea that also dynamic processes could help (also in working processes in which DIVV is better). A reason for this situation is that the action group traffic is only 2 years running now.</td>
</tr>
<tr>
<td><strong>Monitoring</strong></td>
<td>To what extent are evacuations part of DIVV?</td>
<td>Really needed is a monitoring system. Data collected can help for example the Druktometer App (N8 also talked about this app).</td>
</tr>
<tr>
<td><strong>Case - Experience</strong></td>
<td>What are drawbacks of planning mass events?</td>
<td>Traffic works are a problem and are usually not planned according to the event agenda of the city. They form extra bottlenecks in the network. DIVV intern arranges the traffic works, however they are now seen as projects and no connection is made between projects and event agenda for a reason one doesn’t know.</td>
</tr>
<tr>
<td><strong>Case – Worst</strong></td>
<td>Which were the key learning moments for you in your experience with crowd management?</td>
<td>Not dynamic setting of management. Amsterdam’s grenzen zijn bereikt. Nowadays the planning of events is not matched with the license agreements This should be done in the near future.</td>
</tr>
<tr>
<td><strong>Balance</strong></td>
<td></td>
<td>Balance seeking between crowd management and tolerance of measures versus city marketing &amp; mayor tolerance level.</td>
</tr>
<tr>
<td><strong>SAIL – Public Transport</strong></td>
<td>Is the tram 10 going to continue towards KNMI island during SAIL?</td>
<td>This plan is ready in February 2015.</td>
</tr>
<tr>
<td><strong>SAIL - Management</strong></td>
<td>Which traffic management measures are taken for SAIL crowds?</td>
<td>This plan is ready in February 2015.</td>
</tr>
<tr>
<td><strong>Planning of crowd management plans</strong></td>
<td></td>
<td>Usually half a year prior to the event a mobility plan is conducted by the event producer which is than assessed by DIVV the month after. For Queensday in April, in December all safety plans and mobility plans are submitted and in January DIVV assesses these plans.</td>
</tr>
<tr>
<td><strong>Need – Efficiency improvement</strong></td>
<td>What is needed to improve the efficiency of flows of crowds at mass events? More knowledge on crowd dynamics? More knowledge on effectiveness of measures?</td>
<td>Yes Plus monitoring network needed with quantification of crowds and infrastructure. Also more need on psychological factors is needed. Al large scan of the environment is needed. Booking.com can help to assess the amount of extra visitors in Amsterdam. The GVB uses this dataset to plan their fleet.</td>
</tr>
<tr>
<td><strong>Data</strong></td>
<td>Data on crowds are gathered from NS &amp; GVB. At NS Central Station arrive 35000 people in peak hour at Zuid 10000 people per hour.</td>
<td></td>
</tr>
<tr>
<td><strong>Framework - Need</strong></td>
<td>Do you agree there is a need for a framework on planning crowd management measures which combines knowledge on crowd dynamics with infrastructural</td>
<td>Yes totally</td>
</tr>
</tbody>
</table>
issues on the event and situation to come to measures?

<table>
<thead>
<tr>
<th>Framework - Requirements</th>
<th>What should be ideally in this framework to succeed in planning mass events for flow efficiency?</th>
<th>How to prevent overcrowding and how to relax overcrowded situations?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Framework – Who?</td>
<td>Who would be very helped with this framework?</td>
<td>DIVV</td>
</tr>
<tr>
<td>Tolerance Safety</td>
<td>Is main requirement for all mobility and safety plans.</td>
<td></td>
</tr>
<tr>
<td>Sources</td>
<td>Who do I have to spoke with for this topic next to you?</td>
<td>I get the MPC plan of Q-day 2013 and of SAIL 2010</td>
</tr>
<tr>
<td>Topics</td>
<td>Which topics can be helpful or which documents?</td>
<td>I should keep him in close contact and do greeting to Serge.</td>
</tr>
</tbody>
</table>

**Interview Annemarie Langeveld Crowd Manager Police Department of Amsterdam in Dutch**

Annemarie Langeveld is hoofd crowd management en control, zie getekend deel-organogram. Dit is gevestigd op Elandsgracht 117 Amsterdam.

**Organisatie**

Terugkerende evenementen zoals Oud en Nieuw of Gaypride of Q-day worden geregisseerd door de Algemeen Commandant van de Politie, OVV, Werkgroep met Daniel van Motman, GHOR en Brandweer.

**Welke crowd management maatregelen worden genomen bij SAIL?**

- Queuing
- Plaatsing van obstakels en barriers
- Verder in te vullen komende tijd, kom maar praten als af is

**Definities massa evenement?**

Massa evenement wordt niet in aantal mensen gedefinieerd, omdat volgens Annemarie aantallen mensen niets zegt over de veiligheid van een bepaald evenement. Dit hangt namelijk meer af van de situatie en wordt zodoende in risico’s uitgedrukt omtrent openbare orde en veiligheid. Het Structuur Grootschalig Bijzonder Optreden (SGBO) wordt ingeroepen bij een massa evenement maar gaat daarbij niet opschalen door de indicator hoeveelheid mensen.

**Aantallen bezoekers als indicator voor massa/ veilig evenement?**

Vanuit veiligheidsperspectief geredeneerd, de grootte van mensenmassa’s is niet leidend voor het veiligheidsvraagstuk. Ook als ik Annemarie confronteer met theorie van massa’s (hogere dichtheid meer kans op crowd disasters) beredeneert zij nog steeds hetzelfde. Veiligheid wordt zodoende niet gemeten aan het aantal mensen op het terrein.

Sterker nog, toen ik later vroeg of ze überhaupt geïnteresseerd was in aantallen mensen zei ze, ja als het me komt aanwaaien prima dan kan ik bekijken of mijn schattingen klopten, maar anders doen we het nu ook prima zonder.

SAIL wordt zodoende gezien als zeer veilig evenement. Waarom? Omdat het overzichtelijk terrein betreft, er is spreiding (aangenomen dus) over de dagen, type bezoekers zijn laag risico nemend en is geen onrust mee gemoeid, het gebeurt overdag, observatie is makkelijk, maatregelen voor doorstroming zijn te beredeneren (1 richting).

**Ervaring met Crowd Management**

Inrichting van het evenemententerrein is bepalend voor gridlock/instroom. Voorbeeld gegeven was Nijmeegse Vierdaagse Feest waarbij eettentjes in het midden voor het podium waren geplaatst. Daardoor ontstond een trechter en was er congestie bij de ingang. Annemarie verwijdt dit aan het gebrek aan zicht op het podium waardoor mensen door de faciliteiten heen naar voren wilden in plaats van de volledige breedte van het terrein naar het podium te gebruiken.


Mensen voelen zich geen onderdeel van het evenement als ze geen zicht hebben op het podium, ook al zouden ze het wel kunnen horen. Daarom is op sommige plekken net buiten zicht van podium en bij instroom naar podium geen plaatsing van hekken nodig.

Tijdens de GIRO tijdrit in Amsterdam waren er extra loopbruggen ingezet, maar er was niet bedacht dat de loopbruggen vooral zouden worden gebruikt door fietsers i.p.v. voetgangers. Daardoor moest politie helpen met fietsen tillen i.p.v. orde houden.

**Risico beheersing**

Met scenario’s wordt bekeken hoe men op welke situatie kan reageren en wie daarbij worden betrokken. Dit helpt ter communicatie en snel handelen van de operationele eenheden. Er wordt altijd rekening gehouden met het scenario onvoorzien waarbij het proces informatie verzamelen nog belangrijker wordt (BOB= Beeld Order Besluit model). BOB communiceert dan over de situatie met OVV (Gemeente).

Scenario’s worden doorgenomen voor organiserend vermogen van de politie. Het geeft de mogelijkheid om processen te standaardiseren.

Er is informatie asymmetrie tussen de 5-hoek, sowieso omdat de politie niet alle informatie mag delen en dit ook niet altijd wenselijk is om paniek te voorkomen in de bunker.

**Verantwoordelijkheden**

Voorheen voerde politie de boventoon in alle beveiliging van evenementen in zowel de uitvoering als beleid. Nu wordt er meer verantwoordelijkheid verwacht van de evenementen organisator. Dit is waarschijnlijk de reden dat ik zulke tegenstrijdige berichten krijg van iedereen over veiligheid en verantwoordelijkheid.

Doel is voor iedereen hetzelfde, namelijk een onverstoorbaar feest. Om dit doel te behalen is het niet nodig aantal mensen te weten. 190 k of 200 k maakt voor politie niet uit, wel voor de NS. Zie een evenement als een reis, als je alleen de hoog noodzakelijke middelen mee heb, kan je de reis prima maken.

**SAIL**

SAIL 2005 is totaal anders benaderd als SAIL 2010 en SAIL 2015, dit komt doordat de situatie waarin SAIL plaatsvindt leidend is voor de crowd management strategieen die door de politie worden toegepast. Dit hangt allemaal af van tolerantiebeleid omtrent veiligheidsrisico’s en die zijn voor elke situatie anders.

Nu is het nog te vroeg om over SAIL maatregelen te praten, behalve dat queuing voor Tall Ships parallel gaat plaatsvinden aan de massa stroom richting. En dat iedereen 1 richting maar op kan lopen.

**Simulatie**

Voorspellende waarde is beperkt. Er is studie in TU Twente geïnitieerd over waarom bewegen mensen een bepaalde kant op en waarom zijn sommige wel te beïnvloeden door matrixborden en anderen niet? Psychische factoren spelen een rol en die zijn nog niet gevangen in de meeste simulatiemodellen.

**Monitoring**

Crowd watchers, camera’s, operationele eenheden, social media en druktemeter app, tickets, tellen, NS, foto’s, enquête bureaus (zeer onbetrouwbaar vaak).

Hoeveel mensen er wanneer waren is onbetrouwbaar informatie op dit moment omdat dit gewoon niet gemeten kan worden vanwege grote foutmarge van de monitoring middelen. Geeft voorbeeld van overbelastte zendpalen en niet iedereen heeft een smartphone etc.

**Factoren**

Deel is publiekstype, area, inrichting, weer, hoeveelheid attracties, type attracties.

**Control proces**

Als paniek uitbreekt

1) Communiceer naar publiek om te kalmeren
2) Help de slachtoffers
3) Overleg verder doorgaan of afblazen

Wat helpt hierbij is het inzetten van klaphekken, looproutes indicatie en visualisatie, 1 richting paden, route advies, corridors aanduiden (wie wil er geleid worden kan dan geleid worden, kan nooit 100% zijn). Hier hoort evacuatie/ontruiming ook bij in overleg met brandweer.

**Cultuur**

Sommige mensen laten zich niet intimideren door ME of politie. Voorbeeld wordt gegeven van vrouw met kinderwagen die de ME wil doorkruisen?! Gemiddelde Amsterdammer laat zich niet regisseren over welke route te nemen.

**Geslaagd crowd management bij mass events?**

Als het thema feestelijk is blijven behouden. Als het evenement onverstoord verloopt. Als Het evenement veilig is gelet op risico’s. Als scenario’s voorafgaan aan evenement goed zijn bedacht en doorsproken. Als er goed wordt opgetreden, ook in onvoorziene situaties. Als iedereen op comfort level zit en niet gespannen is.
In Figure 27 can be seen that different cases are explained by Annemarie. The 2 drawings picture actually 3 events. On the far left one Museumplein is pictured. Which shows the management strategy to fence near station and only provide exits overthere. All inflow is coming from beneath (far most of stage).

When I addressed the issue of people behaviour in panic situation they prefer the exit they took on their way in, Annemarie said to stimulate use of other exits via good communications (stage director, artist, crowd watchers and police).

The drawing on the right side pictures the Nijmegense Vierdaagse Party on the left and Sail on the right. The party shows better flows of inflow when facilities were placed on the outside of the event area and not in the middle. The SAIL case shows queuing development parallel to the mainstream.

In Figure 28 the example of Museumplein is worked out for segmenting with the so called T-shape structure. The inflow is coming at the largest distance of the stage. Barriers between segments are used which are called mojo barriers. The middle of the T shape is used for employees only and is by indication 1.5 meters wide. At the bottom of this path the Front End Office is located. The larger the event the more segments are considered, although this may also depend on the type of event and type of visitors (more actually than numbers, they do not seem to like numbers as one person can cause a lot of trouble). Within the fenced segments sub-segments are conceptualised for efficient communication processes.

An article from the Ingenieur stated that apps help individuals to be on time with UitopTijd and CrowdConnect for better use of datanetwork of mobile phones with Bluetooth and wifi signals to keep on going communication in those situations were crowdedness of the local network would prevent that.
The Figure 29 shows that the crowd management & control department of the police is a subdivision of ‘extra activities not directly related with the police’. The police men and women working here doing this on the side next to their normal functions. This implies that the attention given to mass events is not a priority.
A.4 Socio-Technical System of Crowd Disasters

A disaster can be defined as any extreme or catastrophic condition that imperils or results in loss of life and or property (Bishop, et al., 2010). A crowd disaster is therefore defined as a catastrophic occasion where people are injured or caused to death because of an unmanageable crowd behaviours. According to Fruin (1993) control over movement is lost in those cases that the crowd density equals the plan area of the human body. This is observed at occupancies of about 7 persons per square meter when the crowd becomes almost a fluid mass (Fruin, 1993). Shock waves can be propagated through the crowd, sufficient to lift people over distances of three meters or more. Breathing problems, the heat and thermal insulation of surrounding bodies cause some to be weakened, faint and fall. Removal of those in distress can only be accomplished by lifting them up and passing them overhead to the exterior of the crowd (Fruin, 1993).

All disasters are socio-technical events in nature with human, organizational and managerial features playing significant roles, often in complex relationships with technical characteristics of the associated failure, not concerned by natural hazards (Hood & Jones, 1996). A socio-technical system is determined by its external environment consisting of stakeholders, regulatory frameworks (technology), and financial/economic circumstances. All three areas interconnect within systems’ goals, people, building/infrastructure, technology, culture and processes/procedures (Davis, et al., 2013). For illustration of this perspective related to hazards find Figure 30 by (Hood & Jones, 1996). In this figure, the approach of one “island” focuses on the special problems associated with managing high-magnitude low-probability (here is meant low frequency) events, usually termed “disasters” or “catastrophes” (Quarantelli, 1991), but it is assumed that these islands actually overlap. These overlapping areas form quasi-natural hazards and impose a multi-perspective risk management strategy (Hood & Jones, 1996).

Although the areas of a disaster indicated here are in a way applicable for crowd disasters, they are still too broadly defined. Inspired by the above definition of hazards, crowd disasters could be seen as a hazardous situation within the mass event as a disastrous coincidence of people, environment, procedures and technology. With these four areas all factors involved in crowd disasters are covered. People represent the crowd and show behaviours with effects on crowding. On top of the people forming the crowd, also the management procedures are carried out by people (employees). The crowd management procedures (measures) have a direct effect on crowding. Furthermore, the environment in which the crowd flows is of direct influence on the safety of the crowd (situational and
external hazards) and available capacity (built environment). The last domain to address in crowd disasters is technology in which data on crowding is monitored by management and procedures or measures are communicated via various media and displayed via various devices. This view on crowd disasters is visualized in Figure 31. In this figure the system in which the crowd disaster occurs is pictured.

![Figure 31 Crowd Disaster Domain based on analysis described here](image)

However, there is a need for more specific information on how the most relevant factors within the 4 domains interact with a crowd disaster as result. Different mechanisms for crowd movement are: contact forces, body movement, cognitive processes and social interaction (Seitz, et al., 2014). These phenomena are not captured in the model presented in Figure 31. Therefore, an additional model to study crowd disasters will help which is conducted by Fruin (1993). His model addresses some issues related crowd disasters in more detail, but in the same time this model does not capture all relevant elements of the socio-technical system just discussed as will be seen later. The framework is called FIST, see Figure 32, and shows overlap with the system description in Figure 31 and the mechanisms presented by Seitz et al. (2014).

![Figure 32 FIST Model for Crowd Incidents based on Fruins’ FIST model (Fruin, 1993)](image)
The theoretical model FIST (Fruin, 1993) is conducted to understand crowd incidents in a general matter. It is assumed that with ‘crowd incident’ a ‘crowd disaster’ is mentioned only with a slightly less emotional gravity. For the sake of this paper crowd incidents and crowd disasters are overlapping in the sense that both indicate the same disastrous or incidental consequences by injuries and fatalities of people in the crowd and thus are now seen as equal phenomena.

FIST stands for Force, Information, Space and Time. Force is related to crowd pressures, the next section (to what extent are crowd pressures dangerous) will go into detail to understand this pillar. In addition to the Force pillar of Fruins’ FIST model, pedestrians keep some distance from borders, obstacles and other pedestrians (Helbing, et al., 2000b). This phenomenon can be translated in repulsive forces which are, according to Helbing et al. (2000b) greater in the walking direction than the direction perpendicular to it. These repulsive forces are also found by Löwner (2009) who addressed them as avoidance forces related to obstacles, walls and people. The following forces are related to pedestrian flows in crowded areas are (Löwner, 2009):

- Motivational/will force, which is the desire to reach a place at a certain time.
- Pedestrian collision avoidance force,
- Obstacle/wall avoidance force,
- Pedestrian contact forces,
- Obstacle/wall contact forces

The motivational force is influenced by a variety of factors among which the time constraints, importance of punctuality, location constraints, importance of reaching a place and staying there long enough etc. All the attraction and repulsive forces together with the determined destination form the basis of why and by which route people move through an area in the first place and on top of that show the need for balance between contact forces from walls, people and obstacles and avoidance (will) force to get in contact with moving people, walls and obstacles.

Next to the importance of force, Fruin (1993) states that real-time information and communication are key factors in preventing crowd disasters. For this reason the Information pillar reflects to the information upon the crowd acts or reacts. This subject includes all forms of communication, sights and sounds affecting group perceptions. Furthermore, it entails ticketing, training of personnel, signs and ticketing or promoting.

The total area of the event and density of the crowd and the physical facilities are captured in the third pillar Space. The configuration, capacity, and traffic processing capabilities of assembly facilities determine degrees of crowding. Furthermore, space includes standing and seating areas, projected occupancies, and the practical working capacities of corridors, ramps, stairs, doors, escalators, and elevators (Fruin, 1993). According to Helbing (1997) a skillful optimization not only enhances efficiency but also saves space used for kiosks etc. (Helbing, 1997), which is thus captured in this model. The configuration, capacity and traffic processing capabilities of activities and facilities are basic layer to estimate expected density during the event.

On top of that, the time pillar captures the duration of the event or disaster, event scheduling and facility processing rates. Over the time horizon of the event, the crowd densities will fluctuate and distribute over the facilities and activities (Fruin, 1993).

**Reflection on Crowd Disaster Models**

If both models Crowd Disaster Domain and FIST (see Figure 31 & Figure 32) are compared there is much overlap but also a large difference. The framework by Fruin defines the main factors within a crowd of people by the element Force. Whereas the crowd disaster domain model captures a larger
part with ‘people’. Not only the ‘force’ of people, but also behaviour aspects and demographic distributions could be taken into account. Furthermore with the ‘people domain’ also employees are considered which shows an overlap with ‘procedures domain’. The ‘procedures domain’ of the crowd disaster model in Figure 31 is referred to in one element Information in Fruins’ FIST model. However, ‘procedures’ are not only information and communication but also related to the strategic decisions within crowd management and the crowd management procedures themselves. Furthermore, the Space pillar in Fruins’ framework captures an element of the ‘environment domain’ of the model in Figure 31, however not fully grasping the full domain context with situational factors like weather or social frictions etc. which also have a contribution to the risk of crowd disasters. The last element in the FIST model is the element Time. Time is not captured in the socio-technical domain in Figure 31. The reason for this is that time is not seen as a factor in the system of crowd disasters, but rather a measure of the duration of the disaster and thus an indicator of the gravity of the disaster.

Both the FIST model and the Crowd Disaster Domain model can be used to address the key concepts in crowd disasters. Although the FIST model is useful to grasp the content of the incident on crowd disaster, it still lacks either a macroscopic perspective of the disaster or a microscopic perspective of the disaster. On top of that the crowd disaster domain model gives an overview of crowd disaster factors but lacks the gravitational effect of these disasters and how these factors influence each other in this system. Therefore, both models need to be combined and extended by a more microscopic view on crowd behaviours to understand the attributes related to crowd disasters. In order to do so, first more knowledge is needed on how crowd disasters occur.

**To what extent are crowd disasters dangerous?**

The pressures experienced within the crowds are the determining factor for injuries and fatalities during crowd disasters. Crowd pressures are related to the density of the crowd. These forces can be mathematically described by the average pedestrian density times velocity variance of body movements around the average velocity of the crowd (Helbing, et al., 2007). These pressures cause injuries and death of people.

Whether a particular situation is fatal is statistical, but general rules may be established (Lee & Hughes, 2006a)). They stated that cases involving trampling, which occurred when pedestrians were moving, was found that the density of pedestrians determines the probability of a fatal accident. The cross-sectional size of pedestrians within the crowd is important in determining whether a particular density is dangerous (Lee & Hughes, 2006b), (Fruin, 1993). Previous studies have also identified the density of a crowd as determining factor for the probability of crushing within a stationary crowd (Lee & Hughes, 2006c).

**Consequences of high pressures**

Consequences of high pressures can be categorized into two types of fatal effects (Lee & Hughes, 2006a). The first category considers high crowd densities but people are still able to move and pedestrians are being trampled to death by percussion of the feet or asphyxiation by others falling on top. In this category the forces are being applied vertically and people falling form bottlenecks in the flow, whereas in the second category horizontal forces are more dynamic and the too crowded area doesn’t allow for people falling down. The second category pictures extremely high crowd densities where movement is almost impossible causing death by crushing or compressing asphyxia (Lee & Hughes, 2006b).

In a study by Australian Building Technology Centre five people in simulated panic conditions were able to develop a force of 1370 Newton. Death was estimated to have occurred 15 seconds after a load of 6227 Newton of 4 to 6 minutes at a pressure of 1112 Newton (Hopkins, et al., 1993). It should be taken into consideration that such numbers are highly influenced by gender, age and anatomical build (Lee & Hughes, 2006b).
The fatal causes can be distinguished into two categories. The first category (orange) of hazards relate directly to crowd disaster phenomena, the second category (purple) relates to hazards from mismanagement on extreme situations of the weather (undercooling, dehydration) or of endless duration of congestion (exhausting). Most of the time a combination of these hazards cause death. An example is that the first two hazards (being trampled and being crushed) can lead to suffocating and exhausting which lead to death

- Being trampled
- Being crushed
- Suffocating
- Falling
- Being undercooled
- Being dehydrated
- Being exhausted
Appendix B

B.1 Overview of Factors Influencing Walking Speeds

On walking speeds enough literature is provided. The main findings are presented here and in Appendix B.3 on 133 and applied for archetypes macroscopic flow models for SAIL 2015 in Appendix C.2 on page 155.

Speed

For the speed in multiple directions, as for a pedestrian if \( v(t) \) denotes the velocity of a pedestrian \( i \), then his/hers speed is defined by (Hoogendoorn, 2012):

\[
v(t) = \|v(t)\| = \sqrt{v_1^2(t) + v_2^2(t)}
\]

In Figure 34 this relationship is shown for the flow and density. Unit for flow is number of persons per meter per second and the density in number of persons per square meter.

The desired speed is found Gaussian distributed with a mean value of about \( 1.34 \, [m/s] \) and a standard deviation of \( 0.26 \, [m/s] \) (Henderson & Lyons, 1972). Next to this statement, Lee & Hughes (2006a) found that a critical density is achieved with \( 3 \, [p/m^2] \) and a free walking speed of \( 1.4 \, [m/s] \) (Lee & Hughes, 2006a). However, what is shown here is that various studies have been performed on desired speed of walking, however all differ in context settings and therefore show different results on free flow walking speed.

An example is found by Liao et al (2014), who stated that the density and velocity inside a bottleneck do not depend on the bottleneck width, while the density and velocity in front of the bottleneck change with the width. A linear dependency is found between the flow and bottleneck width (up to 5 [m]). They stated that by analysing only steady state data the slope of the linear relation is approximately \( 2.5 \, [m/s] \). However, differences appear only if the data from steady states are used. These differences indicate the effects of other factors like bottleneck length et al. on the flow (Liao, et al., 2014). Heterogeneity in pedestrian walking behaviour

Pedestrian behaviour can also differ for population groups related to age, gender, purpose, motivation and condition of the physical body. Next to the difference in demography, also the infrastructure and the environment can result in variable pedestrian walking behaviour. On top of that also the weather conditions and temperature have an influence on the pedestrian flow performance. As stated by Hoogendoorn & Bovy 2003b, the personal characteristics like age, gender, size, and the trip characteristics like purpose, route familiarity, luggage, trip length, and the features of infrastructure like gradient of slope, quality of pavement, sightlines, aesthetics, and the environmental characteristics like weather conditions influence the walking speed.

Heterogeneity in desired speed has a large impact on the probability of flow breakdown (Campanella, et al., 2009). They showed that in a homogeneous flow, the probability for a breakdown was estimated to be 25% with an inflow of \( 1.5 \, [p/m/s] \). With the same inflow and varying desired speed the probability for a breakdown was estimated to become 100% (Campanella, et al., 2009). At a lower inflow of 1.375 pedestrians per meter per second and non-varying and varying reaction times the probabilities for breakdown were 20% versus 85% respectively (Campanella, et al., 2009). The heterogeneity lies especially in desired walking speed in this case. Since it is verified that taller people
walk faster, the number of tall people influences obviously the overall pedestrian velocity (Brščić, et al., 2014). The heterogeneity in desired speed caused a reduction in the average speed of pedestrians from 10% in lower inflows to 50% in higher inflows (Campanella, et al., 2009).

Brščić (2014) showed that speeds of flows may also differ related to the moment in the day (tardiness at evenings and hastiness at mornings). In normal conditions without panic or stress, pedestrians tend to walk at a comfortable average speed at the least energy-consuming walking speed (Miguel, 2013), (Helbing, et al., 2000b).

**Multidirectional vs unidirectional flows**

In Figure 33 a logarithmic scale is used with the uninterrupted line for unidirectional streams with a free flow walking speed of 1.17 \([m/s]\) and the interrupted line for multidirectional streams with a free flow walking speed of 1.10 \([m/s]\). This analysis by Miguel (2013) implies a maximal design density of 3 \([p/m^2]\) for unidimensional flows and 2 \([p/m^2]\) for multidimensional flows. It is found that the relaxation time is higher for pedestrians in the multidirectional streams, because of the interpersonal distances between pedestrians in this domain are larger than in the unidimensional domain. The existence of a multidirectional flow requires that pedestrians are more attentive, and therefore need more time to adjust their motion (Miguel, 2013), which implies a larger relaxation time. The relaxation time is of influence on the maximum density of the flow and the desired walking speed thus on the total flow performance.

![Figure 33](image)

*Figure 33 Pedestrian flow-density diagram for unidirectional streams (uninterrupted line) and multidirectional streams (dotted line) (Miguel, 2013).*

In Figure 34 Miguel (2013) showed the relationship for the pedestrian flow versus walking speed \([m/s]\). The optimal walking speed for multidirectional streams is about 0.55 \([m/s]\) which is only slightly less for unidimensional streams of 0.59 \([m/s]\). This indicates no gain is received by obtaining a dense flow with multiple directions. In fact, only disadvantages are encountered because of a decrease in comfort which can trigger hastiness, pushing or even panic more easily.

In these figures each speed corresponds to one pedestrian flow, however all pedestrian flows are linked to two different walking speeds because of formulation of flow as a function of density times walking speed. In free flow conditions the increase in walking speed can be compensated by a decrease in density, resulting in stable flow conditions. However in unstable conditions after reaching maximum flow, a reduction in flow occurs because of the increase in walking speed which cannot be
compensated by a reduction in pedestrian density (the same counts for an increase in density which then cannot be compensated for a decrease in walking speed). This means that a particular pedestrian flow may correspond to two different walking speeds.

![Pedestrian flow-speed diagram for unidirectional streams (uninterrupted line) and multidirectional streams (dotted line) (Miguel, 2013).](image)

**Figure 34** Pedestrian flow-speed diagram for unidirectional streams (uninterrupted line) and multidirectional streams (dotted line) (Miguel, 2013).

**Physiological and Demographic Factors Influencing Walking Speeds**

There are physiological and demographic factors influencing the desired free flow walking speed of pedestrians. The physiological factors are length, age, body mass and gender. The demographic factors are group size, tasks and nature of behaviour.

**Physiological Factors on Speed Elaborated**

First the physiological factors are being elaborated upon.

**Length and Speed**

Bipedalism is the principle of human locomotion. Increasing speed goes with increasing step lengths (Seitz, et al., 2014). Seitz et al. (2014) showed significant relation between step length, speed and direction. Step lengths may be larger for people who are taller.

There is a relation between the differences of lengths of pedestrians and their walking speeds. An on average higher pedestrian length results in a walking speed increased linearly with the growth of the length from 1.45 [m] to 1.8 [m]. In between 1.2 and 1.45 [m] the speed decreases (Brščić, et al., 2014). Thus it is acceptable to state that a higher share of taller people (above 1.45 [m]) the overall speed of the flow is higher under same density conditions in free flow domain.

**What is known about the difference in desired gap distance between pedestrians?**

Distance in between pedestrians is estimated to become smaller when people hurry (walk faster) or when density increases (Helbing, et al., 2000b). According to Miguel (2014) the gap between pedestrians can be related to the stage in the fundamental relationship between flow and density, see Figure 35.
As can be seen in Figure 35 is that on average the interpersonal distance [m] in one direction is smaller for female than for male at same walking speed and same density. As is shown in Figure 37, the walking speed is correlated with the body mass index. Because of this leverage the interpersonal distance for females was logically expected to be lower than for males. According to the experimental diagram constructed by Miguel (2013) this correlation is found to be true.

**Age & Speed**

In Figure 36 the walking speed in relation to people’s age is shown. The dots in the line plots represent open the women and closed the men. With this figure a clear distinction can be made between elderly people (from 60 onwards) and younger adults (from twenties till sixties). In the research of Bohannon (1997) 230 individuals between 20 and 79 years participated walked over a 7.62 [m] expanse of a floor where both comfortable and maximum speeds were measured. He showed that age, height and all muscle action strengths correlate significantly with both comfortable and maximum (gait) speed. For maximum gait speed, gender correlated significantly. He also stated that no correlation was significant between leisure nor work activity and the gait speed.

The following can derived from the plot in Figure 36 (Bohannon, 1997):

- Elderly female average walking speed = (1.3 and 1.27)/2 = 1.29 [m/s]
- Elderly men average walking speed = (1.35 and 1.33)/2 = 1.34 [m/s]
- Younger female average walking speed = (1.40 and 1.41 and 1.39 and 1.38)/4 = 1.40 [m/s]
- Younger men average walking speed = (1.40 and 1.44 and 1.44 and 1.39)/4 = 1.42 [m/s]
Body Mass Index & Speed

As also can be seen from Figure 37 on average the walking speed is higher for male than for female of same age and this is also related to the higher body mass index of males compared to females (Miguel, 2013).

Demographic Factors on Walking Speed

Here the demographic factors on walking speed and flow efficiency will be elaborated upon.

Tasks and walking speed

Next to this it is found that if multi tasks are performed during walking, the gait velocity decreases as pedestrian movement complexity increases (Li, et al., 2013). This means that pedestrians who make complex decisions about for example their route choice without full knowledge and information on the routes and activities to choose, will reduce their speed. This may result in reduction in walking speed in advance of a cross-section or at the cross-section.
Group size & speed

![Graph showing the effects of group size on average walking speed at low and moderate density.](image)

**Figure 38** Effects of Group size on average walking speed at low density (grey y = -0.04x + 1.26) and moderate density (dark grey y = -0.08x + 1.24) in multidirectional flows (Moussaïd, et al., 2010)

As is depicted in Figure 38 the walking speed depends on both density and group size. Moussaïd et al. (2010) demonstrated that 70% of people in commercial areas are walking together in groups and the group sizes are rarely bigger than 4 [p] per group. The group sizes were found to be distributed according to a Poisson distribution in social situations where stable relationships in combinations of individuals was observed (James, 1953), (Moussaïd, et al., 2010). According to Moussaïd et al. (2010), at moderate density (0.25 persons per square meter) and with large group size of 4 people per group the walking speed is about 0.9 meters per second in multidirectional flows, whereas at low density (0.03 persons per square meter) and equal large group size of 4 the walking speed is on average 1.2 meters per second. A clear trend of increasing group size and lower walking speed is becoming clear from this study by Moussaïd et al. (2010). The slope of the fitted curves per density scenario differ in a factor 2, however if this is significant is not to say. Firstly, because this curve is only plotted through 3 data points and secondly, because the plot of the population B does not seem to fit the data points. The error bars indicate the standard error of the mean value. Therefore, the hypothesis is that the correlation for group size and average walking speed does differ for the different densities, but that the trend is the same (increase in density means decrease in walking speed for different group sizes, only may not be a linear relationship).

In Table 31 the different walking speeds [m/s] are given for varying group sizes from 1 to 5 in four different case studies. Tarawneh (2001) collected data of 3500 pedestrians at 27 crossings in Jordan. Also his result shows the trend of increasing group size and decreasing walking speed. It is argued by Cheng et al. (2014) that the effect of group sizes and related interaction at crossing is weak because people are in relative unsecure situation and therefore tend to cross rather than engage in conversations during their crossings. It is assumed that these crossings refer to crossings of car traffic. This means that the difference in speed found by Tarawneh (2001) at crosswalks do not differ much for different group size.

Another study of walking speed correlated to group sizes on 18 different sidewalks in 5 cities in India at two peak periods a day, showed that the groups of size 5 or higher split in subgroups resulting in a
higher subgroup speed than average speed related to the group size (Rastogi, et al., 2011), see ‘sidewalks’ row in Table 31. At wider sidewalks they found that this phenomenon was absent. According to the social force model of Helbing & Molnar (1995) groups tend to stick together and avoid splitting up. By study of Singh et al. (2009) showed that only in 22% of the cases the groups split in avoidance of collision.

Table 31 Mean Walking Speed [m/s] of pedestrians in different group sizes by four different studies (Cheng, et al., 2014)

<table>
<thead>
<tr>
<th>Source</th>
<th>Locations</th>
<th>Group sizes</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>&gt;5</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Crosswalk</td>
<td>1.35</td>
<td>1.35</td>
<td>1.33</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Klupfel (2007)</td>
<td>World</td>
<td>1.38</td>
<td>1.28</td>
<td>1.24</td>
<td>1.24</td>
<td>1.22</td>
<td>1.10</td>
<td></td>
</tr>
<tr>
<td>Exhibition</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schultz et al. (2010)</td>
<td>International Airport</td>
<td>1.36</td>
<td>1.06</td>
<td>0.96</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sidewalks</td>
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<td>-</td>
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</tr>
<tr>
<td>Rastogi et al. (2011)</td>
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<td>0.90</td>
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</tr>
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<td>Precincts</td>
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<td>-</td>
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<td>1.00</td>
<td>1.00</td>
<td>0.89</td>
<td>0.83</td>
<td></td>
</tr>
</tbody>
</table>

Findings on groups shapes and influence on flow

Up to 70% of people in a crowd are moving in groups which constitute medium-scale aggregated structures in a thong (Moussaïd, et al., 2010). Group sizes are Poisson distributed (Coleman, 1961) as is the distribution of spoken contributions among group members (Moussaïd, et al., 2010). Moussaïd et al. (2010) found that with increasing density the linear horizontal walking formation started to bend forward in walking direction into a V-shape. They believe this shape is conform a comfortable communication position. However, this V pattern is assumed non-efficient for the flow because of the non-aerodynamic shape. Therefore, with increasing crowd densities the trade-off is made between walking faster and comfortable social exchange.

The patterns found differ for group sizes (Moussaïd, et al., 2010). For a group size two, people stand next to each other facing the walking direction. For a group size three the V-shape is formed where the middle person stands back. For groups of size four the V-shape turns into a U-shape where two people on the outside standing in line and in front of the middle two people. For high densities the social interaction constraint loses from the physical efficiency and people start to walk behind each other rather than in V-shapes (Moussaïd, et al., 2010), (Singh, et al., 2009).

Cultural heterogeneity

It is shown that pedestrians have a preference for a certain side (Weidmann, 1993). For example, in Germany this is the right-hand side. Therefore, it is admissible that this preference is culture bounded. Another study by Singh et al. (2009) also indicated a preference for the left side to avoid collision over the right side in the UK (Singh, et al., 2009).
Japanese people have a tendency to walk left side, but splitting of flows in corridors converges to zero in case of very low densities in either narrow and or slightly irregular environments as is investigated by Brščić et al. (2014). It is also stated that by increasing density and increasing separation of flows, fast pedestrians move towards the right side of the corridor (Brščić, et al., 2014) in the Japanese environment. It is assumable that this tendency is the same for all cultures with left side dominancy in traffic. This behaviour is considered part of self-organisation and therefore at high densities this will probably not be observed.

Next to these findings, a study by U. Chattaraj et al. (2013) showed that cultural differences in the distance headway could be explained by the fact that is some cultures the interpersonal space is larger than in other cultures (Chattaraja, et al., 2013) and that this could be interpreted by a change in the speed-density relationship of the fundamental diagram.

B.2 Which features of infrastructure influence pedestrian movement behaviour?

If infrastructure can be seen broader as the interaction facilities between the built environment and pedestrians, pedestrians tend to change the environment by trails which evolve over time (Helbing, et al., 2000b). According to Lee et al. (2006) the local walking speed of pedestrians is not only highly correlated with local crowd density but also in correlated with the local conditions. Thus, the effective walking speed of a crowd varies with the surrounding density and changes with conditional changes in complexity of the environment (Lee & Hughes, 2006a). These statements imply that there is a strong need to take into account infrastructural features in determining the flow of the crowd at different locations in the public urban space.

A remarkable consequence of traffic dynamics on management is that the complex interaction between various flows can lead to completely unexpected results, blaming the nonlinearity of dynamics (Helbing, 1997). According to Helbing (1997) this means that planning of pedestrian facilities with conventional methods does not always guarantee the avoidance of big jams, serious obstructions, and catastrophic blockages (especially in emergency situations). In contrast, a skilful flow optimization not only enhances efficiency but also saves space that can be used for kiosks, benches, or for other purposes (Helbing, 1997).

These features of urban design which influence the pedestrian behaviour are: street profile (height & width), building continuity, presence of trees, quality of facades and pavements, brightness, colour, water presence, sight line length (straightness of streets), view on landmark, curved street and shielded sight (Korthals Altes & Steffen, 1988). These characteristics of the built environment and infrastructure influence the spatial aspects which can be perceived by the individual for route choice. Korthals Altes & Steffen (1988) found that three spatial aspects influence the individual appreciation of spatial quality: privacy/shelter, visual appeal, and spatial orientation. They state that this appreciation is found to be the determining factor for route choice. Korthals Altes & Steffen (1988) motivated that choices for routes in the city of Delft were namely based on those spatial aspects which were seen as the dependent variable for route choice of pedestrians (60%) in this case of way finding through Delft. Korthals Altes & Steffen (1988) also stated that next to the spatial aspects, choices for routes were also based on functional aspects (29%), traffic liveability (9%) and networks aspects (2%). Although this case was on way finding through a city centre in the Netherlands, these findings can be extended towards a mass event area in public urban space were people need to find their way through the built environment. Furthermore, they stated that more research is needed in determining these factors more specifically and thus these values should only be used only as indication.

On top of these urban design features, Helbing et al. (2000b) found that pedestrians keep some distance from borders, obstacles and other pedestrians. These can be seen as repulsive forces which are greater in the walking direction than the direction perpendicular to it, say Helbing et al. (2014). These repulsive forces are also found by Löhner (2009) who addressed them as avoidance forces.
related to obstacles, walls and people. He states that these repulsive forces also depend on pedestrians’ desired walking speed and space requirements to walk in a specific direction (Löhner, 2009). A study performed by Gdoura (2014) showed that placing columns in the walkable areas did not influence the pedestrian motion significantly. Remarkably, even at high densities, the columns had no noticeable influence on the pedestrian motion. Furthermore, the forces measured on the columns were very small, particularly when the density of the pedestrians was highest (Gdoura, et al., 2014).

Next to the repulsive forces, people are being attracted to sights, windows and performances which can be captured by attractive forces (Helbing, et al., 2000b). However, it is found that parameters for these attractive forces are not very sensitive for the total collective performance of pedestrian crowds (Helbing & Vicsek, 1999). Nevertheless, it can follow that within scenarios of mass events these attractive forces can trigger queuing which can block the mainstream flows. Therefore, these forces should not be neglected in the framework. Blocking of flows result in oscillatory changes in the walking direction and periods of standstill occur when different flows cross each other or when the bottleneck (queue in this case) has to be passed which also result in lower flow rates (Helbing, et al., 2000b). According to Helbing et al. (2000b) the loss of efficiency caused by this can be reduced by psychological guiding measures or railings initializing roundabout traffic. Roundabout traffic can be reduced and stabilized by planting a tree in the middle, which suppresses the phases of ‘vertical’ or ‘horizontal’ motion (oscillatory changes in walking directions or periods of standstill) in the intersection area this shown in Helbing et al. (2000b) simulations by an increased efficiency up to 13% (Helbing, et al., 2000b).

At these flow crossings, merging occurs which is a common movement of crowds which firstly is highly complex to study and secondly may cause stampedes and crushing incidents (Lee & Hughes, 2006c), (Moussaid, et al., 2011), (Helbing & Mukerji, 2012), and is such feature which is influenced by infrastructure. It is shown that the merging angle and pedestrian speeds can significantly influence flow rates and headway distributions (Aghabayk, et al., 2014). Although the increase in inflow angle resulting in a growth in flow rate is intuitively assumed to be right, this statement is not yet validated due to lack of data (Aghabayk, et al., 2014).

Infrastructural Features

For assessing the influence of different infrastructural features on the flow or behaviour of pedestrians, a brainstorm sessions was held with PhD candidate Dorine Duives of the TU Delft. With a few infrastructural features the main influences on the flow were reasoned through in case of unidirectional flows. The following describes the most interesting findings of this session.

It is found in empirical research that the experience of outdoor environment, temperature and wind all influence the velocity negatively. However, no consensus on a clear relationship between the influence of weather, wind, temperature and the velocity is achieved. Duives (2015) concludes that pedestrians behave differently depending on the expected duration of movement within the encountered weather conditions (Duives, 2015). Which suggest that in case of high temperatures and longer walks pedestrians will walk slowly than if they only need to cross in the outdoors at the same temperatures. This may be the result of a surviving strategy of human beings.

For assessing as many infrastructural features of importance the following factors were described in their extremes:

- Continuation of the built environment
- Density of crossings
- Shape of pathways, crossings & roundabouts
- View on landmarks
- Aesthetical contribution
These factors were obtained by reading papers on walkability in cities by (Leslie, et al., 2004), (Korthals Altes & Steffen, 1988), and experiencing the infrastructure for pedestrians in Amsterdam by walking the SAIL route physically and via Google Earth and Google Maps street views.

With simple illustrations the subject is given a form. All subjects are discussed here.

**Continuation of the built environment: Long continuation of buildings next to pedestrian walkway**

Because of the profile, pedestrians have less options to avoid obstacles or blockades. In this case there is less natural light on the path. This may result in higher perceived density because of cramped feeling and less natural light.

Next to this, if it rains, here it is dryer than on grassland. When it rains pedestrians tend to walk faster, but this is with the bias that less pedestrians are at the location outside, especially on weekend days. Therefore, it is not known what the influence of rain is on the flow efficiency in case of a mass event. Today, people are better able to prepare themselves because of available and accurate weather and rain forecasts. Therefore, people might not be surprised by the rain when visiting a mass event and thus are well prepared. This entails a population with umbrellas, ponchos and walking boots. The umbrellas might influence the visibility of the visitors, but also the walking speed can be influenced because people want to walk faster to get to the comfort zone quicker and wear appropriate boots to accommodate the speed in the more slippery circumstances. More data should be obtained within for example attraction parks on rainy days on the flow efficiency compared to sunny days with about the same density or demand to see if the rain and/or the wear influences the flow.

**Discontinuity of the built environment & high density of crossings**

Pedestrians are more able to avoid obstacles and have higher flexibility in route choice. A higher set of route choice options will result in lower average speed because more time is needed to decide on routes to take. More crossings will result in more turbulence in general especially at high densities. In this case there shades less natural light on the path. More turbulence and less natural light may result in higher perceived density because of cramped feeling and less natural light.

**Shape of pathways, crossings & roundabouts**

Angular built environment at intersection (bottom-left), circular built environment at intersection (bottom-right) without sight (up-right) and with sight (up-left).

Pedestrians keep certain distance from the buildings. If this distance is cultural related is not known. Perhaps people from cities will pass buildings with a shorter distance in between than people from county sides, but this is a hypothesis which should be tested first. The distance to the buildings is not known, but what can be concluded is that a hallway or a street with pathway directly ending at the presence of the buildings will have less capacity than in case the buildings were replaced by grassland because of people’s need to swerve, and thus need a buffer space to walk at the edge.

In case people cannot see pass the corners or through the corners, the people will walk to the left or right with a larger angle than if they would see through or pass the corners, see picture on the right.
If people have the possibility to see coming pedestrians they are better able to anticipate. By better anticipation, people tend to cross more efficiently. They are able to because they had the possibility to assess the information of the crossing in advance of the crossing. Furthermore, with anticipation self-organisation is encouraged by means of the zipper-effect.

Next to this, if people could turn the corner in a more natural way this would not need the large angle of approach in case of angular corners (see picture on the bottom left), especially if the visibility at the crossing has increased. The angular corner will not allow to cut off the corner, which is a natural habit of people. See as example this crossing on the right a natural angle of turning left or right.

Circular built environment and roundabout with an ordinary tree

A roundabout allows for efficient crossing of flows. The tree gives people the information in advance of the crossing that this crossing will be a roundabout. In this case this limits the information needed to assess the crossing at the crossing and therefore people will take routing decisions earlier. This may result in a faster flow at the intersection. People can focus on operational tasks of walking because of efficiency and simplicity of the crossing and the fact that the tree indicates clearly the middle of the crossing. In this case it is an ordinary tree placed in the middle of the roundabout, however if it was an unordinary object or tree this would lead to distraction of operational walking tasks. In the latter case, people would slowing down or wanting to stop. When the tree is being replaced with information signs on routing, the efficiency effect is being dismantled, because people are being distracted from focusing on the operational tasks of walking at the crossing.

Short stairs

The presence of stairs will assumable decrease the average walking speed. However, the distance covered by those stairs is also of influence on the speed. For shorter stairs the upstairs speed is on average higher than for longer stairs (Kretz, et al., 2006). Next to this, people may feel urged to take a speed which is higher as their desired speed in case densities are higher, this can also be seen in Figure 39. In Figure 39 an overview is presented of the different speeds for a short staircases in case (A) of low density, (B) medium density and (C) high density for short staircases in upward and downward directions at unidimensional flows. For shorter stairs the upstairs speed is on average higher than for longer stairs (Kretz, et al., 2006). Furthermore, Kretz et al. (2006) found that on short stairs upwards people accelerate but never downward and never on longer staircases. However, no common scaling factor was found.

<table>
<thead>
<tr>
<th>Category</th>
<th>A</th>
<th>B</th>
<th>C</th>
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</thead>
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<tr>
<td># of persons upstairs</td>
<td>10</td>
<td>62</td>
<td>19</td>
<td>91</td>
</tr>
<tr>
<td># of persons downstairs</td>
<td>6</td>
<td>38</td>
<td>38</td>
<td>82</td>
</tr>
<tr>
<td>Mean upstairs</td>
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<tr>
<td>Mean downstairs</td>
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<tr>
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</tr>
<tr>
<td>Maximum upstairs</td>
<td>1.43 m/s</td>
<td>1.86 m/s</td>
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<tr>
<td>Maximum downstairs</td>
<td>1.33 m/s</td>
<td>0.96 m/s</td>
<td>1.39 m/s</td>
<td>1.39 m/s</td>
</tr>
</tbody>
</table>

Table 2: Horizontal walking speeds on a short stair.

*Figure 39 Overview on walking speeds on a short staircase (Kretz, et al., 2006)*
Gradient difference, angle of approach and street levelling, obstacles

It is assumable that people walking an inclined slope have a lower speed than average and people walking a declined slope a higher speed than on average at a horizontal slope. Next to this the angle of approaching the main stream is of importance even the direction of flows.

In case the figure on the upper left indicates a mainstream flow at level 1, bidirectional in The Netherlands, the people from level zero wishing to go to level 1 and walk to the left will have a problem because of the angle which is less than 90° and because they have to cross the mainstream flow to the right at level 1. With this angle of approach they will not be fully capable to see coming pedestrians in advance and therefore cannot anticipate on crossing the flow in a self-organised matter (zipper-effect). This may result in a standstill at the first crossing location or turbulence in the mainstream flows at level 1 at the crossing location. Consider the figure at the bottom with the same case as above only in which the levels are also connected on the left side with a larger angle of approach. This case shows that people from level 0 to level 1 to the left can cross the mainstream flow at the right with large visibility because of the angle of approach of about 130°. This will benefit the self-organisation here.

Next to the slope differences, in some cities the street level is different for houses with pathways next to it and separated bicycle lanes and car lanes. With levelling this separation is made clear. However, in cases the whole street profile will serve pedestrians, these levels can reduce capacity because people will try not to walk in the middle of the levelling but aside of it. For lower densities this capacity reduction will be negligible, but for higher densities this is not. Furthermore, these infrastructures ask for careful walking behaviour which may result in a decreased speed.

The picture above presents another issue, which are parked bikes, and street lanterns or other obstacles parked along a dense urban space. This will for sure decrease the capacity and increases local turbulences because of people need to deal with the small reduction in capacity inwards of the stream of people.

\[5\ http://upload.wikimedia.org/wikipedia/commons/f/fa/Amsterdam___Bicycles___1058.jpg\]
People will stand still or slow down for seeing the attraction and deciding to go for a visit. Therefore, there is a possibility that people form a blockade on the main flow and a reduction in flow inefficiency. People are forced to take better notice on signs for directing them to the attraction than if they had full visibility on the landmark. People standing still or forming a blockade can be dismantled by putting fences to block the view or provide standstill space in front of the attraction. In case of full visibility (drawing on the right), people will walk more relaxed and possibly faster because their goal is visible. Furthermore, in this example there is grass and a lot of light which mitigate the feeling of being cramped between buildings. Next to this there is possibility of passing via the grass as such the capacity of the path is somewhat larger than would be in the case drawn on the left.

Aesthetical contribution: Presence of water on one side

Presence of water reduces the available walking space because the edge with the pathway and the water is avoided. Especially flows with children will keep a substantial distance from the water side. Because of the light at the pathway a cramped feeling is avoided. Next to this, natural light of the environment with water presence is highly valued in aesthetics of the environment. This will result in a relaxed atmosphere. If this also influence the walking speed is unclear. It does influence the mood of pedestrians and therefore maybe their walking speed.

In case of fences places at the waterline the capacity is assumed to benefit from this. First of all, because people do not fear falling over the fence and thus can walk very close to the water border. Second of all, if the fences are low enough and in case of multidirectional flows the upper body can move over it, allowing pedestrians to swerve inwards the fence a little bit for passing others.

How do pedestrians route through an environment?

Some principles are found in literature, (Hoogendoorn & Bovy, 2003a), which govern the process of walking through an environment on crowds vs individuals, speed, routing, collision avoidance, and groups within crowds.

Human behaviour and crowd behaviour principles

Human behaviour is goal-directed and people develop goal hierarchies, which influence their decisions as time evolves. This is why crowd behaviour can be described as goal-directed (Lee & Hughes, 2006c). Crowds are able to make cohesive, united decisions regarding their direction and speed of movement even when only a few members have the information necessary to make such decisions because of so-called herding behaviour. On top of that, individuals act rather automatically and do not reflect on their behavioural strategy in each new situation, but instead learn optimal behaviours over time by trial and error (Helbing, et al., 2000b). With learning more information is available to make choices which can result in benefits for individuals to reach a certain destination, access it or be more familiar with the environment. The degree to which these informed individuals can then be influential over the crowd is largely dependent on their spatial positioning, with those in the core likely to be of greater influence (Dyer, et al., 2009). This is particularly important during an emergency evacuation when decisions need to be made quickly.

Individuals will move according to the principle of ‘least effort’ aiming to minimise time and costs, avoid congestion and maximize their speed (Challenger, et al., 2009). They stated that if sufficient time is given to reach a destination, people will walk according to least effort walking speed which is the
normal comfortable walking speed. If multiple route choices of the same length are available, individuals will generally take the one which offers the straightest route and the best lines of sight, with the least changes in direction, for as long as possible (Nishinari, et al., 2006). However, they stated that if an alternative route of equal length is more attractive in its aesthetic features people may opt for this instead of taking the fastest or most direct route.

In order to avoid collisions, people try to keep a certain distance from other people and from environmental borders, such as walls or obstacles. This distance decreases if the individual is in a hurry or if crowd density increases, for instance, around a particularly attractive place, such as a food outlet (Challenger, et al., 2009). Furthermore, Seitz et al. (2014) compared trajectories around a corner 180° or around a corner of 90° of which the trajectories show a clear difference in distance towards the wall. Pedestrians accepted smaller inter-wall distances to the obstacle when walking around a corner in 180° marked with tape than when they walked along a corner of 90° marked with tape and tables of 76cm height, please find Figure 40. A reason for this is that the table influences the perceived available space. For example, buildings or fences do not allow for swerving, whereas over the line swerving does not matter.

Crowds do not fill a space evenly, but rather cluster, exploit short-cuts and exhibit herding behaviour (Still, 1989-2014). Hierarchically organised groups, like parents with children, are likely to behave differently to groups that are not dominantly organised according to a hierarchy (Pan, et al., 2006). They stated that hierarchically structured groups will tend to stay together and follow the leader. If group members become separated, they are likely to try to reform their group before exiting. However, this may produce movements contrary to the main flow of the crowd which can hinder the flow as a whole (Pan, et al., 2006).

Way finding
Furthermore, individuals prefer not to take detours or to move in the opposing direction to the main crowd flow, even if the direct route they subsequently choose is crowded (Helbing, et al., 2000b). Furthermore, when various routes with same length and same qualities such as light, traffic lights and noise are optional one prefers the one which is straight ahead as long as possible (Helbing, et al., 2000b). According to these researchers this behaviour could cause hysteresis as pedestrians tend to use one way to go to a certain point and another to come back.

Often the purpose is to find an exit. According to Haghani et al. (2014) the following factors influence the exit decision: Distance, Congestion, Visibility, Habit, Following, Avoid Turning, Opposite Flow and destination. All have estimated different stated preferences among their respondents. In this study the “following”, “habit” and “avoiding turning” seemed less preferred as dominant factor for choosing a specific exit. While the factors “distance”, “congestion” and “destination” were scored highest of all factors. Furthermore, the factors “visibility”, “opposite flows” received relatively high scores. However, due to the stated preference collection, these impressions should be strictly seen as primary vision to the relative importance of the factors and specific margins of these factors cannot be seen as valid representation (Haghani, et al., 2014).

According to Lynch (1960) way-finding is assisted by (mental) images of spatial features like paths, landmarks, regions, edges and nodes (Lynch, 1960). Way-finding can be described as the act of travelling to a destination by a continuous, recursive process of making route-choices whilst evaluating previous spatial decisions against constant cognition of the environment (Conroy, 2001); or by navigation composed of locomotion and way-finding (Montello & Sas, 2005). Principles for effective way-finding include (Drakos, 1998): (1) create an identity at each location, different from all others; (2) Use landmarks to provide orientation cues and memorable locations; (3) Create well-structured paths; (4) Create regions of differing visual character; (5) Do not give users too many choices in navigating; (6) Give a map; (7) Provide signs at decision points to help way-finding decisions; (8) Use sight lines to show what is ahead. Especially point 5 indicated here will influence the flow of the crowd, because a larger choice set will result in more time needed to choose a route and therefore a longer duration of a lowered walking speed.

According to Montello & Sas (2005) several factors influence the performance of way-finding by individuals. In these factors they distinguish three categories. The first category entails the psychological factors in way-finding which are orientation, attention and the automaticity of way-finding tasks. The next category encounters environmental factors which are differentiation of characteristics in the environment, visual access to various viewpoints within the environment, layout complexity (generally more complex means more articulated space segmented into more parts) and sign placement. The final category are the factors related to technology which are design of information displays and navigational systems. They also emphasize the importance of differences between individuals which influence the performance of way-finding by for example factors like gender, computer experience and spatial skills (Montello & Sas, 2005). The optimal share of verbal and graphical information differs per individual, as such the modality to present the information varies as well.

**B.3 Macroscopic vs Microscopic Pedestrian Flow Models**

A clear distinction has been made between microscopic modelling and macroscopic modelling. Both perspectives encounter benefits and disadvantages. A macroscopic modelling does not involve interactions between pedestrians and ignores the dynamics of pedestrian flows nor the heterogeneity among them. This results in a model suitable to determine loads in a network against relatively low calculation speed, but rather unsuitable for capturing real-world pedestrian flow cases. In contract,
the microscopic model does distinct in individual flow properties, decision-making and interaction among pedestrians by a set of pre-determined rules and thus is better able to present accurate pedestrian behaviour in different situations. However, this goes along with a relatively large and detailed data set needing high computational power and time. Next to the scale of the modelling the models could be discrete or continuous, deterministic or stochastic, rule-based or force-based and contain high or low fidelity (Schadschneider, et al., 2011).

The social force model is a microscopic continuous model of which the concept is drawn by Lewin and Cartwright in 1952 and the model is computed by Heling and Molnar in 1995. This model assumes that the total motivational force for pedestrian motion consists of a summation of 5 forces (Cheng, et al., 2014): (1) desire to reach a certain destination or goal, (2) total influence from other pedestrians (repulsive effects), (3) the total repulsive forces of obstacles and walls, (4) the attraction forces of other persons or objects and (5) the fluctuation term demonstrating complex behaviour. This model is capable of showing lane formation in self-organisation, oscillatory walking behaviour at narrow exits and escaping in panic situations. A main advantage of this model is its simplicity, small number of parameters and its repetitive use which eases simulation. This model is been extended with a group term by Moussaid et al. in 2014.

Other models are the Cellular Automata Model (CAM) and Agent-Based Model (ABM). The CAM is rule-based, microscopic and discrete. It uses a uniform grid of cells and at each time step the variables are updated according to a set of local rules. The ABM is a bottom-up model by simulating autonomous decision-making of agents who follow pre-determined rules. This latter model suits for studying complex environments.

According to Helbing et al. (2007) current simulation models of crowd panics fail at an important issue. They capture no turbulent crowding dynamics because these simulation models neglect the fact that the propulsion force of people will increase in areas of extreme densities (Helbing, et al., 2007).

B.4 Phenomena Related to Crowd Disasters

A crowd disaster can occur as soon as effective self-organised flows are being suppressed. Within a short period of time, the density can increase substantially up to even 10 pedestrians per square meter (Hoogendoorn & Bertini, 2012), (Helbing, et al., 2007). In case of high densities at bottlenecks, smooth pedestrian flows can break down resulting in other collective patterns like stop-and-go waves, shockwaves, and stop-and-go waves (Campanella, et al., 2009), (Moussaid, et al., 2011) and (Hoogendoorn, et al., 2014).

Within these collective patterns in non-free flow states high crowd pressures occur. Here a minor disruption can create a short jam which is very dense and slow-moving (Hoogendoorn & Bertini, 2012). Because the flow at extreme densities does not stop moving (speed will not be zero and uncontrolled movements are observed), overcritical densities occur. According to Helbing et al. (2007) the largest danger comes from the crowd dynamics at high densities which lead to turbulent flows which can then trigger trampling and crushing. In those turbulent situations, the size and directions of forces acting on the bodies move people around in an uncontrolled way. People will have difficulties keeping their balance and when people stumble, fall and get injured this can be the start of a crowd disaster (Helbing, et al., 2007).

But how these high densities occur in a crowd disaster is often lead by a large causal chain of effects. Causality is considered with three components. The first is that the cause must be prior to the effect in time. Secondly, cause and effect should be contiguous in time and space. And at last, there must be a necessary relation between them (Hollnagel, 2004). The complexity with causality within crowd disasters lies in the fact that causation is inferred from observations but is not something that can be
observed directly. As such cause is constructed from an understanding of the situation rather than a found fact. Hence, the cause is selected from a set of possible causes and that it is the result of an act of inference rather than deduction (Hollnagel, 2004). On top of that, often a cause of the unexpected is to be found as understanding of failures. Since the way we understand and explain accidents determines how we respond, the differences are also important for accident prevention (Hollnagel, 2004). When there is more than one potential cause, the probability of the factors to be the cause have to be taken into account (Ale, 2009).

Within this model in Figure 41 layers of phenomena are constructed. These phenomena share a same state of pedestrian flow, referred to the fundamental relationships between speed and density and flow. In some cases these phenomena sharing a layer show interrelationships which are also showed. Furthermore, the layers are placed in disaster development chronological order. The red arrow depicts the trend of crowd disaster development and should therefore be prevented from developing by preventive management. This placement is also in line with the fundamental diagram in terms of flow regimes related to the increasing density by which the chance on crow disaster grows. Therefore, this model provides a logical order both in time and in terms of traffic states over densities.

This model gives the first conceptual definition for mitigating crowd disaster risks by schematic representation of the phenomena underlying the development of crowd disaster. These phenomena will be shortly explained here.
Self-Organisation

Self-organisation is described as the phenomenon of spontaneous occurrence of qualitatively new behaviour through the non-linear interaction of many objects without intervention of external influences (Hoogendoorn, et al., 2014), (Helbing & Johansson, 2010), (Camazine, et al., 2010).

Self-organisation has a view clearly observed phenomena which are presented here: lane and diagonal formation and the zipper effect.

Lane formation & diagonal formation

Self-organisation of spatiotemporal structures can occur in bidirectional flows (lane formation) and in crossing flows (diagonal stripes) (Hoogendoorn, et al., 2014). According to Appert-Rolland et al. (2014) diagonal patterns at crossings of perpendicular flows show the form of chevrons rather than diagonals (Appert-Rolland, et al., 2014). This is also found by Moussaïd et al. (2010) who found that with increasing density the linear walking formation started to bend forward into a V shape. They believe this shape is conform a comfortable communication position.

According to Helbing et al. (2000) mechanisms for lane formation are found in the number of interactions of pedestrians. In mixed directions of motion the number of interactions are high. At every interaction, the encountered pedestrian moves aside in order to pass. Opposing pedestrians are being given way by these sideways moves creating separate lanes of direction of motion. A stable configuration shows minimal interactions and maximal efficiency, meaning uniform lanes of motion have been created.

Self-organisation can be utilized to optimize efficiency of flows with less space (Helbing, et al., 2000b). However, self-organisation can also significantly change the capacities of pedestrian facilities as is described by Helbing et al (2000). To give two examples capacities at doors and crossing flows in general are exemplified.

Door capacity phenomenon

A broader door may not lead automatically to a proportional increase in pedestrian flows through it. This is caused by the allowance of more frequent changes in walking direction which are connected with temporary deadlock situations (Helbing, et al., 2000b). At self-organisation when two doors are available, each door suits one walking direction. Furthermore, at doors arching effects occur in combination with the ‘faster is slower effect’ described below.

Crossing flow affecting flows’ efficiency

Oscillatory changes in walking direction and periods of standstill in between occur not only at a bottleneck but also at crossing flows. This effect can be neglected by roundabout introduction which suppresses the phases of vertical or horizontal motion in the intersection area. In a simulation of Helbing et al. (2000) this improvement increased efficiency of flow by 13%. Next to this, Hoogendoorn & Bovy (2003b) indicated that the efficiency of lane formation reduces the capacity loss in case of bidirectional flows with only 4 to 15% (Hoogendoorn & Bovy, 2003b).

What is meant with ‘the zipper effect’?

Within the self-organisation another effect is discovered which is called the zipper effect. When the crowd is flowing under free flow capacity this effect can occur when flows of same direction need to infix. According to Hoogendoorn & Daamen (2005) the so called ‘zipper effect’ describes the case when individuals allow others within the territorial space diagonally in front of them, as long as the direct space in front of their feet is still empty. The result of this effect is that lanes can become narrower in a bottleneck than expected based on the width of a pedestrians territorial zone (Hoogendoorn & Daamen, 2005). Hoogendoorn & Daamen (2005) stated that pedestrians do not walk behind each other in a bottleneck but rather show staggered layers and lateral displacement that
allows for higher capacity and explains a stepwise increase in capacity with the width of the bottleneck.

**What is meant with the ‘faster is slower effect’?**

In situations where the density in a queue upstream of a bottleneck is increasing, due to the fact that people keep heading forward while the bottleneck is clogged, the faster is slower effect occurs (Helbing & Johansson, 2010). People try to move faster while in mean time the flow is moving slower. The higher densities cause coordination problems since a large number of individuals is competing for a few small gaps. Bodily interaction and friction slow down the total crowd motion.

The clogging effect is build up by two forces which are slowing down due to a bottleneck (doors) and secondly strong inter-personal friction which become dominant when people get too close to each other (Helbing, et al., 2000a). For this reason the danger of clogging (or also called arching in front of an exit for example) can be minimized by avoiding bottlenecks in design of festival areas. However, only widening exits would not help immediately. To make effective exits columns can be placed asymmetrically in front of the exits, which also prevent build-up of fatal pressures (Helbing, et al., 2000a).

The pressure caused by people pushing leads to people becoming jammed in by for example the exit doors which in this case form the bottleneck, also referred to by ‘crushing’. The consequence is that people need to worm their way out with great effort and therefore move forward more slowly, this is also described by the so called ‘faster-is-slower effect’. The more people hurry, the greater the pressure and the longer the evacuation will take (Hoogendoorn & Bertini, 2012). For example, in attraction parks queuing is done in a snake form to forcing visitors to not run towards the entrance of the attraction and avoids arching around this entrance.

**What is meant with cascading effects?**

Cascading effects occur in jam formation and represent the overload of one component of the system challenges other components which therefore causes a propagation of issues throughout the network (Helbing & Mukerji, 2012). Cascading effects are often referred to as shockwaves in Traffic Flow Theory.

**What is meant with spillback & gridlocks?**

Bottleneck in one location impedes other traffic flows at other locations. Traffic jams continue to grow if nothing is done and spread like an oil slick across the traffic network (Hoogendoorn & Bertini, 2012). Although this phenomenon is only found within vehicle traffic literature, for pedestrian networks it might also be slightly applicable. The reason that it is only slightly applicable is that pedestrians flow in more than 2 dimensions. Furthermore, in pedestrian networks, the people can crush into each other and therefore the interpersonal space becoming zero or even allow for morphological change of pedestrians. Whereas in vehicle networks, these headways remain at minimal distances and no crushing is assumed. However, the spillback can still occur when a mass crowd is stopped at one bottleneck and congestion has a cascading effect upstream blocking other exits or entrées as was the case at the Love Parade in Duisburg in 2010.

**Herding**

Herding is described as the situation where uncldearness causes individuals to follow each other instead of taking the optimal route (Helbing, et al., 2005). The statement is being formulates as taking optimal routes is to be seen as the performance objective of pedestrians, however from a network perspective the optimal route might be different than from an individual perspective. In this case, although
pedestrians follow individual optimal routes, inefficient herding can cause grid-lock effects because for example only the most obvious exits or entrees are used. Furthermore, this definition assumes that by following each other (herding) no optimal routes are walked. However, this might not be the case if the ‘leaders’ have found the individual optimal route either by chance, or by being able to assess the optimal route because of their visual abilities (for example tall people can oversee an area rather easily, or being in clear approximation of an exit is a leader position) or either by being informed about the ‘best’ route. A great example are the platforms in the Dutch stations which only allow a few routes to take, herding does occur. Within this perspective herding can be used efficiently when a few ‘leaders’ are assigned to the task to use certain exits on the terrain as to show people these routes exists too. In this case the people are being distributed more evenly than if all would go to the same direction.

Nevertheless, herding often relates to behaviour predominantly seen during evacuation situations (Helbing, et al., 2005) where people usually first act instead of rationalize their situation and optimize their path out of the hazardous environment. Within this situation often panic is the underlying factor which stimulates herding behaviour, but it does not have to be the case. Therefore, herding can better be described as following behaviour without self-thinking or assessing routes, as such network inefficient herding can result in congestion or even grid-lock.

**Pushing**

According to Helbing & Mukjeri (2012) the aggravating factors which may lead to intentional pushing are (1) long waiting times without food, water, entertainment and facilities and (2) the absence of understandable, communicated reasons for the delays and (3) threatening high-density conditions. However, a common misconception is that the crowd is to blame for the disaster to happen (Helbing & Mukerji, 2012). They state that people do not die because they are in panic, but are in life threatening situations and therefore they panic. This means that the congestion and pushing in the crowd happens unintentionally. This is due to the fact that physical forces start to increase whenever density increases in such way that body contact is inevitable, which is the case in a Crowd Turbulent flow regime.

**Crushing, stampede & panic**

According to Helbing & Mukerji (2012) crushing is referred to as the event in which people are moving towards a physical bottleneck and are crushed in front of its narrowest point due to lack of space. An example for a crowd crush is the crowd disaster in Minsk, Belarus, on May 30, 1999, where a sudden thunderstorm with heavy rain caused people to stream into the near-by ‘Nyamiha’ metro station resulting in crushed people in front of the entrance (Helbing & Mukerji, 2012).

A crush can result from a stampede that is caused by mass panic. A stampede is defined by Cambridge Dictionaries Online (2014) as an occasion when many people suddenly all move quickly and in an uncontrolled way usually in the same direction at the same time, especially because of fear (Cambridge University Press, 2014). Although this definition links to panic, there is a difference between those concepts. According to Helbing et al. (2010) panic can be described in 9 observations: (1) People move or try to move considerably faster than normal; (2) Individuals start pushing and interactions among people become physical in nature; (3) Uncoordinated passing of moving or passing bottlenecks occurs; (4) Arching and clogging occur at exits; (5) Congestion occurs; (6) Physical interactions in the congested crowd add up and cause pressures up to $4,450 \text{ Nm}^{-1}$; (7) Escape is slowed by fallen or injured people. (8) People tend to follow each other; (9) Alternative exits or routes are easily overlooked or not efficiently used in escape situations.
What usually is described as unreasonable crowd behaviour or panic may better be interpreted as crowd self-rescuing behaviour (Helbing & Mukerji, 2012), because the phenomena are to be seen as developments of self-rescuing processes with disastrous effects. What usually is described as unreasonable crowd behaviour may better be interpreted as crowd self-rescuing behaviour (Helbing & Mukerji, 2012), because these disastrous phenomena occur because people tend to escape from the disaster of rescue their fellows. This is supported by psychologist and Phd candidate Erica Kinkel from the TU Delft, who in an interview explained panic as the state in which people are behaving illogically in fear. This is also underpinned in the dictionary as panic is defined as a sudden strong feeling of fear that prevents reasonable thought and action (Cambridge University Press, 2014b).

People do not seem to panic easily, but panic mainly appears to occur when people are suddenly shocked. An example of panic is the situation created by the ‘Damschreeuwer’ in Amsterdam at the Dam (main square) on May 4th 2010 during World War II Commemoration Day. Panic also occurs when the danger is imminent (Helbing & Mukerji, 2012). Another example of crowd panic is the Baghdad bridge stampede on August 31, 2005, where pilgrims moving toward the Al Kadhimiya Mosque got nervous due to rumours of an imminent suicide bomb attack, after there had been already armed conflict on the same day. Helbing & Mukerji (2012) stated that if there is time to think, panic is less likely.

On top of that, a stampede can refer to herding as well as the same phenomena are being observed (following behaviour via same path). Therefore, in this research herding is dedicated to following behaviour in which following is a logical response within situations if one is not being able or if there is a lack of time to assess and choose a route. Stampedes are referred to as phenomena in which a lot of people try to reach a certain point within a certain time following the same direction and this phenomenon can be caused by herding and/or panic or a craze. These four phenomena overlap largely and can be all seen as pre-disaster phenomena as they all can cause congestion, trampling, and quakes.

**Craze**

A food distribution crush is a clear example of a craze. Craze like group behaviour has been created where participation in an event, or viewing of a public personage, is intensively promoted. General admission events and so-called “festival seating” concerts which can cause crazes like competition for favourable seats or standing positions close to entertainers (Fruin, 1993).

**Trampling or being trampled**

One should avoid the active form of trampling because being trampled is more correct seen the circumstances under which this occurs. In these situations the people are being walked over the fallen people as such they would be the one trampling but now are being trampled as being a passive actor in the event of trampling (Helbing & Mukerji, 2012).

**Crowd turbulence**

When a pedestrian flow has become unstable (free flow is disrupted), the situation at which self-organisation cannot anymore lead to effective flows, a minor disruption can create a short jam which is very dense and slow-moving (Hoogendoorn & Bertini, 2012). Extreme and fluctuating pressure builds up, when densities become so high that they cause contact forces between bodies to add up, also described as crowd turbulence (Helbing, et al., 2007). These fluctuating forces in a crowd can also be captured by the meaning of crowd turbulence. Hoogendoorn & Bertini (2012) defined crowd turbulence as uncontrolled movements in the crowd (Hoogendoorn & Bertini, 2012). Another definition for crowd turbulence is given by Moussaid et al. (2011): turbulence is referred to as the phenomenon of body collisions together with pedestrian heuristics.
According to Helbing et al. (2007) the turbulence within a crowd can be seen as a different pedestrian traffic state in the fundamental diagram of flow [p/m/s] as function of the density [p/m²], see Figure 42. In this figure the blue line corresponds to the fundamental diagram relationship of Weidmann (Weidmann, 1993), the red plotted data is representative for the empirical study by Helbing et al. (2007) of the Hajj in 1426H in Mekkah on the Jamarat bridge for a specific region of 1 square meter. In this line of reasoning, the crowd turbulent stage would be around the critical density of the fundamental diagram of Weidmann between a density of 2 and 3 [p/m²].

Figure 42 Average local flow as function of the local density compared to the Weidmann (1993) fundamental diagram relationship (Helbing, et al., 2007)

Figure 43 further shows what this turbulence means in terms of speed and density. In Figure 43a three trajectories are plotted for (blue) turbulent flows in which also negative flows are visible, showing that the mass of people is moving around. Within this plot the red curve represents self-organisation in free flow. The curve shows a fast and smooth trajectory of the x-range of 8 meters (with time required scaled to 1). The black line represents stop-and-go-waves in which smooth motion is temporarily interrupted but the mass is not moved in negative directions.

In Figure 43b below the velocity in the y-direction and x-direction for turbulent (blue) flow is plotted with time step of one second. The motion seems to vary irregular in all possible directions. Figure 43c represents the pressure over time in turbulent flows. The pressure is calculated by

\[ P(t) = \rho(t) \text{Var}_t(\vec{V}) \]

Where \( P(t) \) is the pressure over time squared [\( \text{s}^2 \)], \( \rho(t) \) is spatial average of the density in the central recorded area, and

\[ \text{Var}_t(\vec{V}) = \langle [V(\vec{r},t) - \langle V(\vec{r}) \rangle]^2 \rangle_{\vec{r}} \]

\( \text{Var}_t(\vec{V}) \) representing the velocity variance.

In this Figure (c) below a critical pressure can be seen as the indicating value for the start of the turbulent flow state. Here the transition is around a pressure of 0.02/s². In which a maximum pressure of approximately 0.045/s² showed the start of the crowd disaster.

The latter subfigure (d) below represents the probability density function of velocity increments for laminar and turbulent regimes. With a small increment of 0.1 seconds (red), 1 second (green), 10 seconds (blue) and 100 seconds (black). What is shown is that the laminar regime is separated from the turbulent regime for very small increments by a parabolic peaked curve (laminar) over a non-parabolic peaked curve (turbulent). Helbing et al. (2007) indicated that this phenomenon is typical for turbulence. Furthermore, they indicate that in comparison with fluid turbulence where vortex cascades occur, in crowds a hierarchical fragmentation dynamics can be observed. It seemed that at extreme densities, individual motion is replaced by mass motion. However, a stick-slip instability in
those circumstances can lead to ruptures when the pressure or stress becomes too large. In this case the mass splits into clusters of different sizes with strong velocity correlations inside the groups and distance-dependent correlations between the groups (Helbing, et al., 2007).

Congestion: Crowd quake & Shockwaves, Stop-and-Go Waves, Moving Jam

In the turbulent situation a crowd quake can occur which is referred to as people pushing or being pushed around by fluctuating forces in the crowd. This phenomena can be observed as a shockwave through the crowd which travel at high speed upstream of the bottleneck through the crowd.

As soon as the maximum flow has been reached at the critical density, so called stop-and-go waves can be observed. This state is entered directly after the laminar (self-organisational) phase has come to an end. In Figure 44b the average pedestrian flow is dropped from maximum flow of approximately 1.5 [p/m/s] to approximately maximum ‘go flow’ of 0.8 [p/m/s] (Helbing, et al., 2007). The flow maximum at congestion state is not higher than 0.8 persons per meter per second, which means the average flow is even lower about 0.5 [p/m/s].
In the figure (a) above the trajectories is given in densities in the space-time plot. The density is indicated by the colour in which blue represents free flow density and reddish represent jam density. It becomes clear that from 11:53h in this plot stop-and-go waves occur after a free flow stable state from 11:45h to 11:50h. Within three minutes the stable state becomes instable and the stop-and-go waves will continue till the time that the density becomes overcritical which lead to turbulent flows or the density becomes under critical and the jams are solved.

The latter figure (c) above represents a location dependent average velocity field of motion from 11:45am to 12:30am over a central area at the bridge from 20m by 14m. The $x$ – coordinates represent the distance to the on-ramp of the Jamarat Bridge and points into the entrance. In this plot the merging of people from all directions caused a bottleneck effect on the bridge. The colours represent the pressure defined by the average pedestrian density times the velocity variance around the average velocity. The redder the more pressure is detected, the bluer the less pressure is detected. Helbing et al. (2007) indicated that in the reddest part on the bridge, where the pressures were at highest values, the crowd disaster occurred.

B.5 Crowd Evacuation

In case of failure of preventive measures or due to external unsafe situations, evacuation of crowds is only way to save the mass of people. It has been argued that the fast growth of population and urban development is not met with the growth of (road) infrastructure capacity (Pel, et al., 2011). For this reason it is believed mass evacuations will become increasingly more difficult and time consuming (Plowman, 2001), (Barrett, et al., 2000). Especially during a mass event, more people than in normal situations need to be evacuated which can lead to unmanageable situations.

Emergency plan

In case of evacuation scenarios the notification time, preparations time and evacuation time are important. However, the evacuation is unlikely to be achieved for 100% of the population (Ale, 2009). Are evacuation scenarios thus to be seen as unmanageable? In the case that evacuation follows from predicted hazardous situation, the evacuation is defined as manageable. When an ad hoc evacuation occurs because of a situational unforeseen threat, the evacuation is regarded as unmanageable. This definition can be applied for all hazardous scenarios during a mass event.

Evacuation Time

In Dutch a difference is made between timely evacuation and non-timely evacuation or evacuation at different scales. The timely evacuation is called ‘ontruiming’ (Klootsema, 2014). ‘Ontruiming’ does have an equivalent description in English which is ‘Clear or Empty Out’ or in case of a building ‘eviction’ or in relation to settlements ‘dismantling’ or in relation to terrorism ‘disengagement’. But too easily these words are exchanged with ‘evacuation’ both in Dutch as in English practice and literature. The police department distinguishes between them with care because it differs in measures to be taken. Evacuation is seen by dictionaries as synonym for ‘ontruiming’. For the sake of this paper, evacuation will be used as definition for the disengagement of the event and clear or empty out (parts of) the event area.

The Health Survey England (HSE) refers often to a combination of Evacuation, Escape and Rescue under the name of evacuation (EER). The process EER consists of escaping individuals, evacuation of the mass by the police and rescuing of individuals by the fire brigade. The time available and needed for evacuation depends on the decision duration for starting the evacuation, the preparation time of the evacuees, and the notification time by the evacuees, see Figure 45. Note that the decision time on evacuating is sometimes zero if the crowd disaster already stroke and people individually or in groups
start evacuating. The total evacuation time needed will be determined by the notification time, preparation time and escaping/evacuation time.

Factors influencing evacuation planning

Hazard identification, risk assessment, and impact analysis are important steps in the planning process, because many of the key decisions made relative to the emergency plan are based on this information (Bishop, et al., 2010). He states that being prepared ahead of time to deal with the media can also help an organisation get through the incident without the additional damage that can be caused by misinformation and speculation. According to Bishop et al. (2010) an effective emergency response plan involves four important components: planning, reviewing, training, and testing. Ale (2009) emphasized some factors for the success of sheltering, responses of people to warnings and support issues for timely rescue operations which are given here.

It is thus most important to evacuate as many people as possible in the available time. In some cases, sheltering is necessary. In the centre of a city shelter might seem impossible, however according to Temme (2014) the city centre is the most excellent place to provide shelter in the many cafeterias, restaurants, shops and pubs (Temme, 2014).

Success of sheltering lies in the following factors:

- Effectiveness of warnings
- Adequacy and safety of shelters
- Access time needed vs available
- Trapping at shelter entrances
- Leaving too early the sheltered places
- Added:
  - Accessibility of shelters
  - Information asymmetry on shelters
Additionally to the above factors, the factor ‘Accessibility of shelters’ should not be forgotten. If shelters are easy to find (visible and on main routes), people know to which type of shelter they should go and which shelter is in closest proximity, then the accessibility of shelters is high.

Most of the times, people will not be assigned to a specific shelter. In case of high demand and limited amount of shelters, people will go to the shelter they know to find, this might lead to a disastrous distribution of people over the shelters. With the additional factor ‘Information asymmetry on sheltering’ this aspect is captured.

Next to the success on sheltering, the response on warnings is important to maximize the time available to evacuate an area. Responses of people to warnings of threats can be influenced by:

- Age
- Desire to reunite
- Socio-economic status
- Prior knowledge
- Understanding of threat
- Nature and timing of warning
- Added:
  - Perceived nature of warning
  - Experience
  - Compliance
  - Quality of information
  - Trustworthiness of information

Additionally to the nature and timing of warning, the perception of the nature of warning is of importance and the trustworthiness of the information. If people perceive the information to be unreliable, false or exaggerated than they will not be motivated to start evacuation. It is becoming clear that people providing with information on why they should move to a particular place or evacuate the building rather than only directing people is beneficial for their compliance to the plan. The quality of the information is another important factor. Information should be readable, accessible, understandable, timely, applicable to the situation and up to date. Furthermore, there is a clear learning process from evacuating. People with experience on navigating in these circumstances or navigating in a specific place often will improve their evacuation time. Therefore two factors are added to this list: ‘Perceived nature of warning’, ‘Experience’, ‘Compliance’, ‘Quality of information’ and ‘Trustworthiness of information’.

Command support issues concern timely rescue of trapped or injured people through:

- Source reduction
- Effect reduction
- Dose reduction
- Exposure reduction
- Harm reduction

It is assumable that in those factors given for command support issues concerning timely rescue of people trapped or injured that the time of exposure to harm is meant with exposure reduction and harm reduction. In this case the list seems rather complete, otherwise these factors should be adapted.
Evacuation behaviours

The compliance to the advice given on evacuation is known to be limited in western cultures. Leach and Campling (1982) found that people in danger rather choose to ignore the possible threat despite the warnings prior to the hazard. It is observed that people do not automatically follow advice on evacuation by public officials, but tend to find information on the situation themselves, then assess their risks and then make an independent evacuation decision. According to Pel (2011) this statement is supported in many empirical studies.

According to Woodworth (1958) evacuees experience three (quasi-)consecutive psycho-behavioural phases. The decision-making task starts with information acquisition, followed by situation assessment, and finally action execution (Woodworth, 1958). Since individuals cannot assess all available information, the first two phases are undertaken simultaneously (Baddeley, 1972), (Wickens, 1987). Woodworth (1958) stated that information is filtered based on relevance and trustworthiness according to how the current situation is perceived. This filtering process is believed to make the task easier, however it may take some time to accept and appropriately act under changing conditions. This can be explained through the phenomenon of cognitive dissonance. For example, when people perceive themselves as safe yet receive information on a possible threat, then the logical inconsistency in these beliefs is (initially) resolved by rejecting or ignoring this warning information (Woodworth, 1958). See Figure 46 for the cognitive chronological processes describing this phenomenon. In this manner the conflicting information (with intrinsic thoughts) is often discarded as being not relevant or unreliable. Once the danger is recognized and people start responding, their information processing and decision making capabilities might be limited due to mentally demanding circumstances, associated with anxiety and the perception of time-pressure (Leach & Campling, 1982). Wills (1998) argues that in these situations people rely more on instincts and experience, thereby avoiding the time needed for making rationally thought-over decisions (Wills, 1998).

Figure 46 Evacuation Response Behaviour based on (Leach & Campling, 1982) from (Hoogendoorn, et al., 2009)

It is stated that it is the perception of risk that motivates people to evacuate, not the hearing of warnings and evacuation orders (Dash & Gladwin, 2007). This is implied by the psycho-behavioural frameworks constructed in the behavioural sciences, as well as a common finding in empirical studies (Pel, et al., 2011)

Leach and Campling (1982) further argue that during the impact phase there is evidence of a clear distinction between the psycho-behavioural responses of three types of individuals. According to Pel et al. (2011) once people undertake action in the impact phase, some remain calm and rational, others may be stunned by the situation and react in a semi-automatic manner, or may mentally breakdown and react uncontrolled and inappropriately. They state that in most cases approximately 75% of the individuals express the second type of behaviour, while the behaviour of the remaining share corresponds evenly with the first and third type. This is in some way also stated by Police Crisis Control Officer Klootsema (2014) who identified three types of escaping behaviours of which in his perception 2/3 of the people fly, 1/11 fight the hazard and try to rescue others and ¼ of the people freezes (Klootsema, 2014). Interesting is the distinction in movement versus the distinction in panic reaction. The categorization of the police in this case is very interesting for further research to determine if this share in these three types of escaping behaviour is also found by experimental studies.
A last notion to make here is that the evacuation performance of people evacuating (going from the hazard place to a safe place) will benefit from a high flow efficiency. Therefore, the found factors influencing the flow efficiency in terms of initial desired speed should always be considered in evacuating scenarios. See for these factors page 20.

**Shadow Evacuation**

During a regional warning, also areas which are in fact not at risk may start evacuating which is called shadow evacuation (Pel, et al., 2011). Especially considering the findings that escaping is primarily motivated by people’s perception of being at risk, shadow evacuations seem to be likely to occur during crowd disasters. Durham (2007) points out that this may particularly happen during mass evacuations and it would lead to larger travel demand thus hindering those in real need to evacuate (Durham, 2007).
Appendix C

C.1 Class Diagram of Mass Events

Figure 47 Class Diagram of Mass Event
Class Diagram Explanation

As can be seen in Figure 47 on the previous page, a mass event is built up of 4 subclasses: Crowd, Mass Event Organization, Key Stakeholders and Built Environment. These 4 subclasses are further disaggregated and do show interrelationships. For the research on designing a framework for risk mitigation of crowd disasters, this diagram forms the basis for the information necessary to gather on the Event Blocks. For the macroscopic flow model a sub-diagram has been developed for deriving the necessary data in a structured way in full context of a mass event. This sub-diagram is being derived from the Class Diagram of Mass Events and contains only the necessary attributes for in the model.

The Mass Event is disaggregated into 4 subclasses: Crowd, Event Organisation Context, Key Stakeholders in Crowd Management and Built Environment. The crowd is related to the visitor and has the attribute flow regime. The visitor walks a particular route in the built environment which is interfered with by the stakeholders. The event area is also within this built environment, in the scope of this research. The event area contains at least one entrance and exit, one show/activity and one facility.

Considering all attributes will give a complete overview of the mass event characteristics. All subclasses contain attributes of which some are necessary for modelling Event Blocks. These are provided in the main text chapter 7.

C.2 Gathering distributions for Step 3 of Framework for SAIL 2015

The analyses done here show the framework users how to derive distributions on the uncertain variables of route choice, arrival and departure distributions.

Determining Arrival Patterns & Departure Patterns

The arrival of visitors determines the demand for processing flows in the Event Blocks. For events without ticketing and/or with scattered activities over an area, these numbers might be difficult to derive, especially when it concerns public mass events. Although these numbers are not known beforehand or even during the event, with scenario development and simulation arrival patterns can be evaluated to prepare for crowd disaster development due to overcrowding.

A way to derive still some numbers on arrival patterns is by determining the maximum arrival rate as worst case scenario. This can be done by looking at all modalities for arriving at the Event Block entrance. Assuming all visitors arrive by transportation (car, bike, foot, train, bus, tram, plane or boat), what is the maximum capacity of the feeder roads, bicycle lanes, pedestrian ways, frequency of trams, bus, trains or boats? When knowing the maximum capacity of the feeder routes either continuously or discrete for one hour, then assume that this maximum capacity is utilized before each main activity for a period of time. This gives already a prudent scenario of a worst case in arrival pattern.

Next to this, the programming and activity supply gives already an image on how many visitors can be accommodated over time over different locations. Relative popularity can be visualized by the use of social media or other surveys or even by the layout design of the event and the strategy of marketing those activities.

At last, historical data can be consulted as possible scenario for arrival patterns.

Departing is fully dependent on the programming and choice options for visitors. For the different arrival patterns and supply of activities from the programme, together with the main exit routes from these activities to the departure modes, the scenarios for departing flows can be derived. However, easier is to first state the maximum arrival rates and then use these for the maximum departure rates. Similar distributions can be found by looking at transportation to the Event Blocks and the programming.
Arrival Pattern SAIL Event Blocks for Wide Dam & Sumatrakade

The arrival patterns for SAIL are highly uncertain. Because of this uncertainty, no total visitor number can be presented here. However, it is more than plausible that a large number of visitors will be arriving at SAIL via the central station of Amsterdam. When taking the exits of this central station, together with the derived initial speed for the visitors of SAIL, the maximum free flow arrival rate can be determined. In this way, nothing is said about how the total number of visitors of SAIL distribute themselves over the opening times of the event. However, this is a plausible scenario to assume a continuous flow of people will depart from CS to go to either the green or orange walking route of SAIL. It is assumed that all people for SAIL are leaving via the back exits of CS, as this is the shortest route towards the walking routes of SAIL (both green and orange start here). Therefore, it can be plausible to take the maximum outflow of these exits of CS as the input variable for the flow into the Event Block CS to Ruijterkade.

For the next Event Block on the route, the Wide Dam, the input of flow is different from the output of Event Block CS to Ruijterkade, because only the people following the orange walking route are going via de wide dam. There is no known ratio on how many people would prefer the orange route over the green route. But in order to see both routes one need to follow the orange route first and then from Sumatrakade take the ferry towards the green route. When choosing first the green route, one needs to go back to the start of this route in order to go to the orange route afterwards. Therefore, to maximize options also on a later point in the walking route, people might prefer to go via the orange route first and then go to the green route. When people do not want to follow the green route, they can stay on the orange route and return to the mainland via the wide dam in opposite direction.

For arriving a route choice logic the following utilization maximization function is used. All factors taken into account relate to the distance travelled, expected total travel time, expected crowdedness, sailing time, seeing ships and not able to see ships or other activities. The assumed penalties are ranging from 0.01 to 3 with an initial utility for all routes of 10. A bonus is given regarding the amount of ships or activities presented on the route relatively seen. Only small penalties of -0.1 are provided for the factors related to distance and public transport travel times and -0.01 for travel times. This is because people will not come to SAIL when a walk is not preferred over going by water for example. To show relative differences in routes a small penalty is provided for distance and related walking travel times, because still to see all ships during a shorter walk is assumed to be preferred over seeing all ships while walking longer. For going back via the same route a somewhat larger penalty is give of -0.5. Also for expected crowdedness a penalty is given of -0.5. For walking a distance longer than 1 km without seeing any activities a penalty of -1 seems plausible. In case the routes back or routes without seeing activities would have been a detour an even higher penalty would plausible. However, for this case this is not occurring. In ratio the amount of activities, in this case ships, are provided with a minimum of 0 and maximum of 2.5. In this case, there is an option for not seeing famous tall ships, which is why a large penalty of -3 is provided for this route. For the distance travelled by foot a penalty is given of -0.1 per km. For having to go back via same route a penalty is given of -0.5. An initial preference to walk an optional route at SAIL is determined at 10.

From the utility function it is found that the optional routes Orange Only, Both Green & Orange, or Orange first till Sumatrakade and then Green are preferred over only the Green route. This might because of the severe penalty in this function for not seeing famous tall ships at all, in case only applicable for the Green route. If also famous tall ships where provided at this route, the differences would be too small to state a definite difference in preference from these assumed factors for these 4 route options. For this research it is assumed that the most famous tall ships will be moored in the IJhaven, which are only accessible by walking the Orange route. All routes are showed in Figure 48.
Still, the division of people over the routes cannot be known. This is because the arrival patterns for these optional routes are not known. For the CS to Ruijterkade Event Block this is not of real influence, because it is already assumed to work with maximum arrival flows out of CS. Also by assuming conservation of people these flows will also enter to go back to the Central Station via the same route. However, because of the travel time differences of the particular routes, the distribution of departures to CS will differ from the arrival pattern. However, the worst case is that the same amount of people will return to CS as the maximum inflow from CS.

For the Wide Dam Event Block one should know which percentage will go via this Dam. This Dam going from South to North and North to South is separated by a tramline and 2 car lanes on which no people may walk. All people choosing the Orange route will go via the Wide Dam from South to North. For going from North to South only people will go who chose options Both Green & Orange or Orange Only. The people going to the Green Route via the Orange route will make the difference between the numbers of people per direction at this dam.

From Table 33 it can be seen that only the case in which people chose solely the green route differ in preference from the other 3 options. Therefore, it is likely that the option with a score around 8.5 out of 10 will be definitely favoured over the green route solely. Therefore, it is assumed that all people will choose equally between the 3 options with a utility function of about 8.5, that is to say no one will only walk the green route solely. Than it can be assumed that the proportion of people choosing to walk the Orange route only or walk the Green and Orange route both is equal and slightly less than the people choosing to walk a part of the Orange route and a part of the Green route. It is therefore assumed that the division over these options is as follows: 30% walks Orange only, 30% walks both Green and Orange and 40% walks Orange till the Sumatrakade and afterwards walks the Green route. Then the last assumption is that of those 30% who walks both Green and Orange, 50% will first walk the Green route and 50% will first walk Orange route.

Because the distributions over these routes are all based upon assumption, the capacity analysis in modelling the Event Blocks is used for arrival rates rather than the presented values on maximum arrival rates.
### Table 32 Route Logic SAIL Worst Case

<table>
<thead>
<tr>
<th>Starting Point</th>
<th>Direction</th>
<th>[p/s]</th>
<th>Ratio</th>
<th>Event Block Small Case Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS</td>
<td>Exit</td>
<td>25.56</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>Going to Ferry at Ruijterkade</td>
<td>3.83</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>Going to Orange route</td>
<td>21.73</td>
<td>85%</td>
<td></td>
</tr>
<tr>
<td>Ruijterkade</td>
<td>Going to CS</td>
<td>0</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Ruijterkade</td>
<td>Going from Ferry to Orange route</td>
<td>3.83</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>Veerkade</td>
<td>Going to Wide Dam S-&gt;N</td>
<td>21.73</td>
<td>85%</td>
<td>Yes</td>
</tr>
<tr>
<td>Veerkade Afterwards</td>
<td>Going to Centre</td>
<td>?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Veerkade Afterwards</td>
<td>Going to CS</td>
<td>?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sumatrakade</td>
<td>Going to Noordwal</td>
<td>10.22</td>
<td>40%</td>
<td>Yes</td>
</tr>
<tr>
<td>Sumatrakade</td>
<td>Going to Wide Dam N-&gt;S</td>
<td>11.50</td>
<td>45%</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### Table 33 Utility Functions of Route Options SAIL

<table>
<thead>
<tr>
<th>Factor</th>
<th>Sail</th>
<th>Total</th>
<th>Km</th>
<th>travel minute per ferry</th>
<th>seeing 4 ships</th>
<th>Expected crowdedness</th>
<th>Back via same way per route</th>
<th>Walking more than 1 km without seeing activities</th>
<th>Total Walking Time Expected</th>
<th>Not seeing famous tall ships</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utility</td>
<td>10</td>
<td>-0.1</td>
<td>-0.1</td>
<td>0.1</td>
<td>-0.5</td>
<td>-0.5</td>
<td>-1</td>
<td>-0.01</td>
<td>-3</td>
<td></td>
</tr>
<tr>
<td>Green only</td>
<td>5.55</td>
<td>-0.21</td>
<td>-1</td>
<td>0.5</td>
<td>-0.5</td>
<td>0</td>
<td>0</td>
<td>-0.24</td>
<td>-3</td>
<td></td>
</tr>
<tr>
<td>Orange only</td>
<td>8.54</td>
<td>-0.89</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-0.5</td>
<td>-1</td>
<td>-1.06</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Green first &amp; after Orange</td>
<td>8.58</td>
<td>-0.61</td>
<td>0</td>
<td>2.5</td>
<td>-0.5</td>
<td>-0.5</td>
<td>-1</td>
<td>-1.31</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Orange first to Sumatrakade and then to Green</td>
<td>8.72</td>
<td>-0.61</td>
<td>-0.94</td>
<td>1.5</td>
<td>0</td>
<td>-0.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

The following uncertain factors are the population dependent factors necessary to derive an initial desired speed for in the macroscopic flow models.
Determining initial desired speeds for Event Blocks

The flow and the density will be calculated by running the simulation in Vensim. For deriving the nuances of these flows, needed because of context and visitor dependent factors, the desired speed will be adapted for each Event Block as well as the capacity in terms of walking space. However, for deriving the range of these factors a starting value should be derived first.

Speed data is important for the determination of flows. For the same density, the higher the speed the higher the flow will become. This means that the initial desired speed determines the shape of the fundamental diagram for the free flow conditions and therefore determines the capacity of an event only based on the demography of the visitors.

The initial desired speed is determined by the visitor demography for each Event Block and for each stream directional character in this Event Block (unidirectional, bidirectional or multidirectional). However, speed of pedestrians depends not only on these two factors but on over 40 other factors, see Table 34. Within this table all factors influencing the speed are given provided by literature and the brainstorm session with PhD Student D. Duives, please find the details on this in Appendix B.2 on page 133. Yellow colour represents factors increasing the initial speed, blanco shows unknown change and pink shows decrease of speed. Within Table 34 the factors are categorized into the following pillars: Weather, Group, Age, Gender, Purpose, Nature of Behaviour, Infrastructure, Directions and Routing. Next to this categorization, the factors are prioritized based on the importance for determining the initial desired speed of a population of visitors. The priority given varies from 1 as the highest priority to 4 for lowest priorities.

A great share of these factors are acknowledged qualitatively, but a few only are quantitatively acknowledged. This makes it very hard to use these latter factors within the model for crowd disasters. The ones which are quantitatively acknowledged are given the priority 1. A lot of the presented factors from the lower priority groups are assumed to be significant, but are not yet defined quantitatively. One reason for this is that those factors are hard to study independently from other factors as to make sure the influence of this factor is measured independently or correlation is corrected for. This should be subject for future studies.

The range for the initial desired speed is derived from literature. The initial desired speed should be between a maximum of 1.41 [m/s] and minimum of 0.89 [m/s]. These maxima (1.41 [m/s] and 0.89 [m/s]) are derived from the literature study in which in different group size in free flow conditions, with different populations speeds were measured in both unidirectional and bidirectional streams. These values will therefore be used as the range for the initial desired speed of a population of visitors.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Category</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>High temperatures</td>
<td>Weather</td>
<td>4</td>
</tr>
<tr>
<td>Low temperatures</td>
<td>Weather</td>
<td>4</td>
</tr>
<tr>
<td>Group size 1</td>
<td>Group</td>
<td>3</td>
</tr>
<tr>
<td>Group size 2</td>
<td>Group</td>
<td>3</td>
</tr>
<tr>
<td>Group size 3</td>
<td>Group</td>
<td>3</td>
</tr>
<tr>
<td>Group size 4</td>
<td>Group</td>
<td>3</td>
</tr>
<tr>
<td>Group size 5</td>
<td>Group</td>
<td>3</td>
</tr>
<tr>
<td>Group size &gt; 5</td>
<td>Group</td>
<td>3</td>
</tr>
<tr>
<td>Young Adult 12 &lt; 20</td>
<td>Age</td>
<td>1</td>
</tr>
<tr>
<td>Child &lt; 12</td>
<td>Age</td>
<td>1</td>
</tr>
<tr>
<td>Adult 20 &lt; 60</td>
<td>Age</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Visitor related factors influencing speed of 1st priority for SAIL 2015 Case Study</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>--------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td></td>
<td>As already mentioned, the initial desired speed is determined by the demographic representation of the visitors at the event. The factors of priority 1 are representing the initial desired speed. The demography determines the initial desired speed the most, compared to the other factors. Moreover, the factors of priority 1 determine the initial desired speed of the flow for all Event Blocks over time for either unidirectional or bidirectional streams.</td>
<td></td>
</tr>
</tbody>
</table>
The gender and age determine the desired speed primarily. Actually, these factors describe the physical boundaries of the desired initial speed of a visitor on the event. The study by Bohannon (1997) provided a principle on the maximum desired speed of people based on physical limits for gender and age. For this purpose the following Table 35 should help together with the expected composition of visitor public in Table 36 and the ratio women over men for each age in Figure 49. From Figure 49 it can be derived that the distribution of female and men is 50-50 for all age categories. Only a small difference is encountered for the elderly category in which the females surpass the men numbers for the higher ages from 70 up to 100. On the other hand the men under 20 are in larger number than the women. However, because in this case only a difference can be made between elderly and younger people and not within the younger people category, this latter difference can be neglected. The difference within the elderly group cannot be neglected because the female group is larger than the men group for nearly the total range of the elderly category. The difference between men and women is about 3.79% considering 16.8 million people in total of which 23.55% are elderly and the surpassing number of females over men from this plot is 150 thousand.

Table 35 Desired Speed [m/s] based on age and gender based on (Bohannon, 1997).

<table>
<thead>
<tr>
<th>Categories</th>
<th>Female Speed [m/s]</th>
<th>Male Speed [m/s]</th>
<th>Average Speed [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elderly &gt;60</td>
<td>1.29</td>
<td>1.34</td>
<td>1.315</td>
</tr>
<tr>
<td>Young &lt;60</td>
<td>1.4</td>
<td>1.42</td>
<td>1.41</td>
</tr>
</tbody>
</table>

The following table shows the assumed distributions of mass event populations. The distributions are derived from the average distribution provided by CBS (2015). In case no data is available, the particular distribution can be chosen from Table 36 according to the expected visitor population of the event.

Table 36 Population distribution of age

<table>
<thead>
<tr>
<th>VISITOR PUBLIC</th>
<th>CHILDREN (&lt;20)</th>
<th>ADULTS (20-60)</th>
<th>ELDERLY (&gt;60)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAMILIES</td>
<td>50%</td>
<td>40%</td>
<td>10%</td>
</tr>
<tr>
<td>ADULT</td>
<td>5%</td>
<td>60%</td>
<td>30%</td>
</tr>
<tr>
<td>YOUNG ADULTS</td>
<td>20%</td>
<td>80%</td>
<td>0%</td>
</tr>
<tr>
<td>OLD</td>
<td>20%</td>
<td>40%</td>
<td>30%</td>
</tr>
<tr>
<td>AVERAGE NETHERLAND (CBS, 2015)</td>
<td>22.58%</td>
<td>53.60%</td>
<td>23.55%</td>
</tr>
</tbody>
</table>

Another distribution of the population is possible, therefore it is wise to always check the available social media and other surveys and historical data to find out which distribution of age and gender is most applicable to the case. For mass events in the city centre most of the time the average population of a country can be a good starting point.
Initial Desired Speed SAIL Case

For the SAIL 2015 case is it assumed that the family distribution of ages is representing the population of SAIL 2015 the best:

<table>
<thead>
<tr>
<th>VISITOR PUBLIC OF SAIL 2015</th>
<th>CHILDREN (&lt;20)</th>
<th>ADULTS (20-60)</th>
<th>ELDERLY (&gt;60)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAMILIES</td>
<td>50%</td>
<td>40%</td>
<td>10%</td>
</tr>
</tbody>
</table>

Please note, that only the bottlenecks on the orange route for which a certain arriving logic could be found are studied. To model every part of the event is outside the time scope of this research, but would possibly be very interesting for SAIL.

For all Event Blocks (Wide Dam, CS to Ruijterkade and Mooring off Sumatrakade) the fundamental relationships have been derived given the first priority factors by the application of the fundamental diagram of Weidmann (1993).

Non-visitor related factors influencing speed of 1st priority

In the list of factors influencing speed, some are indicated by a star, see Table 34 on page 159(*). These factors are on directions of flows and the angle of approach but do in contrary to their category belong to the first priority factors. These are different from the other factors of first priority because they do not relate directly to the visitors of the event, but rather to the event policy on mass flows.

For bidirectional flows, the decrease in efficiency seems not that large because of lane formation. Hoogendoorn & Bovy (2003b) indicated that the efficiency of lane formation reduces the capacity loss in case of bidirectional flows with only 4 to 15% (Hoogendoorn & Bovy, 2003b). However, this only is
applicable in case of free flow conditions, as only in this state of flow lane formation is occurring. For high density flow regimes, this effect should be neglected.

This finding can be included into the model with a value ranging from 0.96 to 0.85 decrease in flow efficiency in case of free flow conditions in bidirectional flows. In case of bidirectional flows this factors should be included as scenario values with 0.905 as medium value. With flow efficiency is meant the decrease in time duration of the throughput of the flow. This means that the speed decreases for the same density for the free flow state. In this way the initial speed should change accordingly, taking into account the presented minimum and maximum values for the initial speed for the factors related to visitors of this priority group. If this change is also applicable for instable and turbulent flow regime should be subject of future study. However, for this research it is assumed that the flow efficiency decreases proportionally for the free flow regime up to the maximum jam density of $5.4 \frac{p}{m^2}$.

C.3 Specification of Scenarios in Macroscopic Flow Models

The extent to which crowd disaster phenomena can be modelled in a macroscopic flow model is limited. This is mainly because the greater share of these phenomena are not quantifiable. However, the benefit of simulating by adapting the parameters corresponding with the phenomena, the effects of these measures can be simulated. This simulation is very useful for analysing scenarios. Therefore, in this research an attempt is made to quantify the phenomena in specifying functional adaptations for the macroscopic models applied for SAIL small case studies.

In the following Table 37 and Table 38 the steps made from the Scenario Measure Charts towards the specification of the model is presented. The first Table 37 depicts the implementation strategy from phenomenon in the development towards a crowd disaster (Layered Crowd Disaster Model, for example explained in Chapter 3 and Appendix B.4) towards the model. Secondly, the implementation of these phenomena is defined. With this implementation strategy Table 38 presents the specification of these implementation strategies for the variables of the models (functions for the auxiliary or flow variables in the model).

A selection is done for which models these scenarios will be modelled, because of the applicability of the measures to the archetypes. Furthermore, the application of the case studies is an evaluation tool for the framework applicability and therefore this purpose should not be lost in enthusiasm of modelling all. Therefore, if no structural changes to the model where necessary the scenarios are implemented for those small case(s) expected to benefit most of these solutions.

Table 37 Modelling Solutions to Pre-Disaster Layer Crowd Disaster Phenomena & Ineffective Self-Organisation layer. In green are pictured the implemented solutions to the specific cases.

<p>| Solutions to Pre-Disaster | Sub-solution | Modelling Tactic | Implementation strategy and choice in green | Possible in Small Case of SAIL, choice in green |
|---------------------------|--------------|------------------|--------------------------------------------|
| No Pushing &amp; No Craze/Stampede &amp; No Gridlock | Control Inflow &amp; Outflow | Regulating in and outflows by addressing maximum density below critical density | Adapt MAX inflow functions with critical density as maximum density | Wide Dam NS, Wide Dam SN, Sumatrakade Mooring A+, Sumatrakade Mooring B, Bi-Directional A Non-Sym, Bi-Directional B Sym |
| No Pushing | Separation of Flow Directions | No bi- or multidirectional flows | N/A: Stock-flow structure A: Functions for unidirectional flows | Already varied in archetypes |
| Allow flowing out of area | 1) extra outflow or 2) create transfer block as queueing space | N/A: Stock-flow structure adaptation |  |
| No Crowd Turbulence | Re-direct people | Create lower inflow rate | Adapt arrival or demand rate | Wide Dam NS, Wide Dam SN |</p>
<table>
<thead>
<tr>
<th>Solutions to Ineffective Self-Organisation</th>
<th>Sub-solution</th>
<th>Modelling Tactic</th>
<th>Implementation</th>
<th>Possible in Small Case</th>
</tr>
</thead>
</table>
| No Craze/Stampede                     | Allow for queuing | Create buffer space in block | Adapt width and dimensions of block | Wide Dam NS
Sumatrakade Mooring A+
Sumatrakade Mooring B
Bi-Directional A Non-Sym
Bi-Directional B Sym |
| Increasing homogeneity in speeds       | Allow for standstill places and walkways | Extra buffer space or separated block with buffer space for standing still before flowing through to next block | N/A: Stock-flow structure adaptation | - |
| EFFICIENT CHOICE BEHAVIOUR             | Advise on activity choice | Advice based on capacity routes | Adapt inflow, arrival or demand rate on choice distribution and route capacity | Wide Dam NS
Sumatrakade Mooring A+
Sumatrakade Mooring B
Bi-Directional A Non-Sym
Bi-Directional B Sym |
| Even Distribution over Area            | Provide exits for each segment | Provide outflows of each block | N/A: Stock-flow structure adaptation | Wide Dam NS
Sumatrakade Mooring A+
Sumatrakade Mooring B
Bi-Directional A Non-Sym
Bi-Directional B Sym |
<table>
<thead>
<tr>
<th><strong>No Gridlock</strong></th>
<th>See first row Control Inflow &amp; Outflow</th>
<th>Regulating in and outflows by addressing maximum density below critical density</th>
<th>Adapt MAX inflow functions with critical density as maximum density</th>
<th>Wide Dam NS Wide Dam SN Sumatrakade Mooring A+ Sumatrakade Mooring B Bi-Directional A Non-Sym Bi-Directional B Sym</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Provide Back-Up Routes</strong></td>
<td>Create separate blocks and in and outflows</td>
<td>N/A: Stock-flow structure adaptation</td>
<td>-</td>
<td>Wide Dam NS Wide Dam SN Sumatrakade Mooring A+ Sumatrakade Mooring B Bi-Directional A Non-Sym Bi-Directional B Sym</td>
</tr>
<tr>
<td><strong>Direct in advance on alternative routes</strong></td>
<td>Create decision logic in advance of the entrance of the first block of the segment</td>
<td>N/A: Stock-flow structure adaptation and/or A: Adapt inflow, arrival or demand rate on choice distribution and route capacity</td>
<td>-</td>
<td>Wide Dam NS Wide Dam SN Sumatrakade Mooring A+ Sumatrakade Mooring B Bi-Directional A Non-Sym Bi-Directional B Sym</td>
</tr>
<tr>
<td><strong>No Interest &amp; Attraction Peak</strong></td>
<td>Segmental in- and outflow</td>
<td>Discretize inflow</td>
<td>Adapt MAX inflow by pulse function to create batches and adapt the function to a critical density as maximum density</td>
<td>Wide Dam NS Wide Dam SN Sumatrakade Mooring A+ Sumatrakade Mooring B Bi-Directional A Non-Sym Bi-Directional B Sym</td>
</tr>
<tr>
<td><strong>Program Adaption for diffused in- and outflow</strong></td>
<td>Provide lower inflow rate compared to peak demand</td>
<td>Adapt arrival or demand rate</td>
<td>-</td>
<td>Wide Dam NS Wide Dam SN Sumatrakade Mooring A+ Sumatrakade Mooring B Bi-Directional A Non-Sym Bi-Directional B Sym</td>
</tr>
<tr>
<td><strong>Increase Throughput</strong></td>
<td>Remove object</td>
<td>Increase walkable space</td>
<td>Adapt width and dimensions of block</td>
<td>Wide Dam NS Wide Dam SN Sumatrakade Mooring A+ Sumatrakade Mooring B Bi-Directional A Non-Sym Bi-Directional B Sym</td>
</tr>
<tr>
<td><strong>Provide sufficient capacity on routes, activities, facilities and goods</strong></td>
<td>Increase walkable space in order to avoid critical density given the inflow rate and initial desired speed</td>
<td>Adapt width and dimensions of block</td>
<td>-</td>
<td>Wide Dam NS Wide Dam SN Sumatrakade Mooring A+ Sumatrakade Mooring B Bi-Directional A Non-Sym Bi-Directional B Sym</td>
</tr>
<tr>
<td><strong>Solutions to Ineffective Self-Organisation</strong></td>
<td>Sub-solution</td>
<td>Modelling Tactic</td>
<td>Implementation</td>
<td>Possible in Small Case</td>
</tr>
<tr>
<td><strong>Reduce Inflow, see first row Control Inflow &amp; Outflow</strong></td>
<td>Reduce inflow or Regulating in and outflows by addressing maximum density below critical density of 3 [p/m²]</td>
<td>Adapt MAX inflow functions with critical density as maximum density</td>
<td>-</td>
<td>Wide Dam NS Wide Dam SN Sumatrakade Mooring A+ Sumatrakade Mooring B Bi-Directional A Non-Sym</td>
</tr>
<tr>
<td>Faster Effect</td>
<td>Provide exit or entrance per 1 person</td>
<td>Adapt width of entrance or exit to the arrival rate</td>
<td>N/A</td>
<td>Bi-Directional B Sym</td>
</tr>
<tr>
<td>---------------</td>
<td>--------------------------------------</td>
<td>--------------------------------------------------</td>
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</tr>
<tr>
<td>Direct slowing down in advance</td>
<td>Decrease speed of free flow arrivals by the update speed of the 2 blocks upstream</td>
<td>Allow adaptation to speed in advance of 1 upstream block</td>
<td>N/A</td>
<td>Wide Dam NS Wide Dam SN Sumatrakade Mooring A+ Sumatrakade Mooring B Bi-Directional A Non-Sym Bi-Directional B Sym</td>
</tr>
<tr>
<td>Segmentation of flows through small areas</td>
<td>Discretize the flow in advance of the bottleneck</td>
<td>Allow adaptation to speed in advance of 1 upstream block and adapt MAX inflow by pulse function to create batches. N/A: In case of multiple exits, create share function to distribute the flows over the exits. Adapt stock-flow structure to create flows for multiple exits.</td>
<td>N/A</td>
<td>Wide Dam NS Wide Dam SN Sumatrakade Mooring A+ Sumatrakade Mooring B Bi-Directional A Non-Sym Bi-Directional B Sym</td>
</tr>
<tr>
<td>Segmentation based on visibility and availability of exits/entrances</td>
<td>Distribute the flow according to exit and entrance capacities</td>
<td>N/A: Adapt stock-flow structure to create flows for multiple exits. Create share function to divide the batches over the outflows A: Adapt MAX inflow by pulse function to create batches.</td>
<td>N/A</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 38 Specification of implementation of scenario solutions to archetypes

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Implementations</th>
<th>Possible in Small Case</th>
<th>Specification Wide Dam</th>
<th>Specification Sumatrakade</th>
<th>Specification Bi-Directional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters and functions explained:</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>$S_{-1}$ = previous stock</td>
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<tr>
<td>$tt_{S-1}$ = travel time of previous stock</td>
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<tr>
<td>$u_{k,S}, u_i$ = Speed corresponding by stock and its density, initial desired speed</td>
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<tr>
<td>$k_i, k_S, k_c, k_{max}$ = initial density corresponding with initial desired speed, density of the stock, critical density, maximum density</td>
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<tr>
<td>$w_S$ = width of the stock</td>
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</tr>
<tr>
<td>$MAX\ Inflow SN$ = Function to restrict the inflow for the next stock (S) in direction of the flow</td>
<td></td>
<td></td>
<td>See $MAX\ Inflow SN$ Wide Dam</td>
<td>See $MAX\ Inflow SN$ Wide Dam</td>
<td></td>
</tr>
<tr>
<td>$IF\ THEN\ ELSE(x, true, false)$ = function with a premise $x$, upon true, upon false</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>$MIN(a,b)$ or $MAX(a,b)$ = function which returns the minimal or maximum value comparing $a$ and $b$</td>
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<td></td>
</tr>
<tr>
<td>Lookup function = table function</td>
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<td></td>
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</tr>
<tr>
<td>Transfer Flow to $S_1$ = function to regulate the inflow from one stock to the next stock in direction of the flow</td>
<td></td>
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</tr>
<tr>
<td>Transfer in Batches = pulse function to discretize flow</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Adapt $MAX\ Inflow$ functions with critical density as maximum density
   - Wide Dam SN
   - Wide Dam NS
   - Sumatrakade
   - Mooring B
   - Sumatrakade
   - Mooring A+
   - Bi-Directional B
   - Sym
   - Bi-Directional A
   - Non-Sym
   
   $MAX\ Inflow\ SN = MIN\left(\frac{S_{-1}}{tt_{S-1}},\ [IF\ THEN\ ELSE(u_{k,S} \geq u_i, k_i, MIN(k_S, k_c))] \ast u_{k,S} \ast w_S\right)$

2. Adapt arrival or demand rate
   - Wide Dam NS
   - Wide Dam SN
   - Sumatrakade
   - Mooring A+
   - Sumatrakade
   - Mooring B
   - Bi-Directional A
   - Non-Sym
   - Bi-Directional B
   - Sym
   
   For both $SN$ and $NS$:
   - $[0.5; 1; 2; 3; 4; 5; 6; 6.5]$ And
   
   Lookup function with distribution of arrival rates over time. Change in peak hours is not necessary, only change in peak itself with factor 2.

   For $A+$:
   - $[0.5; 2; 4; 6; 8; 10]$ with $Share\ B\ over\ A$:
     - $[1; 0.8; 0.5; 0.2; 0]$ And
   
   Also lookup function with distribution of arrival rates
   - $For\ A$: $[0.1; 0.3; 0.5; 0.6; 0; 8; 1]$ with $Share\ LR\ over\ RL$:
     - $[1; 0.8; 0.5; 0.2; 0]$ And
   
   For $B$:
   - $[0.5; 1; 1.5; 2; 2.5; 3]$ with $Share\ B\ over\ A$:
     - $[1; 0.8; 0.5; 0.2; 0]$ And
   
   Also lookup function with distribution of arrival rates
   - $For\ B$: $[0.1; 0.3; 0.5; 0.7; 0.8; 1]$ with $Share\ LR\ over\ RL$:
     - $[1; 0.8; 0.5; 0.2; 0]$ And
<table>
<thead>
<tr>
<th>3</th>
<th>Adapt width and dimensions of block</th>
<th>Wide Dam SN Sumatrakade Mooring A+ Sumatrakade Mooring B Bi-Directional A Non-Sym Bi-Directional B Sym</th>
<th>Width transfer block 2 to 3 [-1;-0.5;0.5;1] and 3 to 4</th>
<th>Compare cases A+ and B</th>
<th>Adapt width of bottleneck stretch by [-0.5;−1;+0.5;+1] and adapt dimensions with equal length of 50m</th>
<th>Compare with case A</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Adapt inflow, arrival or demand rate on choice distribution and route capacity</td>
<td>Wide Dam NS Wide Dam SN Sumatrakade Mooring A+ Sumatrakade Mooring B Bi-Directional A Non-Sym Bi-Directional B Sym</td>
<td>Max Arrival Rate SN 6.27 [p/s] Max Arrival Rate NS 6.16 [p/s]</td>
<td>Arrival Rate B: [2.6; 2.5; 2; 1.5; 1; 0.5] for Share B over A: [1; 0.8; 0.5; 0.2; 0] For 0.8 share 2.6 p/sec is max Arrival Rate A+: [0.5; 2; 4; 6; 8; 10] for Share B over A: [1; 0.8; 0.5; 0.2; 0] For 0.8 share 8 p/sec is max</td>
<td>Maximum Arrival rate in equal share of 0.5 Left to Right and Right to Left is for Case B 0.71 people/second from both directions and for Case A 0.52 people/second from both directions.</td>
<td></td>
</tr>
<tr>
<td>1 and 4 combined to 5</td>
<td>Adapt inflow by pulse function to create groups and adapt the function to a</td>
<td>Wide Dam SN</td>
<td>1) [ \text{MAX Inflow SN} = \text{MIN}\left(\frac{S_{\text{1}}}{t_{\text{1}}}, \text{IF THEN ELSE}\left(u_{k_s} \leq u_i, k_i, \text{MIN}(k_s, k_c)\right)\right) \ast u_{k_S} \ast w_S ] And 2) [ \text{Transfer Flow to S1} = \text{IF THEN ELSE}\left(k_{s_1} \leq k_c, \text{Transfer in Batches, MAX}(0, \text{MIN}(\text{MAX Inflow SN}, \text{Transfer in Batches}))\right) ]</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
critical density as maximum density

3] Transfer in Batches =
\[ MIN \left( \frac{\text{Capacity \text{batch}} \text{time}}{\text{waiting}}, \text{MAX} \left( 0, \text{Visitors arrived at SAIL for Wide Dam} \right) \right) \]

Pulse Function

6

Allow adaptation to speed in advance of 1 upstream block

Wide Dam SN

MAX Inflow SN
\[ = \text{MIN} \left( \frac{S_{-1}}{t_{S-1}}, \text{IF THEN ELSE} \right) \]
\[ \text{IF THEN ELSE} \left( u_{k,S} \geq u_i, k_i \ast w_S \ast u_{k,S}, \right) \]
\[ \text{IF THEN ELSE} \left( u_{k,S+1} \geq u_{k,S}, \text{MIN}(k_S, k_{max}) \ast w_S \ast u_{k,S}, \text{MIN}(k_S, k_{max}) \ast w_S \ast u_{k,S} \right) \]

4 and 5 combined to 7

Allow adaptation to speed in advance of 1 upstream block and adapt inflow by pulse function to create batches.

Wide Dam SN

1] MAX Inflow SN
\[ = \text{MIN} \left( \frac{S_{-1}}{t_{S-1}}, \text{IF THEN ELSE} \right) \]
\[ \text{IF THEN ELSE} \left( u_{k,S} \geq u_i, k_i \ast w_S \ast u_{k,S}, \right) \]
\[ \text{IF THEN ELSE} \left( u_{k,S+1} \geq u_{k,S}, \text{MIN}(k_S, k_{max}) \ast w_S \ast u_{k,S}, \text{MIN}(k_S, k_{max}) \ast w_S \ast u_{k,S} \right) \]

2] Transfer Flow to S1 = IF THEN ELSE \( k_{S1}, k_c \)  
\( \text{Transfer in Batches, MAX} \left( 0, \text{MIN}(\text{MAX Inflow SN}, \text{Transfer in Batches}) \right) \)
Appendix D

D.1 Emphasizing Discussion & Results on Archetypes SAIL 2015

Wide Dam Case Evaluation

For the Wide Dam case South to North the first expectation is that the bottleneck will occur at the long stroke of 110 [m] and 6 [m] wide. People are forced to walk into this area via a funnel going from 15 [m] wide to 9 [m] wide to 6 [m] wide in 50 [m]. The second bottleneck will occur due to a narrow bridge of 5.5 [m] wide with a length of 55 [m]. However, because the first narrowing is already towards this width of 6 [m], the second narrowing in this case the bridge, will not become a large bottleneck. Furthermore, as small buffer space is provided just before and after the bridge, giving people the opportunity to overtake or adjust speed. For these reasons only a small increase of the density is observed at the bridge.

For the Wide Dam case North to South the first expectation is that the bridge of 5.5 [m] wide will become a bottleneck at high demand. However, what is observed is that in case an arrival rate is chosen over the maximum capacity, the bottleneck is in fact the first stroke of 6 meters wide so people will accumulate just before entering this stretch. Thus the main bottleneck of this event area is the first Event Block selected.

Because the parameters (and structure) are the same for both models of the Wide Dam, their sensitivity only has to be tested in one case, here the Wide Dam South to North is chosen for these tests.

Sensitivity of the Wide Dam Models to uncertainty in parameter values

As is expected, the initial settings for nearly all parameters do influence the numerical output of the model simulations. However, the behaviour of the system does not change if only looking at free flow versus congestion regimes. For the maximum density sensitivity only in congestion regimes sensitivity is shown. For the sensitivity to dimensions of the bottleneck, in congestion behavioural sensitivity is observed in 2 scenarios with decrease in width.

Sensitivity to Dimensions Bottleneck block 3 Wide Dam South to North

For the width sensitivity in congestion states, the behaviour of the system changes from block 2 onwards if the width is decreased by 5% (comparing scenarios III and VII to the others). For scenarios III and VII a breakdown is shown in block 2, just before the bottleneck block 3, please find Figure 50. This breakdown results in a blockade of the total wide dam.
For a constant width but an increase in walkable surface (comparing scenarios I and V), the model is only numerical sensitive, meaning similar behaviour is shown. Comparing V to I the total travel time is lower for V, because of a smaller length of block 3. This effect is also seen comparing cases II and IV. However, because in case II the width is 0.3 [m] wider, this effect is balanced. If the cases with increase in width are compared (II and VI), the total number of visitors in the system is higher for the case in which the length is larger and surface smaller. This is explained to the fact that the density in these scenarios will be higher, see Figure 51, thus a lower speed is assigned and therefore more people are in the system, see Figure 52. This means that the model is sensitive to the length and walkable surface, but especially to the surface because length is only considered in travel time calculations whereas the surface variable is in the loop of calculating flows.
In free flow conditions, the numerical sensitivity is only showed for so called internal variable (risk development per block, densities per block, number of visitors walking over the dam), but not for the total throughput of the system. This makes sense, as in free flow conditions the travel time is similar, but very small differences may exist per block given the changes in length, width and surface. This is shown in Figure 53 where the total number of visitors in the system is pictured and for case VII the highest values are observed. For the risk development at blocks 2 and 3, the relative highest risk development in under critical conditions is for case III, VI, and VII thereafter case IV & V & I and the least in case II. This can partly be seen from Figure 55. So the width is dominant here, however with an increased width but decreased surface the density in the block is relatively higher, so that next to the width, the surface is dominant. Varying the length is not dominant for the development of risks, only dominant for numerical sensitive to travel time calculations. See for the density development in block 3 Figure 54.

Figure 52 Total number of visitors in the system in case of over maximum arrival rate of 6.5 [p/s] for Wide Dam South to North and width sensitivity tests for block 3

Figure 53 Total number of visitors in the system in case of over under critical arrival rate of 6.27 [p/s] for Wide Dam South to North and width sensitivity tests for block 3
Figure 54 Density in block 3 in case of over under critical arrival rate of 6.27 [p/s] for Wide Dam South to North and width sensitivity tests for block 3

To conclude, the model is behavioural sensitive to changes in the dimensions of the infrastructure, especially for the width of a passage way. For the length and surface only numerical sensitivity is observed in line with the calculations for the flow. Therefore, the model output is valid to the input on width, length and surface.

**Sensitivity to Initial Demand Rate, Arrival Rate and Pattern**

The model output shows numerical sensitivity to the initial settings for arrival rate or pattern. Furthermore, the arrival pattern and capacity of the system should be in balance to prevent a breakdown. In this way, the model output is always sensitive to the arrival rates. The arrival pattern of g and h are compared and show in ratio same sensitivity. Furthermore, if g is 40% increased a breakdown is observed. For h, with 6 peaks above the maximum arrival rate, no breakdown is
observed. Furthermore, as can be seen from Figure 22, the total throughput is lower for arrival pattern h and for arrival patterns of g than for the free flow arrival rate maximum of 6.27 [p/s].

The initial demand rate is used for calculating the maximum outflow of the arriving visitors. Therefore, the model shows as expected numerical sensitivity to changes in the initial demand rate. The initial demand rate is set to 1.03 [p/s] considering a density of 1 [p/m²] with speed of 1.03 [m/s], to initiate that this stretch is within the SAIL event area so an average density is likely. So no transient run is needed before analysis the output. However, when changing this initial demand rate along the lookup function (so taking density = [0.75, 1, 1.25, 1.5]), the model shows for both conditions (free flow and congestion) numerical sensitivity in throughput and all internal variables. This is likely, as the initial condition of the flow determines the extent to which the flows can still grow before congestion occurs.

**Sensitivity to Lookup Speed, Critical and Maximum Density Wide Dam**

When the lookup function for assigning speed by calculating density is changed by 5%, 10% and 15%, the model shows numerical sensitivity. The increase in lookup efficiency in free flow and congestion condition shows a very small sensitivity. Whereas if deficiency is being compared, larger numerical sensitivity is observed in both free flow and congestion regimes. As expected, all deficiency scenarios with arrival rate above the maximum shows congestion occurring earlier in the run, see Figure 57. The more the deficiency the earlier congestion sets in. Comparing 1 deficiency scenario in free flow (arrival rate 6.27 [p/s]) and congestion (arrival rate 6.28 [p/s]) value difference is very small and behaviour is similar.
The model shows no sensitivity to a change in the critical density in case of free flow arrival rates, but a small sensitivity in congestion regimes, see Figure 58. This is as expected, as the lower the critical density, the earlier the transfer flow will be restricted by the density in the next block, so the longer the system can still flowing. Therefore, the throughput is smaller for a critical density of 3 compared to 2 in congestion regimes.

Figure 58 Density block 3 of Wide Dam South to North by sensitivity critical density for over critical arrival rate of 6.5 [p/s]

If the maximum density is restricted to 5 logically the total throughput is lower than for same over maximum arrival rate and a density of 5.25 [p/m^2] or 5.4 [p/m^2], see Figure 59. In the model this sensitivity is observed only very small and only for congestion regimes, as could be expected.

Figure 59 Throughput of Wide Dam South to North by sensitivity maximum density for over critical arrival rate of 6.5 [p/s]

Extreme value sensitivity results of Wide Dam

For the extreme value test the case is tested upon zero arrivals (output should be zero) and 2 times the maximum arrival rate, which is 12.54 [p/s]. This is also the maximum arrival rate out of a central station exit of 9.5 [m] wide with an initial speed of 1.31 [m/s] and density of 0.25 [p/m^2]. So this value is also reasonable to consider, though an extreme value compared to the maximum arrival rate of 6.27 [p/s]. As expected, no visitor arrives at the wide dam in case of 0 arrivals. The throughput for 12.54 [p/s] is far lower than for congestion at 6.5 [p/s] because the bottleneck already occurs at the first block within 50 [min], instead in the bottleneck of 6m wide. Please find Figure 60 for the throughput of these cases. To conclude, the model output response to the extreme values is in line with the expectations, therefore the model is robust to extreme changes in arrival rates.
Throughput in extreme arrival rates (zero and 12.54 [p/s]) and under critical (6.27 [p/s]) and overcritical arrival rate (6.5 [p/s]) for Wide Dam Case South to North

Results on solutions implemented at Wide Dam

For the Wide Dam the most effective solutions are to control the inflow arrival rate (by batches, maintain critical density as maximum or by restricting the inflow arrival rate directly). The speed adaptation does not show a beneficial effect in this model nor in other models. The critical density control is very effective in all models. See Figure 61 for the solution to restrict the maximum inflow by maintaining the critical density value of $2 \frac{p}{m^2}$ as maximum density instead of $5.4 \frac{p}{m^2}$. The batch size solution needs further specification for each model.

The batch creation allows to control the inflow, now the capacity is known. This means that the over maximum arrival rate of 6.5 people/second can be maintained if batches (groups) are created of
maximum of 31 people every 5 seconds. This allows the system to find a balance further downstream, in this way a breakdown is avoided. Variations in batch size and waiting time are possible, however the systems output is very sensitive to these parameter settings. Other options discovered are only in same ratios as the one showed here, so 62 [p] every 10 [s] or even 186 [p] every 30 [s], please find Figure 62. Of course, the option 186 [p] every 30 [s] seems unpractical, but 62 [p] every 10 [s] might be possible.

![Figure 62 Throughput for Wide Dam Case South to North batches for same overcritical inflow of 6.5 [p/s]](image)

**Sumatrakade Mooring Case Evaluation**

The Sumatrakade Mooring is the last small case for application. Also for this case the arrival rates and width of the blocks have been subject for validation and implementation of solutions. Next to that, the solution to restrict the density to its critical value has been implemented as well as the capacity dependency for the ferry.

The Sumatrakade Mooring is a queuing place in itself. Thus to model this, a queue is expected. However, the underlying question is when this queue is overflowing to the upstream blocks or even further. To assess this it is necessary to known the arrival rate of visitors (and distribution over time), the choice to go to one of the two entrances, the boat capacity and frequency and the available queuing space at the quay. Because all these parameters are uncertain in SAIL, the sensitivity to these initial parameter set on the output of the model is being tested. For the space available, 2 subcases of this small case are modelled with extra space in A and without this extra space B.

*Sensitivity of the Sumatrakade Mooring models to uncertainty in parameter values*

As expected the model is numerical sensitive to the boat capacity and frequency, loading time, arrival rate and share of visitors over the entrances. The fluctuation in the transfer flow from the entrance blocks to the quay block, because of the discrete departure function (boat) is seen in all scenarios. If the maximum arrival rate of the wide dam is considered, the extra space is needed as well as a boat capacity of 600 [p/boat] and every 300 [s], but already then a risk overcritical is observed at the end of the first hour, see Figure 63. This means, that the Sumatrakade mooring is very likely to become a bottleneck because the boat capacity and frequency are unlikely to increase even more than the case presented. The arrival rate might be lower, but it is a matter of time when the congestion sets in already with a very low arrival rate of 2.5 [p/s] in case A and B for a run of 10 hours.
Extreme value sensitivity results of Sumatrakade Mooring

For case A and B the extreme values of zero arrivals and 12.54 [p/s] arriving are simulated. In both cases the system output is numerical sensitive to the extreme arrival rates in line with the expected output. For case B vs A the breakdown of the system is earlier so the number of people departing per boat is higher for case A as expected, see also Figure 64.

Results on solutions implemented at Sumatrakade Mooring

Because the capacity of this case is limited in terms of space and boat departure frequency and boat capacity, the solutions to restrict the inflow in the Wide Dam case will highly influence the performance of Sumatrakade Mooring. However, as is observed, the maximum arrival rate of the Sumatrakade is 2 [p/s] whereas for the Wide Dam it is 6.27 [p/s]. Therefore, to increase the performance of the Sumatrakade without changing the dimensions, boat capacity or its frequency, an upstream solution to decrease the inflow seems the only solution. The other solutions by batching people or restricting the critical density will in this model be less effective than for the wide dam because of the queuing function of the Sumatrakade Mooring instead of the transfer purpose of the Wide Dam. Sumatrakade Mooring is a very small stretch where only the space for queuing is taken...
into account, so restricting critical density as maximum density or allowing batches of people will only work if the arrival rate is lower than 6.27 [p/s].

**Bi-Directional Case Evaluation**

*Sensitivity of the Bi-Directional model to uncertainty in parameter values*

The first tests executed for this model evaluation are on the behaviour of the system. In macroscopic flow modelling, the walkable surface is the key parameter for determining the density in a stock. Therefore, the microscopic flow effect of a higher efficiency for a funnel versus a square, cannot be considered an effect in macroscopic flow modelling. As this is the difference between the cases A and B, no difference between these cases may be observed. Furthermore, it is stated that bidirectional flows are less efficient than unidirectional flows in the same infrastructure for the same demand. Therefore the second check is to evaluate if a unidirectional flow in this model is more efficient than a bidirectional demand. To check this, comparison is done for the first case with maximum arrival rates from the two directions with the second case with a unidirectional flow for a higher arrival rate than this maximum arrival rate. The last behavioural effect is that a very high arrival rate from one direction should dominate the other direction. Therefore, the third behavioural validation test is upon determining if no direction is dominating in equal flows, or if this dominance is showed when unequal arrivals are the case. Because this model is not considered part of any mass event, the model is ran for 1 hour in all tests.

On the first test, the model shows valid behaviour. Indeed no behavioural or efficiency differences between case A and B are being observed. However, there is a small difference between A and B. For an arrival rate over its maximum (1.59 [p/s]), the case B has a slightly higher throughput. Comparing the maximum arrival rates for A and B (1.57 [p/s]), a small difference is also found in the stabilising phase of the system. Furthermore, for both A and B the maximum arrival rate is 1.57 [p/s], indicating that the capacity of these systems is similar.

See Figure 65 for the departures from Right to Left (RL) for both cases A and B for both arrival rates (1.57 [p/s] and 1.59 [p/s]).

![Departures RL](image)

*Figure 65 Departures from Right to Left for both cases A and B for both arrival rates 1.57 [p/s] and 1.59 [p/s]*

The second check is upon the efficiency of unidirectional flows in this model versus bidirectional flows. It is observed, that indeed the capacity of the stretch is much larger for unidirectional flows than for bidirectional flows. However, this is not proportional to the total inflow. So in case from both direction
1.57 [p/s] arrive, meaning 3.14 [p/s] in total, the unidirectional flow will show a breakdown for this arrival rate. The maximum arrival rate for unidirectional flows is 2.42 [p/s]. This difference is explained by the dynamics of the system. For an arrival rate of 3.14 [p/s] divided over two entrances, the dynamics of the system will search for a stable flow and can still find that because the feedback goes in two directions. However, by considering a very high constant arrival rate from one side this stabilizing behaviour is being constrained, because no limits are put on slowing down the flow by the other direction. To conclude, a unidirectional flow is more efficient than a bidirectional flow. The throughput of unidirectional flows is much higher. This is showed in Figure 66 by the total departures for direction RL for three arrival cases. Furthermore, the risk considered for unidirectional flows versus bidirectional flows is far less in the first case. Therefore, for mass events it would be highly recommended to not consider bidirectional flows if possible. This is showed in Figure 67 by the risk for the same three arrival cases.

*Figure 66 Departures from Right to Left for case B with extreme arrival rates 0, 1, and 2 [p/s]*
The model presented in the framework is tested to be valid on these behavioural effects. However, a small dominancy is showed for the left to right direction over the other direction, see Figure 68, in case of free flow conditions. However, an even bigger difference is observed during an over maximum arrival rate of 1.59 [p/s]. This is explained by the fact that the width of an entrance is first calculated and then the width remaining is assigned for the exit of the other flowing direction. Therefore, always the inflow blocks Left to Right block 1 and Right to Left block 3 will be dominant. After stabilising the difference is very small for the two directions.

Figure 67 Total risk development block 2 (bottleneck) for case B with extreme arrival rates 0, 1, and 2 [p/s]

Figure 68 Departures from both directions for case B with arrival rates 1.57 [p/s] and 1.59 [p/s]
The presented sensitivity tests for the Bi-Directional model are being done with use of case B with the symmetrical infrastructure after concluding the difference in the cases may be ignored.

**Deficiency Sensitivity Test Results**

The first test is on the flow deficiency. For Bi-Directional models with use of the unidirectional fundamental diagram, the capacity of the stretch would be overestimated. Therefore, the efficiency is taken into account from -2.5%, -5%, -10% to -15%. What is expected is also observed that the capacity of the stretch becomes less if the flow efficiency is lower for the same density. For the maximum arrival rate of 1.57 [p/s] this means that already for -2.5% efficiency the breakdown occurs. The corresponding differences in 2.5%, 5% and 10% deficiency is seen in a higher throughput for less deficiency although in all cases a breakdown occurs. In Figure 69 the deficiencies are showed in the Departures Left to Right for both arrival rates of 1.57 [p/s] and 1.59 [p/s].

For the both arrival rates the throughput for less deficiency is also higher than for high deficiency. However, for both arrival rates the difference between 0% deficiency and -2.5% efficiency is remarkable large compared to the difference in -2.5% efficiency and -5% efficiency and the rest. This might be due to the fact that the initial desired speed in free flow stage is also changed according to the change of the flow efficiency in the fundamental diagram. This means that the maximum initial desired speed is lower for each deficiency case. Therefore, the total throughput for an arrival rate of 1.59 [p/s] cannot be as high for 2.5% deficiency as is for 0% deficiency as the maximum speed is also 2.5% higher in the latter case. This speed determines the outcome of the throughput level, because from the moment the breakdown sets in, no visitors will pass.

To conclude, the model outcome is very sensitive to the fundamental diagram and the deficiency chosen for bidirectional flows. The showed maximum arrival rates need to be changed accordingly to the new fundamental diagram chosen.

![Departures LR](chart.png)  
*Figure 69 Departures from Left to Right for case B with arrival rates 1.57 and 1.59 [p/s] for deficiency 0, 2.5, 5, 10, 15%*

**Arrival Rates & Arrival Distribution Test Results**
The expectancy of the dependency of the arrival rate to the performance of the system is already showed by the behavioural test. However, the extent to which the outcomes of throughput and risk are sensitive to the initial setting of arrival rates and distributions is discussed here.

In Figure 70 the departures for the direction Left to Right are presented with changes of the maximum arrival rate 5% and 10%. A change of -5% of the arrival rate is 94% of the normal case and for a change of -10% this is 91%. So a maximum sensitivity of 1% compared to the change in arrival rates is observed. The estimation procedure is therefore reliable for handling changes in arrival rates.

An extreme case would be that the arrival rate is as constant as considered here. Therefore, two distributions are being applied to observe the systems behaviour. The first case G has 13 peaks above the maximum arrival rate of 1.57 [p/s] with a maximum of 1.75 [p/s], see Figure 71. The second case H (in red) has 5 peaks above maximum with the same maximum peak. Both cases vary in peak duration and peak moments. When varying the patterns for both directions sensitivity is observed, see Figure 72.
Figure 71 Arrival distributions G (blue) and H (red)

Figure 72 Departures Left to Right for patterns H and G for both directions
It can be concluded that the model outcomes are proportionally sensitive to the arrival distributions. The extent in which this sensitivity is changing the model outcomes is small given a small difference in arrival pattern, as can be seen from the figures above. It seems that in this case the best performance is a case with pattern G. This is explained by the fact that the total arrivals for pattern G is slightly higher than for H, see Figure 73.

**Initial Demand Rate Sensitivity Test Results**

The initial demand rate provides an initial setting for the model and provides a boundary for the flow given the width of the entrance. For the arrival rate over its maximum, the maximum outflow of the arriving passengers is being adapted towards the new values. However, for the maximum arrival rate this is not the case. Furthermore, for both arrival rates the departures and the development of risk does not depend on this initial demand rate, because of the model specification for both determining a maximum outflow and maximum inflow dependent on the arriving passengers.

**Critical and Maximum Sensitivity Test Results**

The critical density is the parameter for indicating the risk under and overcritical. Logically, by changing the value for the critical density a proportional change in risk development is shown for both under and overcritical risk. See Figure 74 for the overcritical risk sensitivity by an arrival rate of 1.59 [p/s] for changing the critical density by 0.5 or 1 [p/m²].

![Arrivals RL 3](image-url)
Figure 74 Risk overcritical for bottleneck block 2 for over maximum arrival rate and change in critical densities

Figure 75 Risk development in block 2 for change in maximum density, case d is with maximum density $5.4 \text{ [p/m}^3\text{]}$
The maximum density is subject of discussion among scientists in pedestrian traffic flow fields. For this reason, it can be assumed that the maximum density for bidirectional flow fundamental diagram will be lower than for unidirectional fundamental diagrams. A change in this fundamental diagram will result in a change in the risk development over time for an over maximum arrival rate of 1.59 [p/s], see Figure 75. Although counterintuitive it may seem that the risk in this block for a maximum density of 5 is lower, this is explained by Figure 76. In this latter figure it can be observed that the maximum density of 5 [p/m²] is reached earlier than for the higher maximum density cases. Therefore, the risk development stops earlier. The sensitivity to the maximum density is reliable for the model outcomes, however only observing the risk is not enough to conclude on the change.

**Bottleneck Sensitivity Test Results**

The bottleneck is changes 5% and -5% to see the response of this change in the total throughput of the stretch, see Figure 77. In this figure represented by the blue graph a breakdown occurs around 850 [s] for the case in which the bottleneck has been narrowed to 5.7 [m] (including narrowing the walkable surface) at the same arrival rate of 1.57 [p/s]. An increase in bottleneck width by 5% (and increase in walkable surface) was expected to result in a higher throughput. However, a higher throughput is only observed for the first 30 [min], afterwards the same throughput is encountered as for the normal bottleneck width of 6 [m]. An explanation might be that the density in the bottleneck returns to a stable value for this arrival rate because of the dynamics in determining the flows per direction, see Figure 78. The stabilizing process is faster for the case of a width of 6.3 [m]. Therefore, the risk in this block is lowest for the higher walkable surface and higher width passage, as can be seen in Figure 79.

To conclude, the bottleneck width adaptations have a large effect on the total performance in throughput and risk development of the system and the blocks. Therefore, changing the bottleneck width is considered part of a solution to increase the throughput and mitigate risks.
Figure 77 Departures Left to Right Bi-Directional Model for three different width of the bottleneck by same length

Figure 78 Total Density in bottleneck block 2 for 5% change in width and same length

Figure 79 Risk in bottleneck block 2 for 5% change in bottleneck width by same length
Extreme value sensitivity results of Bi-Directional Cases

The arrival rate is doubled for both directions and for the direction Left to Right with zero arrivals at Right to Left and the maximum arrival rate of 1.57 [p/s]. As expected, in all cases a breakdown occurs. This breakdown occurs the fastest in case both direction have an extreme arrival rate of 3.14 [p/s] and slowest for the unidirectional case with this extreme arrival rate. Please find Figure 80 for the results of this analysis on the total density of bottleneck (block 2).

Figure 80 Total Density [p/m²] bottleneck block 2 for extreme arrival rates [p/s]