Mass evacuation - human behavior and crowd dynamics

- What do we know?

Markus Friberg
Michael Hjelm

Department of Fire Safety Engineering
Lund University, Sweden

Avdelningen för brandteknik
Lunds tekniska högskola
Lunds universitet

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Authors: Markus Friberg & Michael Hjelm

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Abstract
The field of mass evacuation has existed for a long time. Already during the Roman Empire era evacuation problems were considered. In modern times, the field has gained more attention during the last couple of decades, especially for sports grounds and stadiums. Through analysis of some well-known historical crowd disasters and through a literature survey the aim has been to compile the most important findings. The aim has also been to analyze problem areas, knowledge and development opportunities. Regarding the problems of mass evacuation, preventive measures like design and contingency plan is of high importance. In addition, there is a need for good communication and to take proper actions when an accident occurs. Some phenomena that may arise during crowded situations have been found. These phenomena are an indication that a catastrophic situation might emerge. With knowledge and understanding of those the expectation is, with the help of live video recordings and simulation software, to get a warning about the elevated risk for the crowd.

Avdelningen för brandteknik
Lunds tekniska högskola
Lunds universitet
Box 118
221 00 Lund
brand@brand.lth.se
http://www.brand.lth.se
Telefon: 046 - 222 73 60
Telefax: 046 - 222 46 12

Department of Fire Safety Engineering
Lund University
P.O. Box 118
SE-221 00 Lund
Sweden
brand@brand.lth.se
http://www.brand.lth.se
Telephone: +46 222 46 12

PREFACE

This is the final report before we graduate, and can get our Bachelor of Science degree in Fire Protecting Engineering. During these three and a half years that we have been studying, we have gathered large amounts of knowledge but also grown as persons. In this paper we have been writing about some of the parts that we find the most interesting concerning us fire engineers. How people behave during disaster is starting to become a topic that constantly grows. In addition to this we are both passionate about all kind of sports. This is why it has been of particular interest to focus on sport arenas and mainly evacuation problems. We hope that the reading of this paper will be enjoyable and that our work could be of use to future students. The report has primarily been developed to gather all the important knowledge that has been developed in the field of mass evacuation, as well as human behavior and movement patterns during those situations. The attempt has been to summarize these parts in a simple and proper way.

There are a few people that we would like to give credit to, who have been helpful to us during this report. They have guided us in the right direction and given us valuable tips.

Håkan Frantzich
Associate professor at the Department of Fire Safety Engineering, Lund University. Håkan has served as our supervisor. He has given us feedback and helpful insights along the way. He also provided laughter and easement in times of difficulties.

Daniel Nilsson
Associate professor at the Department of Fire Safety Engineering, Lund University. Daniel is in charge of the course Human Behavior During Fires, which annually is held at Faculty of Engineering LTH. He has helped us to gain access to valuable material.

Linus Östman
Fellow student at the program of Fire Safety Engineering. For proofreading and helpful comments.

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Markus Friberg   Michael Hjelm

SUMMARY

The purpose of this report has been to give a brief summary of the knowledge and research that have been conducted in the field of pedestrian and evacuation dynamics as well as behavior in fire, with focus on sport stadiums and other event areas. In addition, this report aims to be a basis for future students. In this summary, a number of important aspects and characteristics and how to handle these will be presented.

The critical conditions that may arise are often characterized by crowding and movement at vulnerable locations at a stadium. These locations could be doors, gates, and passages or where many people might accumulate. When obstacles cause disturbance or when the spatial space narrows the flow naturally decreases and a phenomenon called bottleneck often occurs. Critical conditions may occur when highly dense crowds move. The cause for this is the pressure that builds and transmits and propagates through the crowd.

Extremely high density may cause a crowd to, without reason, be unintentionally tumbled around. Forces propagate throughout the crowd in every direction and may cause people to fall. Research shows that a density of more than 7 persons / m^2 can cause turbulence.

The discover that turbulence is a strong indicator that catastrophic disasters are about to happen has led to an attempt to identify when situations may become critical. By using live video recordings and simulation software, situations that may become critical can be identified. The purpose of this is to warn the management and organizers before critical conditions occur. Proper actions can then be taken to prevent an accident.

The use of computer simulations is a rapidly growing approach, where the capacity is primarily limited by the lack of data. Many of the experiments conducted on human behavior and evacuation are flawed as they are often based on smaller homogeneous groups, often consisting of young men, which does not reflect reality in a proper way. To develop these simulations, so they better match with reality, there is a need to gain more knowledge through analysis of real disasters and experiments.

Crowd management is one way to achieve public safety. Some guidance on how to do this is presented in this paper. Crowd disasters are rarely to be blamed on the crowd itself, but instead organizers and poor management is the responsible parties. To achieve a good standard regarding public safety, contingency plans should exist.

Contents

1. Introduction

This document is the final report in order to receive a Bachelor of Science degree in Fire Protection Engineering from the Department of Fire Safety Engineering at Lund University in Sweden. This report concludes with a degree equivalent to 22.5 credits.

In addition to this written part, the work was presented verbally at a public seminar held at Lund University. Finally a verbal opposition on one of the other student's bachelor papers finished this project.

1.1 Background

The security at football- or soccer stadiums have recently been in focus due to the FIFA World Cup that was held in Brazil during the summer of 2014. This was also one of the major reasons for choosing this topic.

The threats for these events include hooliganism, congestion, alcohol, flares or terrorist threats. In addition to this, mainly seen with Swedish point of view, hooliganism has escalated over the last few seasons. The wide threat leads to a variety of situations which may potentially challenge the security as well as the evacuation possibilities at similar events.

Large crowd gatherings at confined spaces has proven to be dangerous. Throughout history, many disasters have occurred in large crowds, mainly at football stadiums and festival areas. The main reason for so many deaths is the high density of people. Is this this the only reason or is it a combination of factors? How will the spatial environment affect? Are there structural properties which can improve the safety? Or might there be organizational measures to be taken?

This has led to a strong interest in examining how the evacuation and dynamics of large crowds occurs and if there are any problem areas. Is it only the high density that causes problems or are there other aspects as well? What have been the cause in the past and how can we prevent these disasters?

Though the area of crowd dynamics and evacuation rests on a physical as well as a psychological basis, and depends on people's actions and reactions. It is vital to gain an understanding of these aspects.

1.2 Purpose & Goal

The purpose of this thesis is to study the theory and available material regarding evacuations, especially mass evacuations but also at an individual and group level. Great focus will be on human behavior and different movement patterns associated with evacuations of larger crowds.

The goal is to study the research already conducted in the field and in a single document present a summary of the findings. The attempt is to make this report as easily understandable as possible. Another aim is to identify problem areas important for public safety and what essentially should be studied further in the future.

1.3 Questions at issue

Before this literature survey started, a few questions arose that hopefully will be answered in this report.

- How do people react when a fire or any other disaster occurs, which requires evacuation?
- Are there any typical movement patterns during mass evacuations and what do they depend on?
- What methods are used today to handle and develop knowledge around the area of mass evacuations?

1.4 Method

The method was based on a thorough literature research. After the main elements were compiled and summarized.

A few disasters have been given extra focus in this report. These disasters were first described and then examined further, and the causes and mistakes were analyzed.

A summary was made on how individuals are affected and behave during fires. Influence from other people and group behavior during and before they begin to move was examined.

Different patterns during mass evacuations and in crowded situations were studied. Some simulation programs, with the attempt to predict and calculate movement time, and when and where critical situations could occur were explored. Different methods and guidelines that are used by management teams to prevent disasters have been evaluated.

Finally an analysis and discussion of the report were conducted. Characteristics and patterns that have been found regarding crowd dynamics were summarized, areas that can be improved, such as weaknesses and uncertainties were then presented.

A description of the method used in this paper is shown in Figure 1.

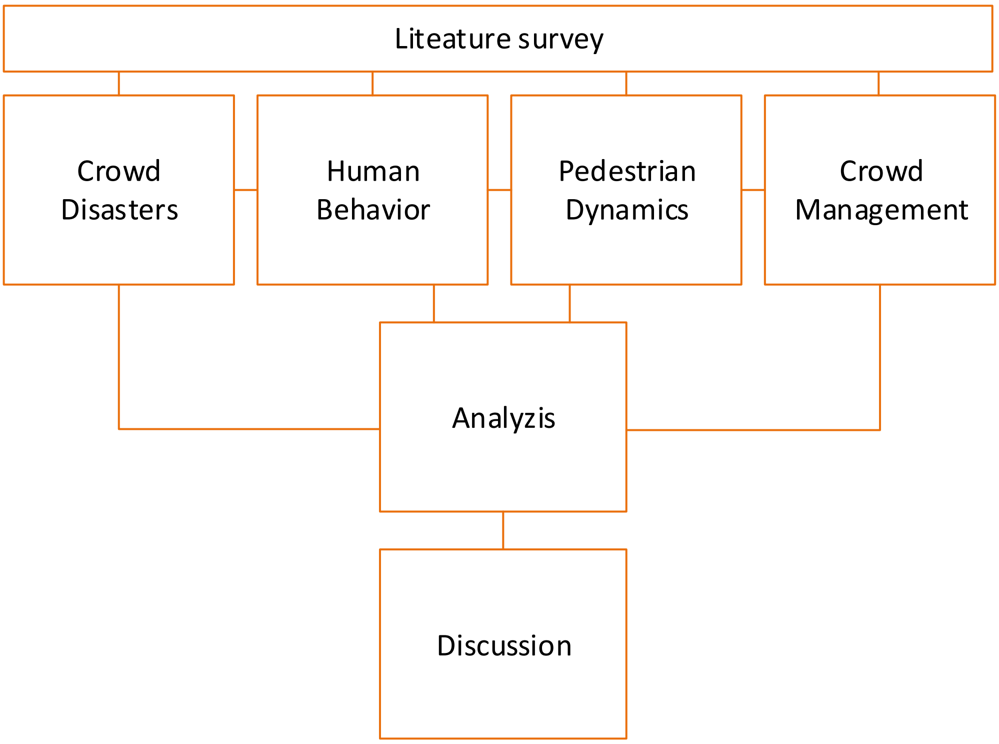

Figure 1. Method used in this paper

1.4.1 Literature survey

First a literature survey was conducted with the focus on human behavior, group dynamics, movement and behavior patterns in fire and evacuations. The most important aspects and theories of these studies were briefly summarized. The search services and materials that were used in this report are primarily Google Scholar, Lund University's search service LUBSearch and available material from the course: Human Behavior in Fire, which is held at Lund University. Much of the material in this paper is based on are academic journals and case studies, thereby the reliability of the sources are considered to be justified.

1.5 Scope & limitations

One limitation was the lack of time which made it important to carefully select and study the materials that actually were relevant to this paper. If more time had been available the study could probably be more comprehensive.

In addition to our own background as engineer students, an engineering point of view has naturally been used. Much of the literature used in this paper mainly focused on the social and psychological aspects. Insufficient understanding of these fields could implicate problems and misunderstandings.

2. Disasters & mass evacuations

Throughout history mankind has experienced many disasters and accidents that have affected a large number of people. These disasters tend to highlight problem areas and therefore they are sadly required. In addition, they result in commitment and willingness for the society to develop the designs of buildings and safety systems.

The definition of a mass evacuation is indistinct. One definition of mass evacuation that will be used in this paper highlights that there are three factors that have to be fulfilled (Drury & Cocking, 2007).

1. A mass of people needs to be involved.
2. There must be a perceived threat to life.
3. And finally, there must be a reasonable chance that within a limited time, be able to escape from danger.

Focus in this report is mainly on evacuations of larger public assembly locations, especially sports grounds, but also on areas were a large number of people are gathered within a small area, like a festival or during pilgrimages. In this chapter some disasters are briefly presented that have either affected evacuation possibility or highlighted problems with large crowd gatherings. These disasters will be further analyzed and discussed in chapter 7 and 8.

2.1 Ibrox Football Stadium, 1971

On January the 2nd in 1971, 66 spectators became victims and lost their lives to one of the first accidents that has been well documented at a sport ground. In addition to the deaths there were about 150 people that got injured. The accident took place at Ibrox Stadium, in Glasgow at the classic "Old Firm" game between the local rivals Rangers and Celtic. The disaster occurred in the final stages of the match, in context with a late equalizing goal, made by Rangers. Because of the magnitude of the match, and because of the late goal, people were euphoric. They sang and partied wildly. Moreover, a large part of the audience was noticeably influenced by alcohol which also could have affected the outcome. The arena had reached its maximum capacity and there were around 80 000 people attending Ibrox this evening. These two factors, the euphoria of the spectators and the high pressure, due to the full seated stadium was underlying causes to the accident (Walker, 2004).

The accident took place at stairway 13 when people fell and the main cause of death was compressive asphyxia as the people piled up. The theory behind the accident is still uncertain but it is believed to depend on someone tripping on his or her way down the stairway, a domino effect set in and more people fell over. Stairway 13 was the most frequently used staircase in the whole stadium, about 20 000 people are believed to have used this stairway. The built up pressure that was created by the people from behind, as everybody was trying to leave the stadium at the same time, which increased the magnitude of this disaster. The people behind did not know that a person had fallen and continued to walk, this pressure made more and more people fall, which resulted in a pile of people (Walker, 2004). This accident is interesting for this report as it highlights a disaster that happened during egress and could therefore be likely to happen during an evacuation. The design for this egress route was inadequate and stressed the importance of design and functionality at sports grounds.

2.2 Bradford City fire, 1985

On May the 11th, 1985 in the city of Bradford, UK, a small fire first started at the Valley Parade stadium's main grandstand at the northern end of the stand. The fire growth phase was rapid and only 7 minutes after ignition the whole stand was in flames. The match should have been a tribute to the team as they had just become champions of the division three in the English football. In this match, which was the last of the season, Bradford City's Football Club faced Lincoln City. Festivities were held before and during the game to celebrate the team, including a parade. In addition to this, the team and various persons were awarded with prizes before the game. Also the team received a championship trophy. This attracted a lot of audience, and about 11,000 people are estimated to have been at the stadium that day. Around 5,000 of the spectators were located in the main grandstand. The fast spread of the fire made it impossible for all the spectators in the main grandstand to evacuate fast enough, which caused the deaths of 56 persons and injured around 300. This is still one of the biggest tragedies in the English football (Klem, 1986); (Popplewell, 1985). This disaster is significant to this paper as the evacuation possibilities were challenged, because of the locations of evacuation routes and the rapid fire growth. Also certain behaviors in case of fire can be evaluated for this disaster.

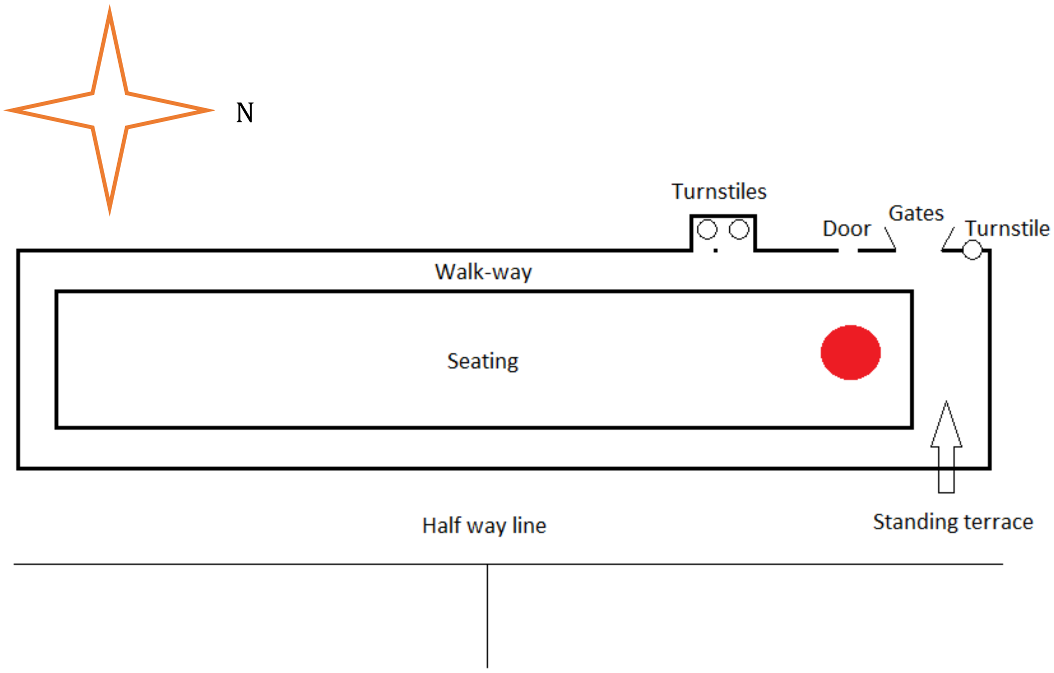

Figure 2. Overview of the main grandstand of the Valley Parade stadium.

2.2.1 Sequence of events

- At 15.40 the rubbish under the stand was ignited and smell of the burning was detected by people. Police were informed and tried to locate fire extinguishers, which could not be found.
- At 15.42 the timber beams beneath the floor were burning. Communication was established with police control center, which in turn contacted fire brigade.

- At 15.43 flames were visible above the floor. The fans in the closest surrounding of the fire started to move down to the pitch or upwards toward the walk way or corridor leading to the exits.
- At 15.44 the fire was several square meters and generated dark smoke which created critical conditions in the walk way.
- At 15.44.30 a clearing off the pitch by the goalkeeper, took away the spectators attention from the game. Police ordered people close to the fire to move onto the field. Some people at the south end of the main stand started to move as well.
- At 15.45 the flames had reached the ceiling and the fire was approximately 10 m^2. Critical conditions were reached in the back corridor.
- At 15.46 flashover occurred. The closest surrounding was emptied but at the south end of the main stand, spectators were still present. Flames started to spread in that direction. By this time the fire brigade had arrived to the stadium.
- At 15.47 almost the entire stand was in flames. At the very southern end of the stand a few people still tried move onto the pitch.

2.3 Hillsborough disaster, 1989

The 15th of April in 1989 another even more tragic disaster occurred in English football. Many blame the police and the security staff because that they admitted more spectators into the arena then it was designed for. When the capacity was exceeded pressure was built up from the people trying to enter from the back of the stand. As many as 96 people died and more than 400 got injured due to the crowd crush. Compressive asphyxia was the main cause of death (Stuart-Smith, 1998); (Hillsborough Independent Panel, 2012).

This accident occurred in the beginning of the FA Cup semi-finals between Liverpool and Nottingham Forest. Over 50,000 spectators were on the site this day. The match was played at a neutral location and for various reasons a large part of the audience were late. As a result of this the police had difficulties handling the large number of fans outside the stadium. To handle the escalating situation a new entrance was opened to enter the stands. Because of the excessive amount of people trying to enter, great forces and pressures propagated through the crowd. The people closest to the fences, that shielded the pitch, were finally crushed (Stuart-Smith, 1998); (Hillsborough Independent Panel, 2012). This disaster is of importance for this paper as it includes phenomenon during an ingress situation that is likely to happen during an evacuation. It highlights the importance of design of the stadium’s structure as well as crowd management and planning.

2.4 The Love Parade disaster, 2010

On the 24th of July 2010, a crowd crush occurred at a festival area in Duisburg, Germany. This disaster took the lives of 21 people and more than 500 people were injured. The cause of the tragedy is mainly blamed on bad planning as well as on the management team and the security personnel at the site (Klüpfel, 2012). The disaster was created when a ramp that was used by people in the festival area met another stream of people who came from an underground tunnel. People constantly flowed into this area, but not as many got out which naturally increased the pressure. Finally it became too high and people stumbled, and because of the high pressure people were crushed (Ma, et al., 2013); (Helbing & Mukerji, 2012). The Love Parade disaster is interesting for this report because it points out different phenomena in pedestrian dynamics of large crowds. These phenomenons have been found to be indicators that conditions are critical and a disaster might occur.

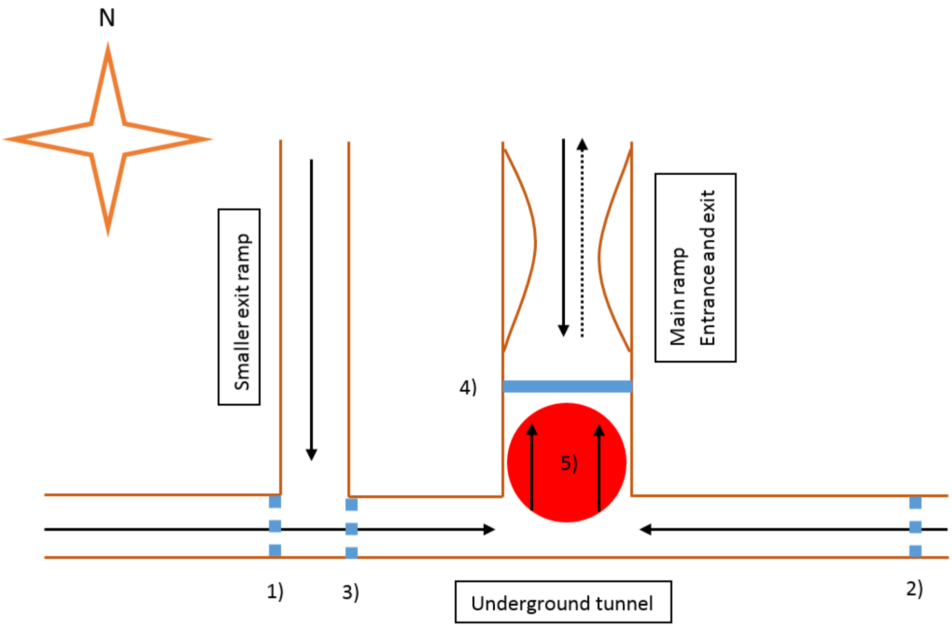

Figure 3. Overview of the Love Parade entrance area, the numbers illustrates different sequences that took place before the accident occurred.

2.4.1 Sequence of events

- The first couple of hours the entrance and exit systems functioned without problem. At around the time of 15.50 an ambulance drove through the tunnel.
- This caused the police to form a cordon on the west side of the smaller exit ramp, blocking people to enter or leave through the tunnel in that direction, 1) in Figure 3.
- 7 minutes later, a new cordon is formed on the eastern side of the tunnel, 2) in Figure 3.
- At the eastern entrance point many gather as they try to enter the festival area, causing the police to move the cordon to the western side of the smaller exit ramp, 3) in Figure 3.
- At about 16.03, why cannot be explained, a third cordon is formed at the narrowest point at the main ramp, allowing only a few people to pass 4) in Figure 3.
- At 16.12 the third cordon prevent all people to leave the area through the main ramp. As more people try to leave, but are unable to, a crowded bottleneck is created at the ramp. The area between these 3 cordons is almost empty. The flow of people wanting to enter or leave the area, cause the other side of the cardons, both at the ramp and in the tunnel to be overcrowded.

- At 16.13 the second cordon, 2) in Figure 3 at the eastern side of the tunnel dissolves, and the crowd can then move towards the main entry and exit ramp.
- At 16.20 the first cordon, 1) in Figure 3 on the western side of the main ramp is dissolved. Flows from two direction overcrowd the lower part of the main ramp 5) in Figure 3. By this time two very dense crowds with a desire to move in opposite directions, are separated by the third cordon, 4) in Figure 3.
- For the next 20 minutes the density increases, as more people want to enter but the third cordon still exist, and due to this overcrowding, the disaster occurs (LoveparadeDuisburg, 2010).

2.5 Pilgrimages to Mecca

The pilgrimage to Mecca is an event that annually endures highly dense crowds. Each year between 2 and 3 million pilgrims gather to perform religious rituals (The Guardian, 2006); (Still, 2014). Several accidents of different magnitude have occurred. The reason has often been the large number of people, and when the crowd in addition constantly moves, high pressures are created (Helbing & Mukerji, 2012).

Figure 4. Pilgrimage to Mecca - Jamarat bridge (Al Bosta, 2010)

It has over the years been a number of serious incidents that have claimed many innocent lives during these pilgrimages. Most of these disasters have occurred as a result of that people have stumbled, due to the high pressure have many of those who has fallen later on been trampled to death. Something that is usually described with the word stampede. The worst of these accidents occurred in July 2nd, 1990. The disaster took place inside a tunnel that led people out of Mecca. The underlying cause for the accident is believed to depend on an overcrowded tunnel, which in turn made people fall. The high pressure that constantly was generated from people behind resulted in 1,400 people to be trampled to death. This scenario has been described as a stampede accident (Al Bosta, 2010); (Still, 2014); (The Guardian, 2006). The pilgrimage is of interest to this paper because of the high density of a moving crowd. There is probably not another place on earth where such a large dense crowd annually assembles. Some phenomenon regarding pedestrian dynamic that has occurred during the pilgrimage, might be comparable and transferable for possible evacuation scenarios at sport events or other large crowd gatherings.

3. Human behavior in fires & evacuations

To understand how mass evacuation works, it is essential to gain an understanding of the underlying psychology. How a person behaves in a certain situation depends on a lot of factors, e.g. personal matters and if the person is alone, or in a group when the fire occurs or another threat which constitute an emergency situation.

Even though a lot has been done in this field in the last decades it is vital to know that science, based on human behavior cannot completely be compared to other scientific disciplines. Mostly because that the results and the assumptions is not based on a universal validity like mathematics and physics. For example, a research made in Sweden cannot be assumed to be applied all over the world. The same thing can be said about studies that have been done on a particular test group, such as age or gender. It is unclear how these results, in an acceptable way, can be applied to other groups. The reason for this is that the different individual factors for behavior described in this chapter, can certainly be expected to vary with the cultural, social and geological environment. In Sweden, fire drills are a common occasion during the primary school years, which will influence one's behavior and actions during an emergency situation. The same cannot be said for poor, developing countries where school access is limited or not existing. People with such a different background and knowledge cannot be expected to behave in the same matter (Brannigan & Kilpatrick, 2004).

The studies that are conducted in the area regarding human behavior is often based on empirical studies based from both real events and experiments and conducted mostly on different homogenous test groups. It is important to point out that there will thus always be uncertainties in this area, and that it is important to understand that these uncertainties gives results that cannot, straight of, be universally applicable (Brannigan & Kilpatrick, 2004).

Most of these behaviors have been discovered in the presence of fire. Fire can be expected to have the same impact on people as other threats to life safety. Although there does not have to be an immediate threat to motivate an evacuation, which will be presented later in this paper. Emergencies can arise even without a specific threat but instead due to high density of people, and most of the behavior presented in this section could be assumed to occur even in those situations.

Studies on behavior in fire situation or other emergencies for large crowds are limited. Instead most focus has been on individual level, and for smaller populations. But it is the individuals that constitute a crowd, and therefore the behaviors observed in smaller groups can be assumed to exist in larger crowds as well.

3.1 Individual behavior

In order to understand behavior during fire and emergency situation, one must know that not everyone will behave in the same way at a certain situation. Therefore, it is vital to first know what different characteristics and factors there are, such as age, gender, educational level, previous experience and cultural impact. It is also essential to know how those factors actually matter during an evacuation.

3.1.1 Uncertainty

A questionnaire was conducted by Hopper and colleagues, on people who experienced fires in their homes. This questionnaire indicated that people actually have a poor understanding the different kinds of fire cues that exist. The perception of the danger from smoke and pyrolysis exposed that people often underestimated the seriousness of this. The lack of knowledge of these cues may lead to worse accidents than necessary, it also indicates that there are risks that a long and valuable time will go before people understand the seriousness of the danger and begins to either evacuate or fight the fire (Hopper, et al., 2002).

Emergencies differ from one to another and the information to the public during a fire is usually ambiguous. Smelling smoke, hearing the alarm or observing confused staff or other people may not indicate a direct emergency feeling or realizing that there actually is a fire. The situation is for most people unusual and unexpected when being at a public place. (Proulx, 1993)

3.1.2 Problem solving & decision making

In the case of an emergency the occupants of a building are faced with problem solving. A classic problem solving model has been developed by Polya (1957). It includes four cognitive stages (Proulx, 1993).

1. Understand the problem. Define situation and determine the problem.
2. Devising a plan. Look for information, make decisions and structuring actions.
3. Carry out the plan, execution of previous made decisions.
4. Assessing if the action made is solving the problem at hand.

First step is of most importance in case of a fire. It is the most decisive step. The time spent on evaluating the situation, seconds or even minutes, in a non-evacuation behavior, leads to less time for the actual evacuation. The information gathered in the first step is the basic for devising a plan to solve the problem. If information is missed, under- or overvalued or if the situation is not interpreted right, this will lead to incorrect and improper decision making (Proulx, 1993).
In the first stage the information may come from different sources. In case of a fire it might come from smoke or maybe even seeing the flames. It could also be a spoken message or a fire alarm. Other people may also be the source of information. Likewise the environment which one is present in has impact on the information as well as that previous experience in similar environment or situations (case of emergency) may have an impact (Proulx, 1993).

In the second stage when one is devising a plan, there are two common reactions. When given ambiguous information in a public place, one ignores the situation or investigates the situation further. Ignoring is more common because people tend to fall back in to their normal roles, when located at a public place, as customers or visitors, who does not take action. They usually assume it is the staff's responsibility to deal with the situation and does not want to overreact to a situation which is already under control and thereby lose face in front of others, leaving one with a feeling of shame. Investigating means interacting with other people and in that way try to identify the situation. Sometimes the person needs to get a grasp of the nature of the incident. This often implies that the person is moving towards the threat, in this case of a fire. According to literature in decision making during risk situations, in case of a fire people will not use all available information from the situation, but instead focus on the options one feels more likely to solve the problem. In such case when a quick solution is needed, a well-run decision plan could be applied. For evacuees this means evacuating trough a familiar route, usually through the main entrance which one used to enter the building (Proulx, 1993).

3.1.3 Gender

Differences between men and women during an evacuation are found differ the most in the earliest stages. When a person first notice that there is a possible emergency going on, men use to seek after more information than women do, in attempt to further understand what caused the alarm. Later on when smoke, or the fire itself is recognized, there are some other typical differences between the genders. Women tend to warn others, and they also tend to close the door to the fire room, before they then leave the building. Women use to seek for help, in contrast to men, who on the other hand more often tries to extinguish the fire by themselves as well as they are more likely to search for people who has been trapped in the fire (Canter, et al., 1980). It is possible that some of the differences between the genders have decreased over the past years, mainly due to an increased equality.

How a person experiences a situation varies. A study on route choice revealed that there were some variations due to gender. Women showed a tendency to rather choose a corridor instead of a door, even though the door was wider, the explanation of this behavior could, due to the analysis, be the uncertainty of the egress behind the closed door. This analysis also showed that especially women associated dark and narrow exits with negativity (Dijkstra, et al., 2012).

3.1.4 Cultural

A person that has grown up in the same environment and country finds it easier to adapt to the common movements of crowds. It has been indicated that people from different countries and cultures find it harder to fall into these common patterns. This indicates that the movement pattern depends on learning. Something that reinforces the importance of understanding how this cultural factor influences (Helbing & Johansson, 2009).

3.1.5 Age

Another study indicates that people either are focusing on seeking information or in helping others during the initial phase of an emergency. This study focuses mostly on people of different ages. It revealed that younger people spent more time in seeking information about the emergency than elderly ones. On the contrary, the younger persons spent less time in helping others. This suggests that younger people do not believe in the safety systems as much as the elders and that the elderly cares more about helping others. The same study tells us that people with disabilities need more time in their attempts to search for information (Kuligowski & Hoskins, 2010).

3.1.6 Stress

A natural response to a perceived threat is the feeling of stress. Stress is an automatic, human defense reaction and it evolves when the body adjusts, in order to prepare itself to act physically. It adjusts to either fight or to flee from the perceived danger. When people gets exposed to elevated stress levels their logical thinking gets limited. Even the social ability gets reduced, which instead becomes more reflexive. Stress is subjective and a situation is therefore perceived differently from person to person. When a person no longer feels that he or she is able to handle a certain situation their stress levels increases (Säterhed, et al., 2008).

3.1.7 Panic

When discussing the concept of panic, the research in this paper indicates there is a need for a strict definition of panic, at least for the field of human behavior. According to Goldenson panic is a "reaction involving terror, confusion and irrational behaviour precipitated by a threatening situation" (Fahy, et al., 2009).

Another definition is that of Johnson; "behavior involves selfish competition uncontrolled by social and cultural constraints," and "breaking of social order, competition unregulated by social forces" (Fahy, et al., 2009).

Panic is an extreme stress response that prepares the body to flee or fight. Panic limits the intellect to act for survival. Therefore, in many cases it is practically impossible to communicate with a person in panic (Säterhed, et al., 2008).

Mawson defines panic as a term that describe behavior during extraordinary circumstances. Panic refers to inappropriate and excessive, or intense fear and-or flight behavior (Mawson, 2005).

Keating defined panic as a concept of four elements (Fahy, et al., 2009):

- Hope to escape through dwindling resources.
- Contagious behavior.
- Aggressive concern about one's own safety.
- Irrational, illogical responses.

An additional definition of panic comes from Quarantelli, "panic as an acute fear reaction marked by flight behaviour and the panic participant as nonrational in his flight behavior" (Fahy, et al., 2009).

The definitions above are from the field of human behavior and psychology. For the general public panic is more likely to be defined as according to the Oxford English Dictionary; "A sudden feeling of alarm or fear of sufficient intensity or uncontrollableness as to lead to extravagant or wildly unthinking behaviour, such as that which may spread through a crowd of people; the state of experiencing such a feeling. Also: an instance or episode of such feeling; a scare" (Panic, 2014).

These findings highlight the need for a joint definition, at least in the field of human behavior, in order to determine if panic actually does occur. According to previously mentioned definitions, irrational responses and actions seems to be the mutual feature.

Mass panic has been believed to be the natural response to physical danger. Recent findings actually points to the contrary, that mass panic and hysteria is not the common response, on the subject of the initial state fire alert. Media often reports fire with the word panic. This lead to a misconception for the public, that fire causes people to panic (Mawson, 2005); (Fahy, et al., 2009). Individuals frequently speak of 'panic' as a description of the emotional state they are in as an evaluation of their capacity to respond to a situation when they feel stressed, anxious or fearful. Panic could also be used as a way to describe the behavior of others who show emotions like anxiety, frightened or scared, or who does not responds in the most appropriate manner for the current situation (Fahy, et al., 2009). Instead people tend to seek familiarity, move to known locations and gather with familiar people. Separation from familiar people is a greater stressor than the experience of physical danger, e.g. a fire or bomb threat (Mawson, 2005).

Studies show that during a disaster or emergency situation, fear is dominated by a collective mutual aid sense. People come together and become helpful instead of their normally egoistic behavior (Mawson, 2005); (Drury & Cocking, 2007). Usually panic is valuated after a certain event by observers of people who experience panic, and the actions taken may seem as inappropriate, excessive, irrational or highly intense by the observers. In case of fire, a collective mass may rush towards an exit, as this may seem as the only rational action to take. Observers may label this collective flight behavior labeled as panic although it is arbitrary (Mawson, 2005); (Sime, 1995).

The misconception that mass panic occurs in case of a fire emergency can in fact be more hazardous than the threat itself. Especially at public places, such as public buildings or venues like different sport grounds, where the occupancy could reach tens of thousands of people. Management may not give the proper information about the threat and furthermore the responses needed by the occupants in the building may be delayed, because of the fear of having to deal with a mass of irrational people. When an evacuation is critical due to a fire, time is of essence (Fahy, et al., 2009).

Almost every research in human behavior points out that mass panic is rare, at least in fire emergencies. From people who have faced an immediate danger, that threated their lives, panic is often used to describe their heightened state of senses. In retrospective, after interviews with evacuees, the action taken indicates that panic probably was not the case as the responses were rational behaviors. As long as media continues to use the word panic and thereby reinforces the impression that it is a usual and probably unavoidable occurrence, the concern for panic will remain for the public (Fahy, et al., 2009).

3.1.8 Individual roles

A person can act in totally different ways, depending on the time and place for the emergency. This depends on the role that the person has at the moment of the fire. A person who is renting a room at a hotel or is at a public location, most likely will be more passive compared to if he or she would have been at home. Instead of taking proper actions, the individual will be waiting for instructions on what he or she is supposed to do. The reason to this behavior is caused by the occupants' role as a guest. If the same person would have been at home instead, the person's action most possibly would have been more capable of action. This indicates that it is of major value to handle out useful information as early as possible, especially in locations and buildings were the occupant does not have prior knowledge of structure of the building or routines as well (Canter, et al., 1980).

3.2 Group behavior

One important aspect in predicting human behaviors, during fires and emergencies is group influence. How a person handle a certain situation depends a lot on the environment as well as the surrounding individuals.

3.2.1 Social influence

Research has revealed that surrounding people and their behavior most likely will have an influence during an evacuation. This is called the social influence. It has also indicated that people often are afraid of making a fool of themselves. Especially when they are in a group of unknown people. This phenomenon often leads to delayed decision times. But as fast as someone in the group takes the first step, and for example begins to walk to an exit door or just stands up, others are likely to follow (Nilsson & Johansson, 2009).

In another study that has been done regarding evacuations out of large retail stores, other factors were found. Indications are given that when a fire alarm or any other factor occurs that results in an evacuation. Half of the individuals will still stay in the area trying to find their relatives or companions until they then start to evacuate (Shields & Boyce, 2000). It has also been shown that a crucial factor in influencing the direction of a person's movement, during an evacuation, were a combination of the person's role and his or her familiarity with the routes and the structures of the building. If the individual's friends or family were elsewhere in the building the person would likely try to find them first before evacuation could be started. This is called the affiliative model, which state that people have a willingness to seek the familiarity during evacuation conditions (Sime, 1985).

Mawson has further explored and developed the concept of the affiliative model by Sime. Social ties have an effect on the human behavior during disaster. The social group which one is connected to usually tries to stay together during the evacuation. In addition employees do not abandon their responsibilities during an emergency, instead they do what they are trained to do and try to help people evacuate (Mawson, 2005).

Flight-and-affiliation is a rare behavior where people escape from a specific situation and move toward another situation or location that is perceived as familiar but not necessary safe. The occurrence of flight-and-affiliation depends mostly on the whereabouts of familiar people, where they are. In the absence of attachment figures who generates a calming effect, the probability of flight-and-affiliation behavior will increase (Mawson, 2005).

People in groups of familiar faces has a general tendency to react slower to initial warnings, slower to leave the area and delay their desire to reconnect with unknown people before starting the evacuation. The assumed reaction of panic and hysteria, will lead to a desire of the officials in charge not to give or delay information about the situation, due to fear of panic spread. By doing so, this could lead to entrapment or death because insufficient information is provided meaning appropriate actions by the evacuees may not be taken (Mawson, 2005).

An experiment from Columbia University indicates that people's ability to act during an emergency gets negatively affected if unfamiliar people surround them. This negative affect especially occurs if the people around are passive and does not respond to, for example, the fire alarm or the presence of smoke. One of the reasons of this negative group behavior depends on the social influence. It has also been indicated that a person can gain much information about an emergency only by looking at others and their behaviors. In this way, a person can avoid breaking norms, such as the risk to be making a fool of her- or himself when taking an own decision. Instead the person can observe what others are doing and then be acting in accordance with their behavior. This process is called normative social influence, the strength of this influence is mainly due to the distance. It gets stronger, the closer the persons are from each other (Nilsson & Johansson, 2009).

3.2.2 Social identity

When a person joins a high-density group of people, e.g. football stadium or at a concert, the individuals one by one will change their usual attitude and mentality. The people at those events have the same expectations and feelings. The crowd can be considered to gain a collective personality and the individuals' personalities reduce (Hoskin & Spearpoint, 2004).

A study presents an approach on group behavior that is called social identity. During many disasters evidence has pointed out how people, even do they are unfamiliar with each other's, are more likely to give help than in normal everyday situations. It has been shown that humans behave differently, as well as that they are having different personalities, depending on the operating environment and the group that they are a part of. One interesting thing is that this approach, the social identity, reinforces why some typical group behavior occurs. In many situations, such as war or sports, people sacrifice themselves for people they normally do not like or might not even know. The social identity approach and theory is mainly formulated in order to obtain a greater understanding of how people affects when being part of a collective which mainly consists of strangers. This is a typical situation that occurs during disasters (Drury & Cocking, 2007).

The social identity approach relies on the theory that people, independent on the members, have a tendency to follow their groups. This behavior increases the more the person can identify with the group. It has also been shown that a group member expect to get, as well as give help to others in a greater extent than persons who is not part of a group (Drury & Cocking, 2007).

It has been indicated that some typical group behavior can be explained by the group's social identity. These identities are divided between the psychological crowd and the aggregate crowd (Drury & Cocking, 2007).

- Psychological crowd, for example the people attending a football or hockey stadium.
- Aggregate crowd, such a group can for example be, the occupants that is inside a supermarket at the same time.

The major difference between those groups is that a psychological crowd shares a common feeling and aim. Which gives a stronger bond between those members compared to the example in the grocery store. People that are exposed to an extreme threat or a disaster get this special fellowship and bond as well, it can be compared to the collective crowd feeling that the spectators at a hockey game has. There are three major points that primarily will stand out, those points has been proved to be stronger in groups that is based on a psychological crowd behavior (Drury & Cocking, 2007).

1. People feel more concern for other people in the group, even to strangers.

2. A stronger pattern of cooperation, but also tendencies of wanting to give help in a higher sentence as well as that self-sacrifices are elevated.
3. People in those groups expect assistance to a greater extent.

Interviews have been carried out with some of the survivors from different accidents. They were asked if they could describe the common feeling of the group or the crowd that they were part of at the accident. Personal feelings as well as what themselves and the people around them did were also asked. It was not unexpected that the usual ethics were maintained during the accident, such as people waiting for their turn in the queue and that people that were authoritarians before the accident continued on this track, even during the accident. In addition, it was found that most people showed most empathy about each other in the smaller groups that they had arrived to the event with (Drury & Cocking, 2007).

3.3 Pre-movement

The pre-movement phase is used when modeling behavior during evacuation, to describe time passed from when a person or group first becomes aware of the danger, until they make any decisions of what to do. When a fire occurs, people adjacently located usually get awareness of the situation, for example by seeing the smoke, hearing the fire alarm or by other people telling them about the fire. But still a lot of people do not decide to evacuate until it is already too late and in other cases there is a lack of understanding in where the escape routes are (Hopper, et al., 2002). Why this happens and some of the underlying reasons to this behavior are presented in the following chapter.

3.3.1 The evaluation process

It is vital to understand that there is a constant decision making process when being exposed to new situations, especially when danger or a threat like fire is present. The process can be compared by a circle. During the pre-movement, a person starts to evaluate the information he- or she has available at that moment. Then a decision on either gathering more information, evacuate or fight the fire is made. The situation or at least the understanding of the situation constantly develops. Every single time the occupant gets new information of the fire or any other circumstances, a new and updated decision-circle is obtained. This implies that a decision that first has been taken often is changed along the way of the movement. This behavior is described by the role-rule model developed by Canter and colleagues and is illustrated in Figure 5. The concept of role-rule model Figure 5 (Canter, et al., 1980).

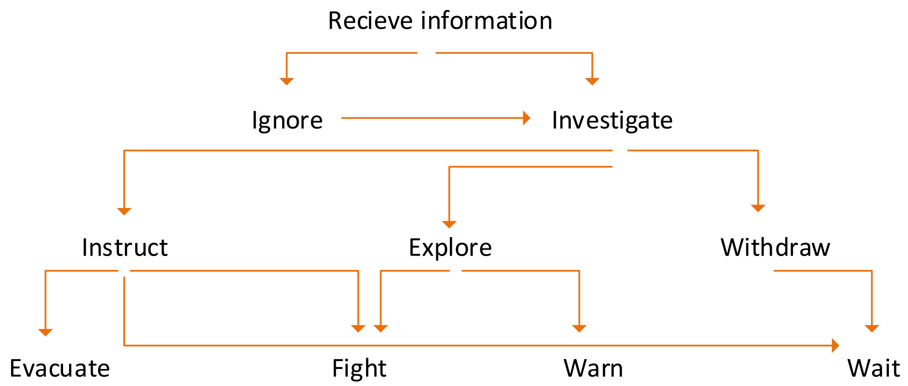

Figure 5. The concept of role-rule model.

When a person finally understands the danger in a situation, most individuals use to choose between to either evacuate or to stay and try to fight the fire (Hopper, et al., 2002). If a person decides to evacuate most of the persons tend to use the same way out of a building or area as the one they entered through (Till & Babcock, 2010); (Sime, 1995).

3.3.2 Knowledge & Understanding

One major problem can be that persons, especially young people, are poor at predicting both fire growth as the seriousness of fires. It has also been shown that this group of people found it difficult to decide when a fire is possible to extinguish (Fridolf & Nilsson, 2011).

Another study supports the allegation that people are poor at predicting the dangerousness of fires. It is also common that people deny fire cues, or any other signal that suggests that an accident will occur. Instead of accepting the cues is it common that people tries to find explanations, trying to reject the danger in the situation. If a person is busy with a task or an activity that demands focus, it is even more likely that the cues will be missed. In addition to this the same study indicates how people are more risk-aware in unknown buildings then what they are in their own homes. This behavior is a problem, especially though the risks of fatalities and injuries in homes still is far greater than in other buildings (Hopper, et al., 2002).

Another problem in this phase is often that people do not know what possible options they have during an evacuation. Humans are creatures of habits and it has been shown that most people tend to take the same way out of a building as the one they entered through (Hopper, et al., 2002). This has led to problem of emergency exits, those doors and routes are in many cases not used as they have been designed for. To succeed in an evacuation, it is important that people actually are using all the escape routes as intended. This problem area has led to a lot of research in attempts to increase the attractiveness of escape routes- and doors and to make people more willing in their efforts to use them (Proulx, 1993).

A study indicates that both men and women tend to get dressed in order to look proper, they also gather their belongings before they begin to evacuate. This behavior often occurs even if it is a waste of valuable time. The behavior may depend on the probability of meeting others on the way out of the building and the fact that people are afraid of making a fool of themselves (Canter, et al., 1980).

3.3.3 Fire alarms & designs

It is common that even though people hear a fire alarm, many assume either that the alarm is being tested, that it might be an exercise or that the alarm most likely started because of an error. It is a problem that many people do not believe in these systems, which can lead to problems and accidents (Drury & Cocking, 2007).

To enhance the opportunities for people to better understand what they are expected to do during fire alarms and evacuations, studies have shown that different types of affordances are needed. An affordance helps you to understand what to do and how. Those are divided on sensory, cognitive, physically and functionally affordances. These affordances are presented in the following text. Affordances are especially interesting when designing buildings and escape routes (Nilsson, 2009).

- Sensory- An emergency exit needs to be easily visible. This can be implemented by using a different color than the walls surrounding it.
- Cognitive- To open a door or to use an emergency route the person who is supposed to use it actually needs to understand that it should be used and it should not discourage people by looking hazardous. Studies have shown that it is good to complement signs with flashing lights. Especially green lights are good, because of the positive association that it brings.
- Physical- In order to help people, an emergency door or route should primarily be easy to access, the door should not require too much strength.
- Functional- A functional door or route is one that can provide a powerful combination of the three affordances named above; sensory, cognitive and physical.

Beyond this, it is important that the affordances do not send contradictory signals. For example if an escape route or door also is provided with a conflicting plate, like the “only personnel sign” then the door will most likely not be used, or at least be used in a lesser extent (Nilsson, 2009). The same aspect concerns fire messages, which often fail because that the clarity is failing. Suggestions is made that those messages, to a greater extent, should specify how the fire or danger has occurred and what the individuals is supposed to do in accordance to avoid it, like finding the closest emergency exit and then transport themselves out of the building as fast as possible (Hopper, et al., 2002).

3.3.4 Denying the danger

A situation or condition that may affect the outcome and the amount of time spent for a person to move out of the building is freezing. The danger with this condition is that a person's instinctive response to save themselves from danger becomes attenuated. There are other reactions that affect the outcome negatively, people have shown tendencies to ignore the danger in situations and instead pretend like nothing has happened, a natural defense mechanism. A facade with an unusual calmness is created, those persons often continue with their everyday tasks. This will make these people waste valuable time before reaching safety (Drury & Cocking, 2007).

3.4 Movement

How fast a person can perform a safe egress out of a building or area depends on a lot of factors. Some of the things that matter are the person's physical attributes, age, gender, knowledge of the building, disabilities as well as the structure of escape routes- and doors. In attempts of calculate an evacuation this, the movement, is often the easiest part. How fast different people can move is well known and easy to measure and concretize. The problematic part though is to learn how to design buildings in a proper way, taking into account all various types of people. Another difficulty is to cover all the different scenarios that can occur during an emergency and thus affect the available evacuation possibilities.

3.4.1 Speed

Some of the factors that concerns how fast a person can move depends on, for example, how fast a person can react and understand the situation. The physical ability is one major factor, both individually as well as for a group level, which will impact the walking speed. Other factors could be age, gender, clothing or disabilities. When people are evacuating as a group is it usually the weakest and slowest person that affects how fast the movement can be carried out. If something interrupts the movement, like observing or fighting the fire the movement will be slowed down. It also depends on how well the individual knows the buildings structure and routes (Hopper, et al., 2002); (Fahy & Proulx, 2001).

At larger venues, such as a stadium, having evacuation strategies could indeed improve the movement phase. It might be desirable to have evacuation in different phases. For a large stadium there could be more than 50,000 people present and movement to safety might be delayed due to high densities. In case of a fire, those in the closest perimeter endure the greatest risk. If strategies are established to focus on those people first, the risk could be minimized as they could evacuate in a faster manner (ISO, 2009).

Empirical studies and experiments have given data on different walking speeds for different types of occupants and buildings type (Fahy & Proulx, 2001). Walking speed in crowds is indicated to depend on density and the distance to the person ahead. Increased density and decreased distance will reduce the speed (Nilsson, 2007).

3.4.2 Structural impacts

There is a need to understand how the environment can influence people during the evacuation. Studies have been done on investigating how color will influence behavior. Those studies have been used in order to try to figure out how to best design the buildings. Indications have shown that the movement phase is improved if the corridors have transparency, i.e. doors at the end are transparent. This enables people to understand and collect information on where to go next. Transparency is especially important in the closest range of decision points. Furthermore studies regarding color psychology have indicated that bright colors like green, blue or white have a positive and calming effect on people which is important during emergency situations, though it enhances the ability to take rational decisions (Abu-Safieh, 2010).

Structural impact is a relatively new science field. The knowledge about how a building and its structure affects people is now constantly developing. It has been shown how fast a person can bring him- or herself out of a building or area, can be improved by making some architectural features. The wayfinding has been indicated to be improved, if the egress routes are wide and bright. This is most important in corridors (Dijkstra, et al., 2012).

In the same way it has been indicated that one must not only think of the buildings structural and geometry when designing evacuation routes and doors, but also to consider how the natural flows looks. Where do most people stay and likewise what areas will be most crucial in an emergency? With this aspect in mind, it is vital to use architectural competences in attempts to naturally lead persons to safe areas, like evacuation routes- and doors (Shields & Boyce, 2000).

Human behavior during the movement phase has been studied. The focus was to decide how exit signs influence peoples' evacuation performance. The test subjects had to wear portable eye-tracking devises, and both people with experience and knowledge of the buildings, as well as people without were studied. The analysis revealed how the people with experience evacuated throughout the building without any use of the signs. Among the persons without experience two approaches were found, those who did not focus on the signs at all and only trusted on their instincts and those who actually used the signs. Not surprisingly, people with prior knowledge and the people that used the signs were able to evacuate the building faster (Till & Babcock, 2010).

4. Pedestrian dynamics & crowd movement patterns

In mass evacuations, human behavior continuous to be an important factor, but the individuals cannot affect the crowd dynamics individually. When the density of the crowd becomes critical, the group behavior dominates and the movement pattern will instead look more like a natural flow, which can be compared to a gas or a fluid (Helbing, et al., 2001). Every year crowd disasters of different magnitudes occur, resulting in fatal outcomes (Helbing, et al., 2007). Recently more research has been conducted for pedestrian movement in high-density crowds (Ma, et al., 2013). During events when a lot of people gather in concentrated spaces, such as sport arenas, festivals or pilgrimages, a few different patterns often occurs. Those are sometimes the cause of disasters, like crowd crushes or stampede. In order to figure out how those movement patterns work, why and when they occur and how to handle them it is important to analyze this area.

4.1 Pedestrian movements

Humans are social beings, driven by needs and goals. Social interaction and acceptance are important foundations. It has been found that the movements of humans follow some specific rules and patterns. If there is a choice between routes, most often the simplest and most direct route will be chosen. Which mainly depends on that people does not like to take detours to reach their goals (Säterhed, et al., 2008). People attending an event, e.g. a football game, tend to fall into a more collective personality, and the movement patterns at those occasions differ significantly from how people usually move in high densities. The high density and the fact that the people are there for the same reasons make it acceptable for people to move closer to each other than normal. This allows the crowd to move faster than otherwise possible in an equal setting with a different mentality of the crowd. People follow the flow of the crowd instead of taking own decisions on where to go and at what speed (Hoskin & Spearpoint, 2004).

Crowd movement is described by three qualitative characteristics (Proulx, 2002).

1. Density.
2. Speed.
3. Flow.

Density is the measurement of people per unit, often expressed in people/m^2. Speed is often expressed as distance per unit time, i.e. m/s. Flow is the number of people passing a specific reference point expressed in people/s.

These three characteristics have a relation in the form of
Flow = Speed * Density * Width (Proulx, 2002).

There are certain patterns that pedestrians have tendencies to follow. People have a desire to walk with their own, individual speed as long as they are not in a hurry, and the distance between pedestrians varies mainly depending on the density and on how the flow velocity changes. When these factors increase, the acceptable distance between one and another is reduced. Pedestrians can be compared to car drivers, as they often take automated decisions. Which means that they sometimes can take non-optimal decisions, e.g. standing in the way for someone else even though this behavior is time consuming (Helbing, et al., 2001).

It has been shown that pedestrians tend to walk along with others more than alone. Since these smaller groups strongly will affect the overall pattern it is important to analyze what typical movement patterns these groups actually have. As many as two-thirds of the people often travels in groups, mostly together with two to four other members. The movement pattern in those groups differs, mainly depending on the density. At lower densities, the people in the group often gather around the one, or two people who speak the most. The group is gathered in a pattern that looks like a V-formation, mainly because everyone in the group should have the opportunity to hear what the others say. At higher densities though, does it become a struggle between social integration and the physical limitations, mainly because the V-shape is not aerodynamic. When the density finally becomes too high the physical limitations wins and the persons are forced to walk in line with each other's (Moussaïd, et al., 2010).

4.2 Counter flows

One of the many phenomena, or patterns, that pedestrian dynamics generates arises when different flows meet each other. Lanes are often formed when humans are walking in the same direction (Helbing, et al., 2002). When two such lanes meets, and need to cross each other's, there are tendencies that the facing groups takes into account one another and are forming, effective, penetrating stripes. Those strips reduce the friction and make the movement pattern more energy-efficient in order to facilitate the passage for all parties involved. This is a pattern, and a human group behavior that occurs naturally, which suggests that it depends- and relies on an emergency group behavior. Especially people who have grown up in similar environments tend to, in a quick and easy way, be able to coordinate themselves in this way, even though they never have met each other before (Helbing & Johansson, 2009); (Ma, et al., 2013).

4.3 Bottlenecks

When the natural flow of pedestrians cannot continue due to a door, corridor or any other obstacle that does not allow the entire flow to get through at once, a bottleneck situation occurs (Drury & Cocking, 2007). The flow of pedestrians varies with a frequency that depends on the width and length of the bottleneck. The longer and narrower it is, the slower the flow. This phenomenon can be compared with the function of a sandglass (Helbing, et al., 2001).

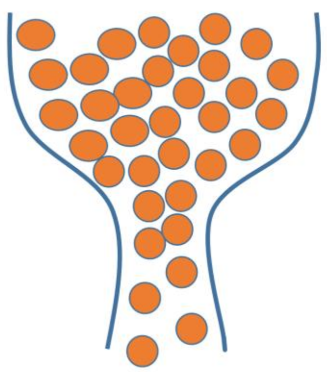

Figure 6. The principle of a bottleneck situation.

When a person near the bottlenecks center manages to find an opening, and thus can escape from the bottleneck, a field or lane is created after this person. This makes it easier for people that are directly connected to do the same. When people manage to get out from one side of the bottleneck the pressure decreases temporarily at that site. The result is that the people from the other side begins to push and move against this new, available space, which in the end creates a fluctuating pattern (Helbing & Johansson, 2009); (Ma, et al., 2013); (Helbing, et al., 2002). This phenomena is consistent with the theory that pedestrian movements can be compared to a granular flow and in accordance to the second law of the thermodynamics, a closed system always strive for balance and equilibrium (Helbing, et al., 2001).

Bottlenecks are sometimes the most crucial during an evacuation. When there are counteracting flows in a bottleneck, there is a risk of clogging. This has been proved to, sometimes, happen to granular flows through funnels. To prevent this when humans is involved, it is important that people do not constantly move and push, but that they instead move slow and safely. In these situations it can be concluded that the speed of the group's movement increases the less stressed people are (Helbing & Johansson, 2009). If the pressure over a bottleneck gets too high, the opportunities to evacuate can be paralyzed. When this actually happens, it can also be very difficult to reduce the already built up pressure, as well as to release the people who has been trapped. The people in the back do not know how the situation actually looks, the pressure often continues. This was the cause of the very tragic disaster, which occurred during the discotheque fire in Gothenburg 1998. A bottleneck effect and the pressure as well as a high density led to people getting stuck in the doorway and jam caused no further people to evacuate. The people in the back did not know that the pressure they built up only obstructed the evacuation possibilities, as fast as someone in the front managed to get out, people from the back pushed harder. This tragically led to the loss of a lot of youngsters lives. (NFPA Fire Investigations Department, 2000) This phenomenon is explained as an effect due to poor lack of back-to-front communication (Sime, 1995). Back-to-front communication is also one of the reasons for the major loss of life in the 1989 Hillsborough incident, where people in the back of the crowd wanted to get in, not knowing that the people at the front rows were pressed up against the metal fence, and thus experiencing asphyxia which were the common cause of death (Sime, 1995).

In another case, the main reason that could cause a problem is the lack of understanding pedestrian dynamics. A staircase right outside of the entrance of University of Maryland Comcast Center was given more focus in appearance than safety issues. The top of the stairs where about 40 % wider than the bottom of it. No one thought of the risks that this design could bring. If an emergency situation occurs, the capacity of 20,000 people would be exposed to a great risk of getting stuck in this bottleneck situation, or even crushed on their way out (Brannigan & Kilpatrick, 2004).

The velocity through different bottlenecks follows the specific flow concept, which means that the speed depends linearly on the bottlenecks width. It also indicates that the flow through a bottleneck gets slower the longer the bottleneck is (Rupprecht, et al., 2010). There is a theory available that indicates how bottlenecks are linked to stop and go waves. It indicates how a smooth flow of people, at a certain time, makes a transition to a pattern that instead reminds of stop and goes waves. This occurs when more people are trying to get in trough an opening than the number of people who is getting out of it (Helbing, et al., 2007).

There are several disasters where police and staff lock the exit gates in order to keep the peace and order. It has been witnessed by spectators that during a game in South America that a handful of fans entered the football field at a stadium after an undesirable call from the referee. This led the police to shoot teargas into the spectator stand and creating unbearable situation for the fans. In turn this caused a lot of people wanting to leave the scene but as the doors were locked, some people instead died due to the high pressure when being forced against the blockage as the passages got narrower (Still, 2014).

4.4 Stop and go waves

It has been shown that when a large crowd is moving, there are two different densities that affect, or split up how the movement pattern looks. The velocity in those three density groups that then is obtained is linear. In this case when talking about density, a distance to the person in front is instead talked about. Those three density groups are presented below (Appert-Rolland, et al., 2012).

- When the density, or in this case, when the distance to the person in front is more than three meters the flow can continue without any stops.
- Distance about one meter until around three meters makes it harder to walk in your own speed and sometimes the persons need to stop because of the more and more unstable crowd movement.
- When the distance becomes less than one meter the flow gets strongly crowd dependent and stop and go waves are frequently seen at this density

If the density of people is high simultaneously as the speed of the pedestrians is low, and drops beneath a certain level, stop and go waves do arise which turns out as longitudinally waves (Helbing, et al., 2007).

Figure 7. Illustration of stop-and-go waves taken with long exposure time (Johansson, et al., 2008)

The backward movement, or the stop and go behavior in the group is caused by low speed. When the movement is low people start to look around, which leads to stops and sometimes even collisions that gives backward forces. There are differences between individuals' behaviors and preferences. How much space a person prefers differs as well as how fast a person reacts, which forms the basis of how quickly a person can start to walk again after the person has been standing still. The probability of stop and go waves increases with the density. When the density is so high that the distance to the persons in front is one and a half meter, regular waves occurs (Portz & Seyfried, 2010).

4.5 Turbulence

Though a high density crowd can be compared to the functions of granular mediums (Helbing, et al., 2001), it is reasonable that density-driven waves can be created in conjunction with a forward motion. Likewise, it can be assumed that turbulent appearances do occur at even higher densities. This appearance can be compared with the aftermath of an earthquake, where various forces randomly are distributed in all the different directions (Helbing & Johansson, 2009); (Ma, et al., 2013).

When the density of a crowd that is under movement becomes even larger than what has been presented under stop and go waves, turbulence sometimes occurs. With a density of about 8 persons per square meter there is no longer any space between the persons, at this stage waves can move the individuals up to 3 meters in lateral directions. Crowd turbulence has for example been proven to be the cause of the Love Parade disaster. Video recordings revealed how people started to stumble when the pressure became too high (Helbing & Mukerji, 2012).

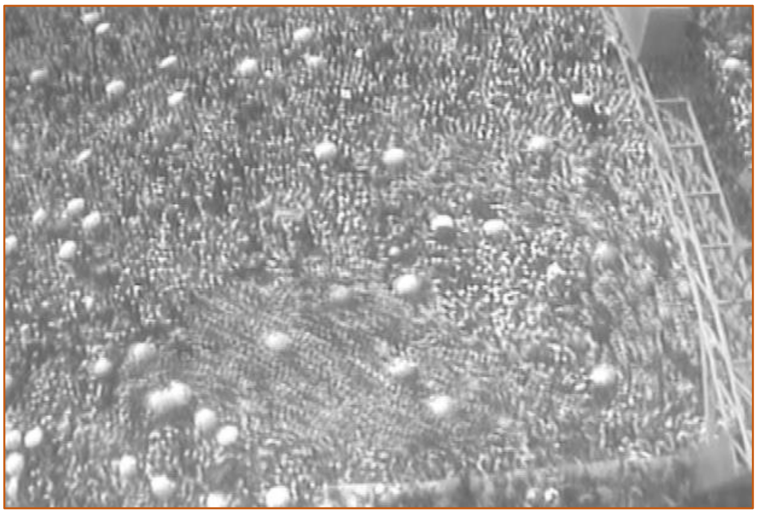

Figure 8. Illustration of turbulence taken with long exposure time (Johansson, et al., 2008)

Turbulence is created when a lot of people gathers in a restricted area. During the Love Parade disaster the density has been calculated to be around 11 persons per square meter. When the pressure is so great that the individuals movements propagates through the body contact to persons in the vicinity, at such high densities this forces can propagate a long way. It has been found that the density remains unchanged, but that the speed of the individuals changes during these conditions. This speed fluctuation depends on the forces that are generated by body contact between individuals and it indicates that speed is a more important factor than density. Although these two factors nevertheless depend on each other it has been determined that pressure is the indicator that best can assist in calculating this phenomena (Ma, et al., 2013). The critical factor is pressure, which is caused by the density of people as well as the variety of speed. When turbulence occurs, pressure waves can be generated in all directions. This is a very critical moment and there is a high probability that a person in the group could fall. When this happens it is possible that others will fall as well, which may cause people to be trampled to death. Attempts have been made to try to calculate when and where critical situations with turbulence will occur. One of the critical values that have been found depends on the pressure in the crowd. This unit depends on variation of speed as well as the density of the crowd. It has been found that if the pressure reaches a value of $0{,}02/s^2$ and if it is maintained, accidents will be likely to take place within minutes. By video analyzing the crowd's movement and density, together with this critical value it should be possible to hand out correct instructions to the safety personnel and further out to the pedestrians, which likely would help in order to avoid accidents with stampedes and crowd crushes (Helbing, et al., 2007).

4.6 Stampede & Crowd crush

When researching for different crowd disasters stampede seems to be a regular occurrence, especially at football stadiums when football games are played. A stampede is a collective rush of people towards either united direction or destination or in a random manner. The forces building up in crowds can be either vertical or horizontal. Whether people are standing up and thus pushing and leaning against each other creates a domino effect in a horizontal direction, or if people gather vertically as a pile, the fact is that this leads to great forces for people at the end of the of the crowd in the direction of the force (Schadschneider, et al., 2009); (Still, 2014).

These forces propagate through the mass and the pressure causes compressive asphyxia. This is the cause of death, contrary to what media often reports that trampling is the reason why people die. This phenomenon is referred to as crowd crush and should not be viewed to be the same thing as a bottleneck jam, all though in both situations compressive asphyxia is the cause of death.
It is not the crowd who are to be blamed for crowd disasters but instead it is poor management and planning which is the cause for these tragedies. In reality it is the amount of people in a concentrated space, the density, which is the biggest reason for a large number of deaths and injuries, but it could be avoided with proper design and management (Still, 2014).

As this paper focuses on disasters mainly occurring at larger stadiums there have been various reasons to why a stampede occurs. The joint reason seems be heightened level of excitement for some initial triggering action. Here a few reasons will be presented that has been observed at real events.

- Spectators are about to leave the stadium before the game is ended. A late minute goal, especially at high profile games like world cup qualifying games or important cup finals, make people wanting to re-enter the stadium. The sudden transition from despair and dissatisfaction to euphoria causes people to rush back into the spectator stands and thus causing crowd crushes.
- Witnesses recalled that when trying to leave the arena from the stairs inside the stadium, for no apparent reason rather than by accident, someone trips and fall causing others to do same as a domino effect and this in turn leads to a crowd crush.
- Violence seems to be a recurring factor causing stampedes and crowd crush. It may be as a result of a bad call by the referee or that competing team' supporters engaging in a fight. This reason seems to be more frequent in South American countries compared to European countries.

- Fire may also allow people to act in a no regular order and thereby lead people to be subjects of stampedes (Still, 2014).

5. Evacuation modeling

During a mass evacuation it is important to be able to evacuate a big arena, train station or any other area with a lot of people, and this must be done quickly and easily. To develop a wider knowledge about this, much research has been done in this field. During the last decades a lot of focus has been on implementing information, knowledge and other aspects that matters during an evacuation into computer models. The main reason has been to make it possible to implement more and larger tests. A computer model saves time and effort and can help to make the work more efficient. It is still important to understand that models are based on experimental studies and cannot fully be expected to reflect reality, these models should be seen more as a guide and a tool.

When performing evacuation simulations, the aim is to determine whether or not a safe egress for all intended people in the building, public space or enclosure could be achieved. In order to assess this two different time sets are commonly used, RSET and ASET. RSET is the required safe egress time and ASET is the available safe egress time. The ASET during fire condition can be calculated through different methods to determine when critical condition for health safety is reached. Critical conditions may be toxicity, temperature, smoke layer height or visibility etc. RSET is a combination of different time periods, and the definition of the SFPE handbook suggest that (Nelson & Mowrer, 2002):

$RSET = t_d + t_a + t_o + t_i + t_e.$

The different terms in RSET is defined as follows (Nelson & Mowrer, 2002):

t_d = Time from when the fire starts to detection of the fire.
t_a = Time from the detection to when people are notified.
t_o = Time from notification to when people decide to start to act.
t_i = Time from decision to starting to act, i.e. start to move.
t_e = Time from starting to move until a safe place is reached.

If the evacuation is safe it means that RSET is considerably lower than ASET, i.e. it takes longer to reach critical condition for people than the time it takes to perform the process of evacuation. The last element, t_e in REST is the time that is usually simulated in computational simulations. The first two elements, t_d and t_a depends on the performance of the fire alarm equipment. The remaining two elements, t_o and t_i, are factors that depend on the occupants ability to make decision and is usually based on empirical studies and experimental observations (Nelson & Mowrer, 2002).

5.1 Computer simulation programs

In order to simulate and calculate evacuations, many different computer models have been developed. This is under rapid development. It is not possible to present all the models available and it would consequently be possible that some important programs will be missed in this report. The focus in the following chapter will be to present recently developed software, which considers to be at the forefront in the development.

5.1.1 PedGo Guardian – Evacuation Support System

This all started with an idea called the Hermes Project. The project has been developed in Germany and primarily been tested at the Esprit Arena in Dusseldorf. The aim was to produce an evacuation assistant that should be able to calculate were and when critical situations could occur, in accordance to the crowd's behavior and movements (Holl, et al., 2012).

The Hermes Project formed the basis of the PedGo Guardian. PedGo Guardian is an assistant that is based on actual real-time simulations. In this way is it possible to analyze the crowd's density and movements and together with underlying models it is then possible for the assistant to predict how the crowd will move and where different stages of critical situations are most likely to occur. The evacuation assistant, PedGo, is constantly conducting simulations. The assistant is aware of the thresholds for the different parts of the arena, those thresholds are based on the ASET time. When the simulation time for a certain part of the crowd exceeds these values, then warnings are sent out with messages on recommended preventive measures. The assistant is continually given information about the situation and how it changes, this includes if emergency exit are available or not, as well as the status of fire protection systems. In this way is it possible for the assistant to frequently give new information with upgraded instructions of how to best manage the situation. The aim of this assistant is mainly to help security staff, police and rescue services. The PedGo Guardian simulates 15 minutes into the future. In order to help security staff even more is the pedestrians divided in three different categories. Those are marked with green, yellow or red. These follow the logical order were green symbolizes that the area is under control and does not need back-up. Yellow indicates that there is a potential for elevated pressure and that assistant can soon be required. Finally, red which symbolizes that immediate assistance is required and that focus needs to be on evacuating this area (Klüpfel & Meyer-König, 2012).

5.1.2 Pathfinder

Pathfinder, which is an evacuation simulating computer program, is one of the latest tools that have been developed and are used by today's fire engineers. Pathfinder uses Agent Based Modeling. The purpose of the program is to facilitate the work, but also to improve the results and the validity of simulations that regards mass evacuation. The program can treat tens of thousands of spectators. It is based on simulations with large number of spectators, all with their own individual characteristics. The subjects are assigned goals, characteristics and perceptions. This can be applied to larger groups as well as to each individual. The program is based on artificial intelligence, which means that the individuals also are able to adjust, based on other peoples' movement. This allows people to avoid colliding with each other's. It also means that the subjects does not strictly need to follow the shortest path principles. Something that naturally gives a better flow of the pedestrians compared to other models, which are based on different calculations. Pathfinder is built from a coordinate system in 3D, the structure of the system can be created directly from the program, but can also be imported from other applications, such as CAD software. During a simulation, the user can follow the progress, pause or rewind, just like in a regular movie. To further develop the program, the hope is to integrate it with FDS. There is also a desire to develop the dynamics of the program so that doors and similar could be both opened and closed (Thornton, et al., 2010).

6. Crowd Management

To avoid accidents at events with large crowds the security staff needs to be prepared. A lot of guidelines and approaches have been developed. Some of those will be presented in the following chapter.

6.1 Preparing & planning

The biggest focus has so far been on teaching people how to handle and distinguish an actual fire. In order to develop peoples understanding in the future, more focus should be on teaching how to prevent and avoid fires. For example by teaching the society about different risk-sources (Hopper, et al., 2002).

During the last decade, the trend has been that risk mitigation measures constantly have become more important. The knowledge on how to handle crowds has developed, mainly because a better understanding of crowd dynamics and communication between people working at the arenas has been developed. Furthermore better and upgraded systems and methods are available for the security workers, which for example has made it easier to communicate with the crowd. Warning systems through communication, emergency signs, as well as regular alarms has evolved. Today, it is a natural step to analyze the building's design in new constructions, which has improved the integration between the natural flows of pedestrians out of a stadium to its exit doors and routes (Hoskin & Spearpoint, 2004).

Before the Olympic Games in Beijing, 2008, simulations of the different stadiums and areas around were carried out. This was done with the Legion Studio V2006 Software as a basis. Expected flows and densities were calculated, which became the basis for the analysis that was conducted. In this way, problem areas at an early stage could be found inside the stadium, but also in areas outside. The results that were produced could then be used to improve the planning of the area's structure as well as to improve the management planning (Zhu, et al., 2008). Similarly, the program Smart Crowd has been used to simulate evacuations from the football team River Plates´ stadium in Buenos Aires. This program is based on the same principles, it takes into account every spectator and calculates the forces that affect each person. In this way, the program can determine the most suitable escape routes and it can predict areas with increased risks regarding high levels of densities and pressures (Moldovan, et al., 2005).

6.2 Operational

At big stadiums in Australia and New Zealand, methods have been developed about how to give information about risk sources and emergency strategies to raise their awareness around the emergency procedures. What they are supposed to do and how is illustrated on the big scoreboards, both before the game has started as well as during the half times. Illustrations about this is also available on the tickets, toilet doors as well as at the entrances (Hoskin & Spearpoint, 2004).This is a new safety concept that can be compared to the way airlines have been working in long times now, with pre-flight safety demonstrations.

In 2006 there was stampede at the pilgrimage ritual in Makkah in Saudi Arabia. 364 people died and some 300 were injured due to the high pressure that was built up and propagated though the dense crowd. This resulted in the building of the new Jamarat building with five different levels to accommodate the approximately annual three million visitors. The new building has 12 entrances and 14 exits in order to distribute and disseminate the masses to appropriate scale. The installation of 700 cameras, which of 90 cameras uses automatic software to identify areas where critical conditions may occur. The organizers can then control the flow at the points where critical conditions are about to happen. In addition, scheduling of the attendees were also implemented, so that organizers know at when and where people would appear at site. All of these implementations made the pilgrimage at Makkah run more smoothly for the years following (Al Bosta, 2010).

6.3 Guidelines – The Love Parade disaster

In the aftermath of the Love Parade disaster a lot of research and studies was made in order to establish what was causing the accident, but also to learn how to prevent similar disasters in the future. The authors from one of them have compiled a guideline, with their thoughts of what are the most important aspects to be considered before and during an event of this magnitude (Helbing & Mukerji, 2012).

6.3.1 Before the event

In the following text, some of the most crucial points follow that the management team at the site needs to consider when hosting an event of great magnitude (Helbing & Mukerji, 2012).

- The location of the festival area should ideally have been through similar events since before. It is also important that some of the persons, in the crowd management team, have experience as well as expertise about how to manage those crucial situations that could occur during such events. The management team should not only exist of locals. Professionals, with experience from national or global level, should also support them.
- Before the event, a date should be set that will serve as a limit of when all the security work must have been implemented. Those that are involved and are a part of the crowd management team shall know what is expected of them. They shall also have been completed drills at this date.
- During the planning phase, the expected number of visitors has to be considered instead of just planning after the capacity of the area. It is also important that an analysis is made regarding the in and out flows of the pedestrians, mainly to determine when the risk of large flow variations in is greatest.
- It is vital to listen to all questions regarding the safety at the festival area. Even if only a small part of the group are concerned about a particular risk, this must be taken seriously. It is also important to let consultants give their expert opinions.

6.3.2 During the event

It is also important for the staff to know how they are supposed to handle different kinds of situations during the event. Guidelines have therefore been developed, which mostly depends on observing the density of people. The different hazards, or observations, have been ranked from 0-8. A suggestion follows after each one of them, telling the staff members how they are supposed to handle the different situations that could occur. It is also important for the personnel to understand that a critical situation can escalate and change fast. Which makes it crucial to always be a few steps ahead of the actual situation of the scenario (Helbing & Mukerji, 2012).

Table 1. Rule of thumb, regarding which actions that are required by the Crowd Management Teams, during an event.

	Observation	**Assessment**	**Actions**
0	Less than 2-3 person/m^2	Normal operation	Keep track of the flows, it is not allowed to exceed 82 people/minute and meter
1	Certain areas begins to be crowded	A bottleneck or similar situation occurs, which slows people down	Inform the police about the situation and allocate personnel to the areas that need reinforcements. Narrow the inflow until the reason for the accumulation is determined
2	The mass of the crowd constantly grows	Lesser outflow then inflow, high and dangerous densities can occur over time	Cooperate with the police and communicate with the crowd. Attempt to get people away from the critical area
3	Shock waves occurs, and people are pushed	People cannot walk in their own speed, high risks	Open emergency routes, and tell the crowd about it, in order to ease the pressure. It is important that the police are ready to take over the control of the situation.
4	It is impossible to move freely and people are squeezed between each other's	The density and pressure in the crowd can lead to injuries	Now the police should get the highest responsibilities of the situation. It is vital to communicate with the crowd, in this situation is an evacuation recommended.
5	People tries to get out of the area by violence	Critical situation that may get out of control	Now evacuation is needed, it is still important to speak and inform the crowd. The crowd management team should now inform hospitals and emergency units about the situation
6	Crowd turbulence occurs	A clear sign that a disaster soon could occur	It is vital to calm down the crowd and inform them about the situation. Be ready to support and give first aid. Emergency teams needs to back up this situation. Continue evacuation.
7	Stumbling makes people falling to the ground	A crowd disaster is now happening and many will get injured	The team needs to be ready to give first aid. The situation is crucial. It is also vital to further inform hospitals about the changed situation.
8	People crawl over each other	A disaster has happened	A serious disaster has occurred, apply the rules for how to handle a serious emergency

6.4 Guide to Safety at Sports Grounds – The Green Guide

This is a handbook that consists of guidelines regarding the safety on different sport arenas. The focus is on the safety of its spectators. It is especially designed in order to help engineers and others that are working with or are developing the safety at those arenas.

All parts regarding the safety of a sports arena is handled in this guide. It ranges from how the security should be implemented during games to how to calculate the acceptable capacity of an arena. Beyond this fire safety and communication is also treated. The Green Guide will, just as it sounds, mainly serve as a guide or a manual that infers how security at a stadium could be achieved. The handbook does not consist of many clear rules, but instead mostly gives indications of what actions to take and who is supposed perform them. The demands on those actors are presented as well (Sports Grounds Safety Authority, 2008).

After the disaster at Ibrox that occurred 1971, Lord Wheatley wrote a report on the need to increase the safety levels for sports stadiums. This report became the basis for the first edition of The Green Guide (Hillsborough Independent Panel, 2012).

According to the manual, it is not enough to have a written safety policy, the key is to follow it all and that all those that are involved knows their individual tasks. Also it points out how important it is to not only draw up contingency plans, but also to regularly test and practice them. The security in the stadiums should not be considered as a set of rules or conditions, but rather as different standards that shall help to establish an improved safety culture. It is important that a positive attitude is apparent from both the management team as well as from the security personnel. This will help in order to create a common feeling that the spectators and the safety personnel are working together towards an increased safety environment (Sports Grounds Safety Authority, 2008).

If stadiums shall be able to handle a big accident it is a requirement that there is a thorough contingency plan available. This requires that all the parties know what is required of them in such a situation. Therefore, the management team at the stadium has to work with the municipality as well as the police and emergency services such as rescue team and ambulances. The guide also points out that the safety and the quality of stadiums should be examined regularly. The handbook states that this is not going to settle within a certain time interval. It rather suggests that this should be regulated based on every stadiums individual standard, quality and size. However has the Standing Committee on Structural Safety given a recommendation that indicates that this should be done between every 6-10 years (Sports Grounds Safety Authority, 2008).

In order to enable the spectators to smoothly get in and out of the arena during both normal and critical situations, the routes, doors and stairs should be integrated naturally with the in and out flows of people. There are recommendations for distance, widths and how the routes and the stadium shall be designed in general. These recommendations also depend on the current distance to the stadium's center. The Green Guide also points out some of the risks that exist around the spectators and congestion. For example does the handbook point out hazards that may occur due to the security staffs attempts to facilitate a potentially hazardous situation. For example, the risks that comes when new lanes or doors are opened, with the goal of trying to reduce the current pressure (Sports Grounds Safety Authority, 2008).

6.5 MSB – Guidelines for events

This is the Swedish safety guide for events. It has been developed by collaboration between the Swedish National Police Agency and the MSB, the Swedish Civil Contingencies Agency. The guide is designed to facilitate and assist all the stakeholders who are involved in dealing with the security at an event area. The aim is to create a common understanding regarding safety aspects, as well as to improve the communication and collaboration between these groups. The focus is mainly on how to prevent an emergency and to create a safe environment, but there are also some guidelines regarding the safety during the event (Säterhed, et al., 2008).

There are three basic conditions that need to be fulfilled in order to have a good crowd management (Säterhed, et al., 2008).

1. That the workers have a good understanding in the different situations that can occur.
2. That the area has a structure that favors crowd management.
3. To have a good communication between both the audience and the management team as well as between the various groups that is working with the safety in the area.

It is important to analyze where each area's focus points are. These are areas where the risks are elevated due to possible crowd gathering. It is also important to analyze at what time the highest risks are expected, this could be routes where most people are expected or at a stage. Furthermore it is important to analyze the nature of the audience before the event to create an audience profile. Factors like age on the audience, what kind of music that will be played, if the artist or group appears to affect the audience's behavior in some way, alcohol and more depends in this profile (Säterhed, et al., 2008).

To calculate the output rate, it is mainly the width of the exit routes or doors that matter. A measure that is used is that, if the surface is good, a maximum of 100 people can be expected to pass per meter and minute. If stairs has to be used this number is reduced to 73 individuals per meter and minute (Säterhed, et al., 2008); (Sports Grounds Safety Authority, 2008).

These routes are of great importance though they are exposed to higher risks. There are primarily risks that are associated with the stop of flows, this can easily lead to increased pressures in a particular area. Some rules have been set to avoid this. The routes should be few and should as well consist of soft turns. The routes width should be the same throughout the whole passage, in order to avoid designs that evoke crowd crushes (Brannigan & Kilpatrick, 2004). It is also important to avoid having large routes that intersect, and that the routes do not pass through any stationary mobs (a place where a lot of people are assembled), such as through a stage area (Säterhed, et al., 2008).

Though a crowd does not have the ability to communicate with itself, information between management team and the crowd should take place trough speakers, billboards or megaphones. In addition is it not possible to believe that correct information can spread from person to person in the crowd, the information will then be uncontrolled and the content will probably change, which can lead to false rumors. This further reinforce the importance of having a sound system that allows the information to reach out to everyone in the audience. In addition to this it is possible to use a host on stage. This person can be used before or during a performance, though the audience is the most receptive during these times. It is important that the person that performs this task is respected by the audience (Säterhed, et al., 2008).

7. Analysis

In this chapter we will analyze the different disaster mentioned in chapter 2. The purpose is to see if behaviors and movement patterns described in chapter 3 and 4 can be observed. Some suggestions will be given to what was the cause for these disasters as well as possible improvements and actions that could have been taken in order to have prevented them. In addition, some general findings will be presented.

7.1 Ibrox Football Stadium

A clear pattern that can be distinguished is that many of the accidents that have taken place at various sports stadiums have occurred during the most important and high profile games. Often in classic games between rivals or in matches that have particular importance. “The Old Firm" derby between the Rangers and Celtic is a typical game that fulfills this point.

When analyzing accidents that historically has taken place at the Ibrox stadium, there is an indication of elevated risks of “The Old Firm' derbies (Still, 2014). Although these derbies are a minority of all the matches played, almost all fatal accidents that have occurred on this football stadium happened in these matches. The assessment of these elevated risks considered mainly due to the elevated empathy for the spectators. People that attempt football matches easily fall in to the common emotion and behaviors of the audience's (Drury & Cocking, 2007). The rivalry between these clubs have been built up over a long period of time, which often leads to that the spectators, more than during usual fights, at some points loses their natural- and rational behaviors. It is common that people are screaming, standing, jumping, and generally are noisy in these contexts. These behaviors escalate at especially dramatic events, such as goals or judgments. The euphoria, alternatively the anger and disappointment that in those moments arises, have in many cases led to irrational behaviors. Due to the dramatic end of the match at "The Old Firm" derby in 1971, it is estimated that most people's state of mind caused a degraded rational crowd behavior. One can imagine that people were euphoric, and that the movements on the way out of the stadium not followed the usual standards. This may have been an underlying cause of the elevated pressure that was created in the moving crowd, a pressure that in turn was the cause of this tragic accident.

In addition to these elevated risks that exists in specific games it is notable that there are certain periods that are particularly critical during a game. Close to the start of the match, during half time or at the end of the game, most of the accidents happen. The reason for this probably goes hand in hand with an increased pressure obtained from the audience's side. It is at these moments that the audience moves for various reasons. When people start to move, each person gets a certain momentum, in conjunction with the many people that are moving closely together as a granular flow (Helbing & Johansson, 2009), every person’s momentum is added and summed up into the great mass movements. This leads to high pressures, generated in the crowds. The accidents that historically has taken place is mainly due to the fact that the exits and escape routes has a lack of capacity, and are not able to handle the size- or force from these flows.

This was the case at Ibrox, for the disaster in 1971. Directly after the final whistle of the game, too many people tried to get out of the stadium at the same time. When the pressure finally became overwhelming, a person stumbled, which in its turn led to a crowd crush (Walker, 2004).

Before this accident occurred, the security at stadiums and sports grounds had barely been treated and there was simultaneously a lack of standards and rules. At this time, it was widely accepted to be exposed to high pressures when being part of a crowd at different sport grounds. Just as it was accepted to lose control of his or hers body movements and instead be brought into the mass´s movements. The Ibrox stadium, and especially stairway 13 had been through similar, though smaller, disasters with fatalities even before 1971. In order to avoid future accidents the staircase was renovated a few years before this accident. The club got attention and was praised for this action (Walker, 2004).

However, when the disaster occurred in 1971, experts said in retrospective that the renovation of stairway 13 should have been done differently. Experts said that if focus had been on improving the design instead of just renovating it, this accident could have been avoided. The experts considered that the stairs instead should have been designed in zig-zag style, which would have brought down the speed and worked as natural turning points, in order to avoid high pressures when people left the stadium the exits should also have had a wider bottle compared to the top. This disaster led to the Weatley Report (Walker, 2004). A report regarding the security at English football stadiums, it highlighted the risks of different accidents and the need for rules and standards. Something that culminated into the first edition of, the Guide to Safety at Sports Grounds, or the "Green Guide", as it is usually called. This guide is still the basis for the safety at English sports grounds (Sports Grounds Safety Authority, 2008).

The conclusion that can be drawn from this accident is that the main reason was the incorrectly dimensioned escape route. Had the same situation occurred today, there would probably not have been any accident. By using simulations with programs such as Pathfinder, the improper design of stairway 13, which was unable to handle the current flow, could have been found beforehand. This in turn would have had led to a different design of the stairway to enhance the safety. One of the metaphors that have been described previously is the one of Colosseum. This classic arena consisted of a large number of outputs that basically led the audience straight out (Helbing & Mukerji, 2012). If safety had been the only significant point in the construction of a sports stadium, many venues could have taken a lesson from the structure of this arena and focus on having a large number of egress options. However, there are other important points, such as the looks and designs but perhaps primarily the desire to accommodate as many spectators as possible, due to the financial gain that each stadium can receive from each spectator. This is an ongoing battle that must be examined in every new construction and renovation and the economy is constantly the strongest interest. The knowledge that this indeed is the case makes it important for the engineers to highlight the economic benefits of actually implementing the safety properly and at an early stage, in order to avoid future costs that accidents can bring.

7.2 Bradford City fire

The cause of the fire is believed to be due to that one of the spectators at the site released a smoking and glowing object down under the stands, supposedly a cigarette stub. There were various factors that caused the spread of this fire.

Among other things, there was much trash and combustible materials under the stands, in which the fire could grow. In addition to this, there was a good supply of air though the floor of the grandstand since it was not sealed, due to cracks and gaps. As the floor furthermore consisted of dry, old wood and the distance to the source of the fire was small the fire could spread further. The final factor behind this rapid fire development was the roof. When the combustible gases and the flames reached the ceiling the spread dramatically increased. The rapid development also depends on the re-radiation. The fact that the roof furthermore consisted of asphalt tarpaulin gave the fire even more combustible material and the dripping asphalt both spread the fire as well as it wounded the spectators (Popplewell, 1985).

It has afterwards been indicated that the exits of this stadium were too few and undersized. The evacuation of the stadium took long time even under normal circumstances. In addition, some of the doors were closed this day, which complicated the evacuation further. According to Popplewell (1985), if the "Green Guide" had been followed on this occasion, the accident would not have been able to occur. This guide highlighted the danger when garbage was collected under the stands. Nevertheless, it was found that trash had been accumulated under the main grandstand for about 20 years. In addition to this the guide stated that a wooden stand like the one at Valley Parade needed to be able to be fully evacuated in less than 2.5 minutes. This was deemed impossible by the Chief Inspector at the site (Popplewell, 1985).

7.2.1 RSET vs ASET

After watching videos of the fire (Ivan, 2010), it is easy to say that RSET was indeed longer than ASET.

t_d = Time from when the fire starts to detection of the fire.
From video footage available and the report and summary of details from the fire, the growth phase was very rapid. This leads to a belief that the spectators closest to the origin of the fire should have detected the fire in an early stage, as smoke developed early and rapidly became thicker and darker, hence more visible. This indicates that no fire detection system was present, and in the report of the fire there is no mentioning of such a thing (Popplewell, 1985).

t_a = Time from the detection to when people are notified.
The stand was over 70 years old, built before the First World War, and constructed with a lot of wooden material. Because Bradford was at the time a division 3 club, it was not required to fulfill the guidelines of the "Green Guide" according to a newspaper article (Pithers & Pallister, 1985). These two factors combined with visible light grey smoke 3 minutes before people entered the field gives an estimation that automatic fire detection and warning system were not present at this facility (Popplewell, 1985). According to The Guardian newspaper, lower division clubs did not have the finances to enhance their stadiums safety issues (Pithers & Pallister, 1985). These allegations concur with the observations from video footage that the entire stand did not seem to have a grasp of the seriousness of the situation. From video we draw conclusion that no message or signal was given to indicate that there was a fire, based on the fact that police and staff urged people to start moving onto the field. Also as some people already starting to move in the stand, the players keep on playing, thus stealing the attention from the spectators from observing the danger of the fire.

A few people had already entered the field but the game still continues. A clearance out of bounds from the goalkeeper at the same time as more people enter the field brought the game to a halt.

t_d and t_a takes too much time in contrast to the rapid fire growth and especially as smoke was noticed. If this part of the evacuation had been performed properly, the outcome would probably not be as catastrophic, as time is valuable in case of fire.

t_o = Time from notification to when people decide to start to act.
t_i = Time from decision to starting to act, i.e. start to move.

t_o and t_i could be assumed to be as one in this scenario as there are no necessary actions to engage in before starting to move, except for maybe try to fight the fire. But as this is a public place of assembly the spectators are more likely to stay in their role as spectators, and they probably suppose that staff and management will try to extinguish the fire. As seen from footage the people in the closest boundary of the fire start moving onto the field. By this time the flames are clearly visible and the smoke generation is quite extensive. The other spectators at the opposite side of the stand took a lot longer time from notification to decision of starting to move. This is understandable since the scenario develops in such a rapid way which probably surprised them. Supposedly there had been several public announcements from the speaker using the public address system to warn and urge the people to move on to the field. There is no evidence supporting this and the belief is that it was either too much noise or the public address system malfunctioned, maybe as a result of the fire. Video analysis shows that the magnitude of the flames was not too bad when the flames first came up through the floor and when the first people started to evacuate, although by this time the smoke was dense. From approximately a couple of square meters of flames transitioned into a rapid spread horizontally, the people still in the stand were those exposed to immediate danger.

t_e = Time from starting to move until a safe place is reached.
Because the exits were located at the back of the stand along a narrow and long corridor, the space quickly filled up with dense smoke, causing people to evacuate to the field. People had to jump over a fence, which could be considered as a type of bottleneck because the flow slowed down as this action took longer than walking down the stands. The field should not be considered as a safe place and by that mean this time element is indeed longer than necessary.

7.2.2 Panic

The conception of mass panic, at least in a fire scenario as this, could be discarded based on observation of video. At first it seems that people underestimated the seriousness of the initial fire. Photos taken from the stand at an early stage, as the fire was still concentrated to the space underneath the floor, show how people are still at the stand. Instead of starting to move at that point, people probably believed someone would come with a fire extinguisher. When the flames became visible and during the rapid spread from a couple of square meters of flames to a flashover and the entire stand in flames, people moved towards the field. They started rushing down the stand, jumping over the fence and then enter the field, as this seems to be the only rational thing to do. Therefore mass panic could be considered not to be the case. Once on the field you can see how a lot of people are cheering and dancing, which also disclaim mass panic. The stand on the short side which was next to the main stand, no immediate actions were taken by the spectators. It was first when the entire stand was in flames that stand started to evacuate starting with the people closest to it. Most likely the heat was unbearable by this time. Also there is no observed competition between the evacuees, instead people are helpful to each other, especially helping those with problems getting over the fence as well as dragging people who had been disabled. Although it cannot be said with certainty that some people experienced panic, the crowd did not seem to suffer from mass panic.

7.2.3 Conclusions

- Design and dimension of escape routes were inadequate.
- Combustible material should not be able to accumulate under the stands.
- The construction of the stand should not exist of combustible material. This caused the fire phase to develop rapidly.
- No signs of mass panic could be observed.
- Evacuation should have started earlier when smoke and flames were noticed.

7.3 Hillsborough disaster

The match had a particularly importance, as it was the semifinals of the FA Cup in England. This further demonstrates the elevated risks that are associated with these high profile games. Also it indicates that the acceptance of risk aspects differs depending on the character of the game.

One of the first conclusions that an analysis of this disaster gives is that it highlighted the importance of having a crowd management team with elaborated contingency plans. Both at the site, but also that it is important to early on, have discussed various critical situations that may arise.

The problems this day started even before the game because of a large part of the audience was delayed. Something that led to higher pressures over the inputs than regularly, neither the structure of the building or the police were able to handle this (Stuart-Smith, 1998); (Hillsborough Independent Panel, 2012).

Regarding the stadium's design, the biggest mistake was, that the high metal fences were placed between the stands and the pitch (Stuart-Smith, 1998); (Hillsborough Independent Panel, 2012). This fence was most likely placed there to prevent fans from entering the pitch to cause disturbance. But in this case it was a death trap. The great forces from the entering fans pressed the people in front against the metal fence and they died mostly due to compressive asphyxia. Here it is find out that the lack of back-to-front communication was one of the catastrophic factors. The people in the back had no idea of the trouble at the first couple of rows at the stand.

A simulation with today's technology would probably have pointed out that those people had a risk of being subjected to high pressures. The most natural thing would be to eliminate these fences, as they constituted the greatest danger. After this accident all stadiums in England removed fences at the front rows. Another problem was that people did not manage to enter the stadium quickly enough which indicates that the design should have been different. More and wider entrances would enable more people to get in, but it is equally important that the flows can allow spectators to their individual seats in the stands, to avoid constipation. Meaning that the flows should be naturally integrated throughout the entire passage. If this is not achieved, critical situations like bottlenecks could occur, and can lead to even worse situations like crowd crushes and jam of people at gates or door openings.

It is easy to be wise in the aftermath. Some of the measures, particularly what the police should have done differently is presented below. There will also be some suggestions on how the structure of the stadium instead should have been dimensioned to reduce the probabilities of critical conditions.

The first action that the police on the scene should have taken, along with the crowd management team, is to postpone the start of the match even longer than already had been done. The reason that a new entrance was opened, which is not usually the case, was enabling the spectators' entrance into the stadium in time before kickoff. However, they did not manage the security requirements, including the missing of policemen or stewards available in the tunnel to direct the audience up to their seats. Had the game simply been postponed further along with the police informing the spectators about this, the fans may have been calmed down. The risk of high pressure would then most likely have been eliminated in a simple and easy manner.

However, there are unfortunately conflicting interests regarding such an action, as our analysis previously spoke of it is often the economic interests that weigh heaviest. The focus has fallen on financial gain, it is sponsors, broadcasters and betting sites that currently control where and when the various matches will be played. This makes the whole situation even more problematic and even if a situation like this should occur today, it would probably be difficult for the police and stewards to get such a desire through, to postpone the game.

Having this said, it is therefore even more important to have elaborate contingency plans, mainly because it will help the security staff to feel confident in how to act, but also for them to be able to have a solid foundation to stand on and that can be used as an argument against these conflicting interest groups. Another mistake the police force made was that they assumed that the spectators tried to force themselves in to the field. In fact, it was the pressure from the audience that forced them against the fences.

Though the pressure does not only depend on the density of people but also on speed and movements was a bad move from the security team. In order to keep spectators away from the pitch had high steel railings been located between the pitch and the stands. The pressure was so high that some of the railing collapsed and a crowd crush happened. The cause of the deaths was asphyxia, mainly caused because the people at the front rows were pressed against the metal fence, hence suffering from loss of air (Stuart-Smith, 1998); (Hillsborough Independent Panel, 2012). It has been admitted, a long time after the disaster, that the police withheld the truth from both fans and media. They already knew at the match day that the safety could not be maintained. Furthermore, in connection with the accident, a large part of the police force did not understand the seriousness of the incident and therefore acted inappropriately. They assumed that people tried to invade the field. This led to the fact that the police initially kept people away, instead of helping them. In addition to this neither the police nor the security workers directed the crowd to their seats after they entered, which they usually did (Hillsborough Independent Panel, 2012).

This incident attracted much attention and led to the accident report that is known under the name, the Taylor Report (1989). A report that led to changes concerning the security in sports grounds. The main changes were that fences no longer got to serve as a barrier between the stands and the pitch. In addition, it was mandatory that all stadiums would consist of only seating. Something that would serve as a check point on that not too many people are allowed in to the grounds (Stuart-Smith, 1998); (Taylor, 1989); (Hillsborough Independent Panel, 2012).

The analysis of this disaster indicates that it seems that the police lacked an understanding about the risks related to metal fences, something that their actions speak for. It also seems that the communication on several occasions was insufficient, mainly because a large part of the force focused on keeping people away instead of helping them. Even though the situation then had been critical for a long time. Some of the measures that should have been implemented and are considered most important are summarized in the following list.

• Postponed the match, thus giving the spectators more peace for their way into the stadium. This should have reduced the pressure.

• Have police officers in the tunnel, to assist in directing and holding discipline.

• Gain a greater understanding of the risk with the fences as well as that they should have worked more for the audience benefits than against them.

7.4 The Love Parade disaster

Initially a too large number of visitors were released into the area. This area had a capacity of 250 000 visitors. In retrospect, it was unclear exactly how many people were found inside the area of the accident, but most evidence indicates that over 1 million people were at the site when the accident occurred. This means that the area was populated for over 400% of its capacity. It is sufficient to only see this number in order to understand how high the risks must have been inside the festival area. Mainly risks associated with high pressure during the movement of the crowds inside the area were present. Because the entrance and exit paths were closed for nearly an hour, a high pressure was created.

When this accident was analyzed it was easy to see a connection to the different movement patterns that have been found to occur in crowds, those movements have been presented further in chapter 4. In the following text the patterns that emerged and were behind the accident are presented.

- Counter Flows – One thing that happened this day was that two flows met each other, a phenomenon called counter flows. One of the flows came from a tunnel that led people into the area, and the second came from an oncoming ramp that was used by people inside the area. This counter flow made it more difficult for those persons who wanted move away from this area. In addition, the tunnel was used as both entrance and exit to the festival area. This mean that people were walking in both directions in the tunnel, thus counter flows existed in the tunnel as well. To prevent this from happening, the tunnel could have been divided into two lanes. One lane for exit and one for entrance which could have generated a better and more constant flow. Another way to prevent this could have been to have exit and entrance in one direction, one end of the tunnel could form the entrance and the opposite used for exit. This way is probably less desirable arrangement since this could result in a detour.

- Bottleneck - Furthermore a bottleneck situation was formed. This occurred when the flow of new arrivals, from the tunnel, was bigger than the people who managed to get on, mostly up on a ramp that would lead people away from the area in question. One of the causes behind this critical situation was that the ramp was not used to its full capacity, as it was designed for. The ramp had been provided with fences on the side, probably from a safety perspective. However, these fences primarily led to a decreasing of the ramp's input which gave a lower flow rate than expected. The purpose of the fences is difficult to understand, since the areas behind the fences do not seem to be used for anything special. Personnel who work with preventive measures as well as active security at stadiums and similar areas should understand the risks associated with this phenomenon. They should understand which zones within the area that is most critical, i.e. where there is an increased probability for this phenomenon to occur. Analyzing and finding of these elevated risk areas makes it easier to eliminate or reduce those risks. Preventive measures can be made calculating predicted flows and then comparing these flows to the size and the capacity of the inlets. Simulations like this can be made by programs as Pathfinder. In this way the simulations can calculate how different designs on walkways and openings will influence the situation. In addition to this preventive action, more direct measures can be used by crowd management. If security personnel know about those critical zones, strategies can be developed at an early stage. If the parties- and individuals involved knows what is expected of them the possibility of a disaster could be reduced.

- Turbulence - The last phenomena or pattern that was detected in this crowd was turbulence. When people were accumulating between the ramp and the tunnel it was only a matter of time until this pressure would be too high. Turbulence has been proven to be a clear sign before an accident in a crowd will occur. In a situation like this, with critical density and pressure, it is difficult for the police and security guards to be able to counter the situation. An attempt was made when the police shouted in their megaphones that the tunnel could no longer be used by the new arrivals. However, this was not taken seriously, and people continued to fill up in spite of this announcement. This situation displays the importance of knowing what to do and how. If the police had had a well-elaborated tactic they would probably have deployed police officers in the beginning of the tunnel. Such an action would have reinforced the message that it, for that time, was prohibited for new people to enter the festival area.

It is a good finding that these patterns actually occurs because it gives the opportunity to gain knowledge about at which densities and speeds various phenomena occur. This can result in better developed and improved simulation programs. Hopefully these programs will be able to alert, for example the police, where and when critical conditions are achieved in the crowds. There have been attempts where cameras have been set up during the pilgrimages to Mecca, in almost the same way works the German PedGo simulator. This simulator is used to predict crowd flows during a football match, but could also have been used at the Love Parade. Regarding how the development curve looks like in various parts of the crowd, alerts can be sent out. In order to further develop these simulation programs, unfortunately, similar accidents are required in the future. There are still too few accidents that actually have been filmed and documented like this festival accident in Germany. It is therefore dangerous to draw too many conclusions with only this accident as a basis. It is possible to draw conclusions at which density and velocity or at what pressure, different phenomena actually occurred. This gives a good indication of what levels that actually are critical in similar crowds but the situation may be different depending on a lot of different factors. Those factors and uncertainties have been presented further in chapter 3. The knowledge about those uncertainties makes it important to gather more information and to continue to develop this relatively new field.

This accident also showed the importance of being well prepared. This applies to everyone involved, from the police to the event workers. After analyzing the available material from this accident it seems that the communication between the different groups failed during this event. A conclusion that can be drawn is that communication is one of the most important factors in crowd management. If this communication is failing, different parties may sometimes even work against each other more than they help. It is also important that everyone involved knows what is expected of them and how they are supposed to handle the different kinds of situations that may arise. This indicates that preparation and training often pays off. However, it is impossible to successfully prepare for all accidents or situations that might arise. Therefore, it is important to have general plans and have a wide range of thinking when these contingency plans are developed.

The accident was, as mentioned earlier, caused when too many people began to accumulate in the vicinity of a ramp, the ramp was also in connection with a tunnel where new spectator constantly flooded in. One of the reasons for this accumulation was due to that the festival was postponed for an hour, which meant that the pressure increased even more once they finally were allowed into the area. The crowd's density in the area of the incident has subsequently been measured to be over 10 persons per square meter, this confirms that there was no coincident behind the accident. This extreme density is an indication that turbulence set in. Another interesting angle is that despite that this critical phenomena occurred, no mass panic could be seen, something that has been debated heavily during the last decades whether it is a phenomena that occurs or not during disasters (Helbing & Mukerji, 2012).

Regarding the bad planning, one major mistake was made even before the festival had begun. This was the first year that the festival took place in Duisburg. Since previous years, even though the festival had not taken place in Duisburg, the organizers knew early that they could expect more than a million visitors. Despite this, they also knew that this new area had a limited capacity that would have difficulties to cope with this crowd pressure. According to available documents the area could manage a load of 250 000 people. Previous years this festival was held in a number of other cities. Occasionally it had been canceled because it was considered unsatisfying regarding the safety requirements and some accidents and emergencies also occurred (Helbing & Mukerji, 2012); (Klüpfel, 2012). The aftermath of the 2010 Love Parade disaster resulted in a series of guidelines regarding how the handling of safety work should be implemented on similar events in the future (Helbing & Mukerji, 2012)

7.5 Development through history

Accidents at large stadiums have long been a well-known fact, which for example can be seen in the design and evacuation possibilities of historical stadiums. One of the oldest example of this is the historical building Colosseum, an arena that was built during the Roman Empire and most of it still exist today. Regarding evacuation time, this arena is still considered to be able to compete with today's stadiums. Although Colosseum had room for up to 70,000 people, calculations reveal that it probably could have been completely emptied in only 5 minutes. A time that that not many of today's stadiums can beat. The major reason that this arena differentiates from today's stadiums is particularly the availability of exits. Colosseum consisted of more than 60 large outputs located around the entire arena (Helbing & Mukerji, 2012). The stadiums today usually do not have that many ingress or egress options. Instead there are a couple of main entrances in order to access the stadium, then there are a lot more entrances to the different sections of the stands. This means that during ingress or egress a lot of people are situated in a confined space which in turn can lead to congestions at bottlenecks. When having as many entrances as Colosseum the flow of people is probably more constant and faster. The possibility of accidents at bottlenecks also decreases as the density level probably not reaches critical limits.

Disasters regarding football arenas have since the early 1900's mainly been an effect of poor building structure and construction engineering. The reason for peoples' death was often that parts of the arena collapsed, e.g. a section, a fence or a wall. In the mid 1900's and later in recent times these errors seem to be less frequent and instead it's mainly due to overcrowding that disasters occur. When researching for crowd disaster in general, a lot of them seems to be connected to just football. According to a list of some crowd disasters a majority happened at stadiums (Helbing, et al., 2002); (Still, 2014). Why accidents regularly occur at stadiums is something that should further be explored and studied. From this list we can draw the conclusion that the magnitude of the disasters tend to decrease over time. The closer until present times, less people dies. One explanation might be that crowd management has improved as well as more regulations have been implemented.

It is interesting that the number of deaths has decreased in recent times (Helbing, et al., 2002). There might be several explanations to this. Firstly we believe that engineering has improved over the years and less accidents due to collapses of the structure occurs. Secondly, regulations on maximum capacity are taken more seriously and intentional overcrowding is probably less frequent. Also crowd management seems to be focused more upon, for example through the "Green Guide" which highlights aspects to consider in order to maintaining public safety.

Disasters and the possibility of them, especially at larger sport stadiums, seem to be recognized in most of the literature studied for this report. Much of the literature uses sport stadiums as example for evacuation for large number of people from a complex environment. This is an indication that safety at sports ground is being considered, and that focus is put on maximizing the security and prevention of crowd disasters.

7.6 Wrongful definition

Stampede seems to be an expression used to describe a chaotic state in which people get crushed. The definition of stampede is originally used for when herd animals start rushing for no clear purpose. In terms of crowd disaster there does not always seem to be a rushing of people in order to define it as stampede. Instead in crowd disaster and mass evacuation literature, stampede is used as when people are crushed due to forces included with high density. In some disasters there is an indicator that something influenced people to suddenly move in a hasty manner, thus complying with the original definition. Example of this is when a late minute goal suddenly makes a lot of people who are about to leave, to re-enter the stands for celebration. There have been various disasters where this is the reason for a stampede to occur. For many cases though, stampede seems to be a synonym for being trampled to death. In those cases turbulence is probably a better description than stampede. For pilgrimages stampede is frequently used to describe the reason for crowd disasters, often implying that people have been trampled to death. Even for these scenarios turbulence is considered a better fit, as a collective rush has not been observed. The main reasons instead seem to have been due to high pressures in those moving crowds.

8. Discussion

Many reports about crowd dynamics discusses the concept of panic and how management can mitigate this phenomena. This is contrary to the findings of Fahy and colleagues (Fahy, et al., 2009), which concludes that it is rare. If it is mentioned in various reports it gives us an indication that panic is a problem in at least crowd dynamics. The reports about panic in fire situations discusses that it does not happen, or at least is a rare occurrence. Most reports indicate that panic does not happen in an early stage, when the alarm sounds, or due to initial cues like visible flames or smoke, smell of smoke. What do we know about what happens when people are trapped in an enclosure and has no or at least limited means to get out. If such an incident occurs and if there are no video recordings or survivor statements, it is difficult to analyze what happens inside as these people are trapped. We believe that during these circumstances panic is most likely possible as people probably do recognize that their life is about to end. When panic is discussed in crowd emergencies we believe this might occur at highly density crowds as turbulence sets in or in jamming situations when a door or path is being blocked. On the other hand, research about panic for people who are about to die because they are trapped in an enclosure might be considered unnecessary.

The term mass evacuation is hard to define. Is it the number of people involved that determines if it is a mass evacuation or is it maybe the structural knowledge? Our belief is that it should be called a mass evacuation if it happens at a public place where a lot of people are involved, e.g. parades, pilgrimage, sporting grounds and at venues such as concerts, underground metro station, festivals and fairs etc. If an evacuation happens in a building where people have prior knowledge of escape routes and even if there is a high number of people needing to evacuate, there might be strategies so that high densities are not achieved.

When searching for literature regarding mass evacuation, most available information is regarding evacuation due to natural disaster such as floods, storms, tsunamis or earthquakes. It seems like there is not much research on mass evacuation in enclosures and buildings such as arenas and venues. Maybe each arena have their own contingency plans and strategies and keep it to themselves, and thus we are not able to access this material. Considering the fact that sport grounds are frequently related with crowd disaster, specific contingency plans should exist at all larger stadiums. The question is how to regulate this? Should it be by law or is it an organizational matter. When discussing football, at least the world football organization FIFA should be included to make sure that all football arenas prioritize public safety.

In disasters according to the literature we study, it seems that it is not during the evacuation phase that people are most likely to die. Instead these phenomena like jams in a bottleneck scenario or crowd crush and trampling seems to happen due to the high density of people. As this paper initially was set out to focus on the evacuation, rather than what happens in large crowd, not enough information has been found during evacuation of larger stadiums. Before this study our belief was that there first had to be some kind of threat to justify an evacuation. Then at some point when densities get too big or there is a blockage, then trampling and crushing would occur. At the different events we studied, at least those at sporting grounds, only the people in the area of high density died or got injured. This indicates that the evacuation of stadiums works well, but that poor management of many people is the cause for these tragedies to occur.

Also the design is of importance to obtain crowd safety. In the Hillsborough disaster, one major reason for the magnitude of this incident is the placement of a metal fence at the first row to separate the crowd from the field. When the pressure from the entering supporters propagated from the back to the front, the spectators closest to the field had no way to go. We assess that this incident probably affected the design of future arenas, as it is rare to see metal fences for the spectators at arenas today. The reason for having this fences was most likely to ensure the safety of the football players. When analyzing the Hillsborough accident it seems that it was only the first couple of rows that experienced the high pressure and got pressed against the fence. What is interesting is that according to recent statements from police in England they were aware of the danger involved in such high profile games (Källström, 2014).

In many cases it seems that officials and management for the events does not take their responsibility for the events. In many cases they blame the accidents on the spectators and the total crowd, even if the people in charge know they have the responsibility.

As mentioned above, there does not have to be an emergent threat to cause congestions and overcrowding leading to peoples' death. Also not every disaster in large crowds happens during evacuation egress but could just as well happen during the ingress phase. The sale at large retail stores in the United States during the holiday of Black Friday is a great example of this. The major discount offers from these stores attract a large number of people. When the store opens a lot of people try to enter the store at once. Stampedes are frequently observed and the extremely high densities at bottlenecks can cause jams. Competitive behavior is often implied in these situations as people have a desire to make the best deals on goods (Dawson, 2010).

A majority of the accidents at sports grounds seems to occur in developing countries such as some African, South American, Central American, or Asians countries (Helbing, et al., 2002). Many of the disasters occurring at stadiums in these countries are generally due to a heavy overcrowding that causes people to die. Cultural and social differences and how well developed the country might be some explanations to why crowd disasters are more frequent in those countries. Another difference is probably the interest for football. Only high profile games will fill up the stadium in Sweden, compared to for example Spain or England, or the developing countries, where a sold out stadium can often be expected.

There have been situations where capacities of between 60,000 and 70,000 for the stadium actually took a total amount of more than 120,000 people (Still, 2014). For some scenarios too many tickets were sold and thus it was indeed the organizers fault as they intentionally made the decision to overcrowd the stadium. In other cases the fans forced their way into the stadium and that makes it harder to anticipate that a disaster might take place. On the other hand a lot of these disaster happen during high profile games. Therefore it is justifiable to increase security staff for those types of games to prevent these disaster to even happen in the first place.

The reason for intentionally overcrowding by selling more tickets and force more spectators into the stadium than it has capacity for are most likely money. One question that arises is why is more frequent in developing countries in recent years. Are the organizers more willing to accept the risk compared to in European countries? On the other hand the organizers might think they do the fans a favor by letting more people attend, and most likely the atmosphere will increase with more people. Better atmosphere and more cheering might give a boost for the home team players which can justify the overcrowding. Some of the games that had been overcrowded were World Cup qualifying games. Who is ultimately to blame here? Is it FIFA or is it the domestic football association for the specific country?

To prevent stadiums to be overcrowded, standing sections should not be allowed. If a stadium only have sitting seats, people are organized in structural pattern. The capacity can then easily be determined. For a standing section capacity can vary depending on the management, i.e. how many people are allowed to that section. When having seats, people are organized in rows, which act as a natural barrier between people in different rows. This will prohibit forces to build up and keep densities in reasonable ranges. The Bradford fire and the Hillsborough disaster caused England to have their stadiums with only seated sections.

It is easy to see where the development of this area is going. Like most areas is mass evacuation has under a strong scientific and technological development. That is to say, more and more knowledge is stored into more powerful models. With these models a new world has opened up, where simulations can easily be implemented at stadiums with a capacity of several 10 thousands of spectators. Which was impossible a few years ago. However, it is important to understand what these computer programs are made up of, and to understand what the basis of these programs and models are. It is mainly experimental and different analyzes of actual events that these models are based on. After analyzes of those experiments and events, patterns, movements and behaviors have been explained with the attempt of mathematical models. It is these mathematical equations that form the basis for today's computer models.

It is nevertheless important to be critical and to understand that there are still limitations to these models. One of the reasons is that most of the experiments, which historically has been conducted has been based on certain homogeneous groups. It has often been healthy young men such as soldiers and students who constituted the test subjects. This fact leads to uncertainties, particularly around how these movement patterns and behaviors can actually be applied to other homogeneous groups and foremost about how these can be applied to a regular group of people. A normal random group of people in today's society consists usually of a mixture of many different ethnicities, ages and genders. Beyond that a large part of the society's individual’s has disabilities to various degrees. This fact makes it difficult to believe that such test groups can indeed be regarded as a sufficiently credible foundation stone for these simulation models. In many of the models available today, it is easy to give different individuals different physical characteristics. There are many tests that have been made about this physical part and then perhaps mainly around walking speeds for different age groups and genders and so one. However, it is difficult to measure the differences in a more psychological level both for various persons as for different groups. To eliminate these uncertainties and thus manages to improve future simulations further research should be conducted on real events. In addition more experiments on mass evacuation should be executed, particularly with test groups reflecting reality in a more equitable manner than it has been in the past.

There are some limitations in the PedGo assistant, mainly since it is based on different probabilities and assumptions about of how the crowds will move. When the people are controlled by a variety of factors, including emotions and psychology, it is impossible to completely simulate the future in a comprehensive manner. Additionally, this program simulates 15 minutes into the future, something that may seem unnecessarily long when the most critical situations on football matches take place in conjunction with the start of the game, half or the final whistle when people start moving. The critical situations that throughout history have occurred have often escalated quickly. It is doubtful that an assistant like this would have had time to help as well as instruct the police or the security staffs on site in time before these critical situations arise.

Pathfinder is based on artificial intelligence, something that makes people both trying to get out of the stadium by the shortest possible route but at the same time, they can take new decisions depending on whether it comes persons or objects in their path. This eliminates some limitations that have been found in other simulation software, for example, that moving people get stuck and cannot get past each other. The main limitation of this program is really the same as mentioned earlier, that the intelligence not has been developed as much about all the psychological behaviors that we humans constantly use. This relates to the need to conduct more experiments and analysis of behaviors during these mass evacuations situations. Another limitation of this program is that it currently it is not possible to simulate with fires. However, this is a project that is currently being developed and it is hoped that the program should in future be cooperative with FDS, (fire dynamic simulator).

Some literature used in this paper might be questioned regarding the relevance. One factor that might be different today is the difference between genders. As today's society strive towards more equality between men and women, the actions taken during an evacuation might have changed as well. The literature used is from 1980 which might not be considered to be too old, but still it is not a reflection of the relations between genders as of 2014.

9. Conclusions

The field of evacuation has during the last couple of decades gotten more attention and focus. The research has improved over the years especially as technology has developed exponentially. The symposiums for Human Behavior in Fire as well as Pedestrian Dynamics and Evacuation have certainly had an impact. It allows researchers and scientist to share and explore the field more. So far most experiments and studies have primary been focusing on smaller test groups and populations, with not enough heterogeneous groups to reflect the reality.

The development of recent software as PedGo Guardian and evacuation simulation programs like Pathfinder makes it possible to evaluate problematic aspects for buildings in crowded situations when evacuation is needed. These software are based on the research conducted, which justify more research for larger crowds.

Crowd disasters, especially those at football stadiums, have motivated improvements to ensure public safety. Planning and preparedness as well as crowd management to control the people is one way to ensure this. The other aspect is to ensure that the building and the environment can provide safety for ingress, duration and egress for occupants within a building or enclosure.

One aim was to identify problem areas regarding mass evacuation. The findings of this paper suggest that the major problem is the amount people gathered in a confined space. Most problems regarding mass evacuations seem to be connected to overcrowded spaces. In the future more studies should be directed to situations and locations where overcrowding may occur in order to prevent further disasters.

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