vfdb

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TB 13-01

March 2012

Static and Dynamic Crowd Densities at Major Public Events

By Dr. Dirk Oberhagemann

1st edition March 2012

Technisch-Wissenschaftlicher Beirat (TWB)

der Vereinigung zur Förderung des Deutschen Brandschutzes e.V.

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Table of Contents:

1. Introduction

Major public events (for a definition see (16)) are very popular among the general public. They attract ever-increasing numbers of people, who want to experience and share in occasions such as fairs, concerts or football games. One consequence of such events is that many people are collected in an enclosed space. The lack of information about the number of people expected and of their behaviour makes it difficult to successfully plan such events and assess what emergency services may be required.

Between March 2009 and February 2011, the vfdb coordinated a research project on this topic within the framework of the German government's security research programme. The aims of the project were to produce planning criteria for the improvement of risk assessment, evacuation procedures and rescue concepts.

Most recently since the Love Parade in Duisburg, attention has been focused on the risks associated with major events, especially the issue of overcrowding, crowd management pedestrian flows and how to control them. These issues form two important aspects in the hazard analysis of major events. Analyses of overcrowding and pedestrian flows are to be considered not just within individual restricted spaces, but also within the event space as a whole, including entrances and exits.

2. Hazard Analysis

The basis of any hazard analysis is a description of the event. Amongst other things, the event description identifies what type and number of attendees is expected. Furthermore, the intended acts of the event itself are described, i.e. the attractions, as well as how and in what order they will occur. These conditions are the reason why the attendee comes to the event. Cancellations, delays or a reduction in options have considerable influence over how attendees behave and move around.

In a report (1) on the subject of 'Preventative Fire and Safety Measures at Major Events', Munich Fire Services listed the possible cases of damage to be considered when undertaking a hazard analysis. Where appropriate, such cases can be revised for event-specific scenarios, and after the first examination any non-applicable cases can be disregarded.

- Crowding: indoors and outdoors
- Overcrowding: indoors and outdoors
- Fire
- Gas dispersion
- Accidents (e.g. fairground rides, motor sports events, stunt shows, animals)
- Structural collapse
- Severe weather (e.g. heavy rain, strong winds, hail, thunderstorms)
- Power cuts and other technical disruptions
- Danger due to potentially violent attendees and participants (e.g. hooligans, extremists)
- Threat for individuals in need of protection
- Violent rampages (including flying object)
- Improvised explosive devices (IED); with possible secondary attacks
- IEDs with radioactive content ("dirty bombs")
- Violent rampages with weapons
- Mass illness (e.g. food poisoning)
- Radioactive/nuclear attack
- Chemical attack
- Disruption to public transport (e.g. due to personal injury)
- Disruption of individual/private transportation (e.g. accident on access routes)
- Disruption of infrastructure affecting attendees (e.g. dispensers, cash desks, toilets)

As well as the possible cases of damage, normal environmental conditions must also be considered. As with all open-air events, weather conditions play a significant role. Rain can have an effect on escape and rescue routes. Sun and high temperatures can affect health, causing, for example, dehydration. Arrangements must therefore be made to provide drinking water and, if possible, rest areas in the shade. Rainfall and slippery conditions, especially in combination with slippery surfaces such as cobblestones, can lead to increased falls. This will be taken into account in the risk factor calculated by the Cologne Algorithm.

In the past, common causes of damage were high densities of crowd and overcrowding of parts of the event areas. Assessing these factors in the run-up to an event, evaluating them during the event and taking appropriate, effective preventative measures is often a crucial and difficult issue when creating a safety concept. Addressing these issues will therefore be a central focus in the following chapters.

3. Static densities and their potential hazard

In Germany, there are two approved types of crowd density. According to federal assembly regulation for buildings two people per square meter is the basis for evacuation requirements to be implemented. According to traffic legislation, standing room on busses allows for eight people per square meter. An authorised crowd density of eight people/m^2 may politically be classified as safe (2, 3), but it is not scientifically justifiable.

Alongside the discussion of authorised crowd density comes the issue of critical crowd density: crowding in which an acute safety risk can no longer be ruled out.

The first issue to be considered is the maximum crowd density per square meter. According to Weidmann (4) the average citizen of Central Europe has a minimum space requirement of 0.085 m^2. This is due to the oval shape of the human body when standing on the ground. This result comes from a projection of the human body when standing on the ground as an oval shape.

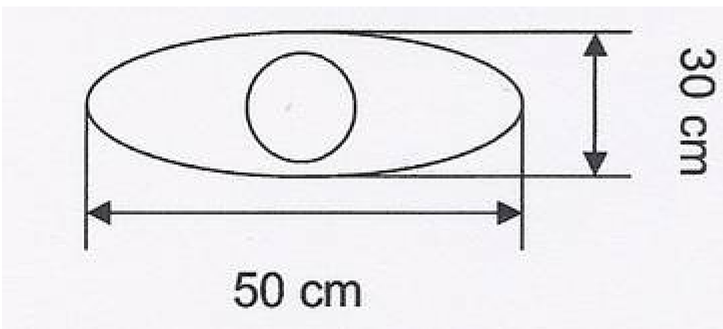


Figure 1: Proportions according to Weidmann

Theoretically, this results in a value of 11.8 persons/m^2, taking into account the unfilled gaps in-between. If these gaps are discounted and the surface area is taken as a rectangle, then the resulting required space becomes 0.11 m^2 with a maximum crowd density of 9.3 p/m^2. Taking clothing and feet into account increases the space requirement to 0.15 m^2 and the maximum density then drops to 6.6 p/m^2. Therefore, the maximum crowd density possible lies between 7 and 9 p/m^2. If we compare this, however, with research from Asia, we see a maximum density of 9.2 p/m^2 instead of 6.6 (6).

3.1. Average densities in an event space

Numerous pictures of events were analysed as part of the research project. With regard to the measured crowd densities we must distinguish between an intentional, voluntary density and an enforced, involuntary one. With an intentional density, people are standing close together in a particular space, without external force being applied. Here the maximum observed densities lie at between 5 and 6 p/m^2. However, at the majority of events the maximum observed densities did not go over 4 p/m^2. In relation to the total event surface area we can therefore assume an average density of less than 2 p/m^2, as there are always areas with a considerably lower density.

From this we can also deduce the maximum capacity of an event. For this estimation we require the available surface area of the event and the average duration of stay for each attendee. The available surface area of the event is not the total available space, rather the net area. The areas containing structural systems and escape and rescue routes must be deducted from the total area.

Our analyses of all of the public free accessible events have shown that the official crowd numbers lie at least a factor of 2 above the actual crowd numbers, when we take crowd density of 2 p/m^2 as a basis. The local densities at an event fluctuate substantially from less than 0.5 up to 5-6 p/m^2. Therefore, requirements for a maximum continuous density of 2-3 p/m^2 are rather theoretical and impossible to put into practice, especially when it comes to public events. Nevertheless, increased densities as such are not always synonymous with risk; indeed the audience sometimes even favours them. The hazard assessment must also always take into account what state the terrain is in. In rainy and slippery conditions, for example, a density of 2 p/m^2 can be estimated as to be too high. Furthermore, all types of tripping hazard in the area must be avoided in order to ensure that evacuation is not slowed down. Tripping hazards can also lead to a reduction in the level of crowd density permitted. This does not just apply to static crowd density, but also to densities in pedestrian flows. Our video analyses of crowd movements verify that crowd densities can alter considerably in the space of 1-2 minutes and that fluctuations of 0.5 to 2 p/m^2 are possible. Whether the attendee is situated in a crowd of people or in an empty section of the area of the event, the individual evaluations result in overcrowding of the event.

The following pictures show examples of recorded crowd densities at events.

Picture 1: Public Viewing football, World Cup 2006 (3.8 p/m^2)

Picture 2: Public viewing football, World Cup 2006 (5.0 p/m^2)

3.2. Calculation of real crowd densities

There are two reasons why we need information on crowd densities. Firstly, government event regulations in Germany require a calculation of the maximum attendance limit. Secondly, actual crowd densities at major events are needed in order to be able to give information on crowd numbers and associated pedestrian flows, as well as on how many first aid services will be required. Yet the approach of these government event regulations is not to ask: ‘how many people can a particular area hold?’ rather: ‘how many people can be contained without risk?’, thus restricting the number of people to a completely harmless mass in terms of safety regulations. This is how the figure of 2 p/m^2 was established in Germany. Projections in other countries are, to varying degrees, considerably higher or lower (5). If we examine crowd density values that present a clear risk, e.g. at bottlenecks or during evacuations, then a value of 6 p/m^2 is often estimated in Germany. Measurements in Japan, however, show up to 8 P/m^2.

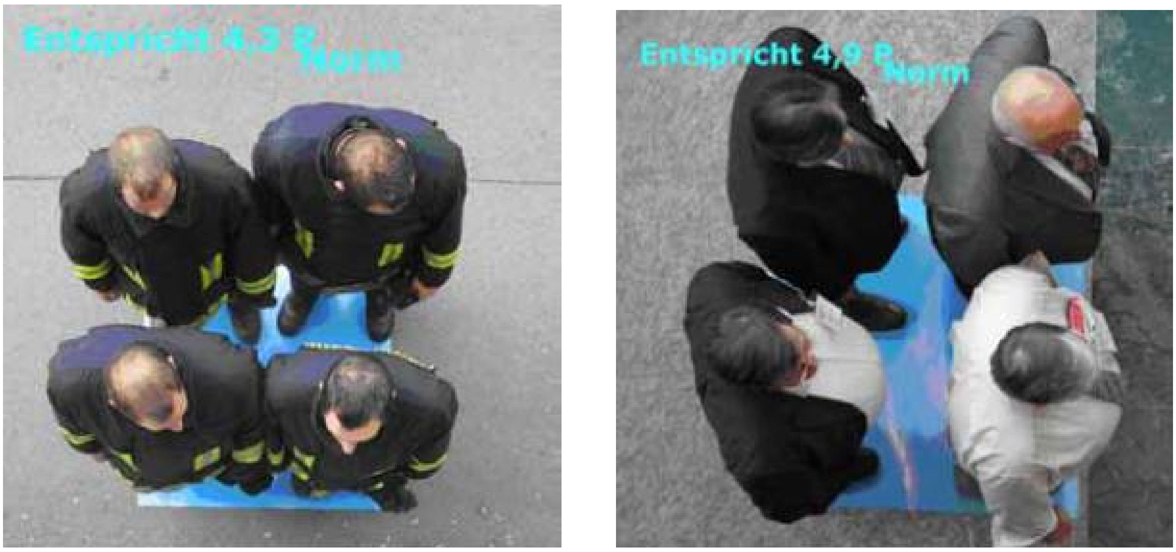
How realistic or how useful is the designation of the number of people per m^2? Can the number of people be used without taking into account the characteristics of the people themselves?

Medical science offers an approach towards characterising people. One method concerns itself with calculating the surface area of the body (S). Using empirical data it has been possible to create various formulae which estimate body surface area based on body weight and size. Mosteller’s formula presents one such attempt (7):

$$S = \sqrt{\frac{L \times M}{3600}}$$

Here, S is the body surface area in m^2, L is the length in cm and M is the weight in kg.

If we assume that those people specified in the government event regulations are slim, with a Body-Mass-Index (BMI) of 23, then a P_{Norm} would be 1.80m tall with a weight of 75kg. This approach is also taken in the construction of lifts. This P_{Norm} has a body surface area of 1.94. The following two pictures each show a crowd density of 4 p/m^2 and the corresponding P_{Norm} of either 4.3 or 4.9.



Pictures 4 and 5: Crowd densities of 4 people per square meter.

In order to describe how many people can fit into a given area, we must always take each person's specific features into account. The below picture demonstrates the use of the approach in a real scenario.

Picture 6: Crowd density at a security gate

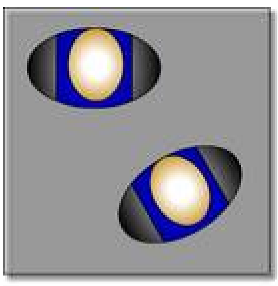
109 people are gathered in the marked area in this picture. This corresponds to a crowd density of 4 people in an area of 27 m^2.

The average body surface area S comprises 1.94. The calculated figure therefore corresponds to a P_{Norm} figure.

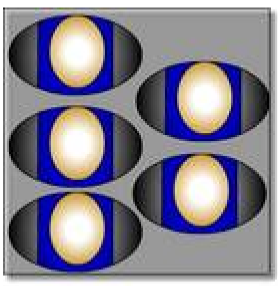
If we use the calculation for Shimada and Naoi's (6) measurements of up to 8 p/m^2 and assume an average size of 1.6 m and average weight of 55 kg among the Japanese students, then we arrive a a P_{norm} crowd density of 6.4 p/m^2. We can see, therefore, that the approach allows a comparison of differing measurements.

4. Risk to people by people

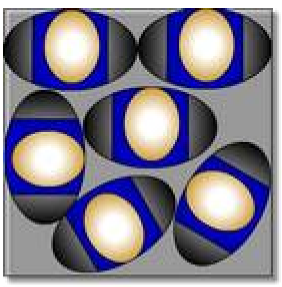
In order to obtain an estimate of physical characteristics in different densities (7) (p/m^2), the following section will attempt to gauge at what point it can become dangerous for people to be situated in a crowd. This is done by using the characteristics of one individual to deduce the characteristics of a square meter filled with people, and from here taking an estimation of a larger area.



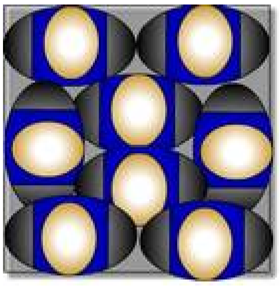
In a crowd density of 2 p/m^2 individuals are completly 'decoupled'. Occupancy of this kind of area has no effect on the adjacent areas. Due to the 'decoupling' a fall does not impact other people.



In a crowd density of 5 p/m^2 there is still ample space between people to allow movement, although it is limited. They can, for example, absorb whatever force may occur through a lunge, a swerve, or by leaning into it. The effect to externals is still zero, or to a limited degree shielded from externally occurring forces.



At 6 p/m^2 each individual in the group can still move freely and still exert force on their neighbour by tilting. However, the increased density makes the alternation of occurring force impossible because there is almost no room left for the individual to manoeuvre. The legs of people standing in front or behind restrict lunging. If one person stumbles, then the force created by others, who also stumble will add up and push force out into the surrounding area (approx. 100 N * 6 persons = approx. 500 –600 N from one meter squared).



In this picture we see eight people within one square meter. This occupation of space is made possible through squashing and angling the body. Theoretically up to 8.2 p/m^2 can be achieved. At this density the people are standing upright and are stable. Some stability is achieved through friction in clothing. However, dynamic conditions on the outside can destabilise this internally stable structure. In fact, densities of >=8 p/m^2 are only ever reached when external pressure is exerted upon people and when external limitations make any avoidance impossible.

Hence, the critical density in a dynamically developing process of compression is around 6 p/m^2. A crowd density of 6.2 p/m^2 imposed by an external force of people was, for example, measured at the train station during the Dortmund Love Parade.

But what happens in a single square meter of a major event is not the deciding factor for whether people come to harm or are even killed. For this to happen certain boundaries must be exceeded, which can be evaluated as follows:

a. Suffocation: Inhalation is initiated automatically by a muscle contraction in the diaphragm (the diaphragm is pulled downwards) or by inflation of the chest. If an external pressure prevents this muscle contraction from occurring, then the person can no longer breathe. After three minutes the brain is irreversibly damaged, and a short while later death occurs. The boundaries for tolerable pressure are estimated at 2-3 kN/m^2. This translates to approx. 800-900 N exerted on the chest. If we assume that the individual vectors of force being produced in the area are not all moving in the same direction, then 2 to a maximum of 4 squared meters of absorption area – i.e. 10-12 rows of people – suffice to produce a potentially fatal pressure in the front row. This pressure would have to be sustained over a period of time.

b. Mechanical damage to organs: this damage could occur at a value of less than 10 kN. This figure would theoretically be reached if around 120 rows of people standing behind each other and pressing forward.

Risk minimisation:

a. The existing spaces in the setting of the expected attraction (e.g. the stage) must be divided into sections. Densities of 5-6 p/m^2 must not be exceeded in the individual sections.
b. The access routes can be equipped with barricades to prevent additional force. Barricades should be placed no less than 10 meters apart from each other. It is important that these are made visible on emergency routes and that the pedestrian flow is not compromised.

The barricades must be designed to withstand significant pressure. Site fences, for example, are not suitable barricades. Site fences serve the singular purpose of separating sections of ground; their function is to guide people or calm traffic. In this sense they are not structural measures as they can be easily knocked over. An overturned panel represents a tripping hazard, leading to an increase in danger in all areas with potential for crowding. Munich Fire Brigade has outlined this in a report on the suitability of 'Mobile Safety Barriers for Events' (8).

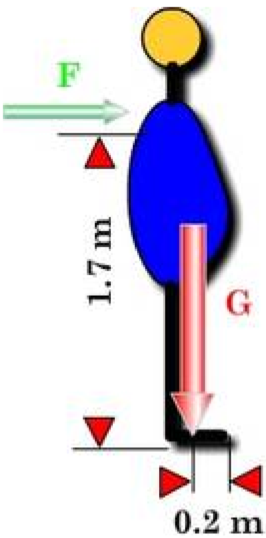
The threshold for a critical crowd density is around 6.0 p/m^2, in the transition zone between a voluntary accepted density and an enforced one. At this stage the variances at which people are able to avoid or absorb imposed external forces become problematic. From a density of 6.0 p/m^2 it is barely possible to absorb force through steps and movements. People pass the emerging force onto those next to them. Their neighbors increase this force through their own instability. This is how areas with increased crowd density (compressions) emerge, which move forwards as a visible wave through the mass of people and with a speed that depends on the density level of the crowd. The best-case scenario here is that these compressions dissolve again in areas with lower crowd densities and cause no damage.

The following picture exemplifies one such pressure waves in a crowd. It was taken during the Love Parade in Duisburg. The floats were brought to a stop on the grounds at a particular point in time. After a time, crowds of people packed into the area around the floats. When the floats moved away again, the people had to move to the side to avoid them. This involuntary force resulted in pressure waves amongst the tightly packed attendees.

Picture 6: Pressure waves at the Love Parade

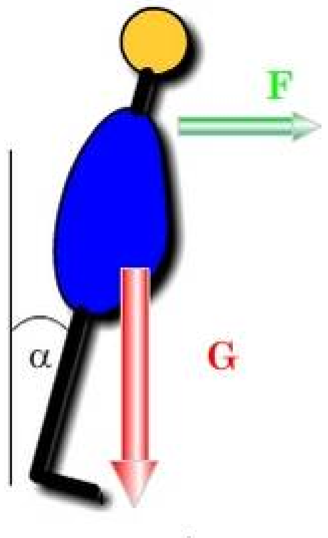
One can see the waves moving away from the floats, which, in this case, is accompanied by a wave movement coming from the opposite direction. The people located between the pressure waves are exposed to shear stress, which can cause people to fall over or lead to breathing problems. These stresses only lasted for a few seconds in this case.

At this point a few more physical considerations (7) should be added.



“The depicted person is in reality not a ‘fixed’ entity, but moves and can change its physical characteristics. One example of this ‘intelligent’ transformation of characteristics is the lunge step forwards or backwards, or a shift of weight brought about by bending the body to absorb a force placed upon it. But these reactions are only possible when the body or legs have enough space to carry out the movements necessary to maintain balance.

The asymmetries in the simplified evaluation of stability that now follows should be disregarded. Indeed the stabilising forces when pressure is exerted from the front are lower because the body’s centre of gravity is nearer to the heels; stabilising forces are slightly higher at the sides of the body because there is further leeway for the leg to move sideways. For this reason there are statistical differences in size and varying levels for in-coming forces etc. Also the figures do not stand in neat lines, but at angles to each other, or even turned at 180 degrees. In this respect it can be assumed that any individual asymmetry amongst a number of people who happen to be standing in one space will be balanced out again.



The figure in the picture is beginning to fall over, if F*1.7 > G*0.2 (assumed shoulder height: 1.7m, assumed distance of the projected centre of gravity to the toes (centre of rotation): 0.2m). For a 75kg 'average person' this would come to a surprisingly low 88 N. When the figure tips over, the required force to continue the falling process reduces when the tipping angle increase because the projected centre of gravity moves towards the toes. From a tipping angle of around tan α + 0.2/130 (9-10˚) the figure will fall over, even without external force being applied.

At a tipping angle that exceeds this critical point, the figure can exert an increasing force of its own upon an object (such as a wall or other people).

The relevant force that can be exerted upon another person is around: F=G*cos α* sin α. With our 'average person' the critical 88 N for the neighboring person will then be reached when tilting at an angle of about 15 degrees. This means that if people were to stand in a row, then not just one but all of them would fall over, theoretically exerting a growing force (of up to 345 N) at up to a 45 degree tilt. The most well known example of this is of dominoes toppling.

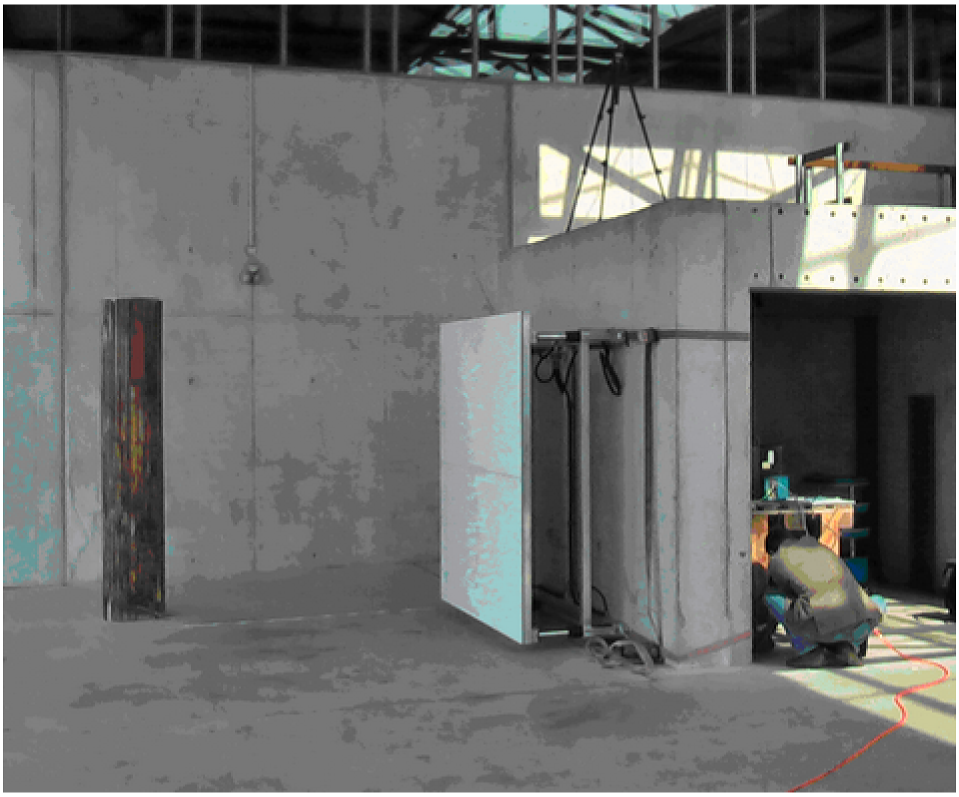
However, several limitations must be made in real-life situations. Given that a real person is not fixed, he will topple over before he reaches an angle of 45 degrees. Also the effects of friction from clothes rubbing against each other, or differences in size and weight (etc) change the result. Further research and consideration is thus required to adapt this simplified picture more to correspond with reality.

4.1. Pressure caused by people

In large crowds of people, people themselves and their efforts to move in a particular direction can build up pressure. The critical boundary thereby begins at a crowd density of 6 p/m^2. Barrier systems are therefore often used to divide up crowds or fence off unsafe areas. Yet the literature offers scarcely any information on possible pressures caused. We thus require the design basis for barrier systems, as well as details of potentially dangerous situations and information on the extent of injury in crowds of people.

Until now it has been assumed that the force created by a high crowd density can reach up to 4,500 N/m (9,10). However, references for this are not available.

On June 22 2010, experiments on this topic were conducted at the regional fire fighting school in Bruchsal (11). A panel was used as a barrier, with an area of around 4.4 m^2 (220x200 cm), and made from wood-based material (Thermopal, 8 mm thick) with a plastic coating.



Picture 7: Experiment set-up

This panel was fitted on to an aluminium profile (75x50 mm). Pneumatic pressure gauging cylinders were secured next to each of the four corners. On the opposite side of these cylinders a rack from the same aluminium profile absorbed the force, which ultimately came to bear upon a vast concrete wall. The pressure gauging cylinders were connected to a pressure cell (Kistler, 500 bar measuring range, 0.01% resolution), which piezoelectrically registered pressure and allowed it to be electronically recorded with a data gathering system.

Picture 8: Pressure sensor

Static and dynamic pressure patterns were measured. To do this we began with a row of five firemen who ran towards the barrier and then continued to push forwards. The rows were then increased by five people at a time until they reached twenty people. The same experiments were conducted without the run-up in order to compare the static loads. No further increase in pressure was detected here between fifteen and twenty people, as it is likely that the pressure was distributed amongst the mass of people.

Image 2 shows a typical example of recorded pressure. All related diagrams can be found in Appendix 2.

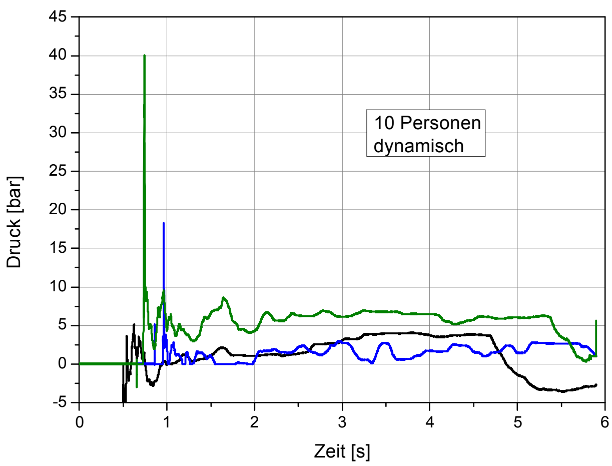


Figure 2: Force created by people pushing against a barrier (Pressure (bar), Time (Sec.) (10 persons, dynamic)

The peak force recorded is strongly reliant upon an equally-weighted impact of people against the barrier. The highest recorded value here amounted to 40 bar and the density of people came to a maximum of 8.4 p/m^2. A further increase in density was not possible under the prescribed conditions.

The static experiments (i.e. without a run-up) gave a higher sustained pressure than the dynamic experiments. In all, up to 15 bar was attained for the recorded time of six seconds of sustained pressure. 1 bar correlates to 100,000 Pa, giving 100 kN/m^2. This shows, then, that simple barrier systems in crowds of people can merely guide crowds, but not protect an area from them.

The experiments also helped determine what mass of people was required for no further rise in pressure to be measured in the barrier area. The threshold for this was at three to four people standing in a row directly behind each other and pushing forward. This row, with its high crowd density, had a length of around 1.2 meters. On the other hand, this means that in a circle with a radius of 1.2 meters, the maximum possible force can be produced and the origin of this force can come from any side. In other words this means that in the middle of a circle with an area of just $4.5m^2$ and containing 38 people (i.e. a density of 8.4 p/m^2), a force of up to 15 bar can be produced.

5. Analyses of pedestrian flows

Analyses of pedestrian flows help us find out more about the distribution of people on the site and their behaviour when arriving and leaving. Amongst other things, then, they provide guidance for the implementation of public transport. They also make it possible to determine the causes of disturbances, irregularities and congestion. Lastly they can be used to build up a profile of the behaviour and composition of attendees. Detailed analyses of pedestrian flows make it possible to predict congestion and respond to it in good time during the event. These analyses also allow conclusions to be drawn after the event about the types of attendees. They serve as an analysis of irregularities over the course of the event and therefore as a tool for planning recurring events.

Various recorded pedestrian flows and possible conclusions will be introduced below. The description of the event and the data records are available at: http://www.vfdb.de/Veroeffentlichungen.159.0.html

5.1. Simple pedestrian flows

A simple example will be used to clarify what a pedestrian flow is. At a football stadium a ticket check takes place after stewards have carried out a security check. For this the attendee inserts the ticket into a slot and then the turnstile is released. This data was recorded at the

Cologne Stadium. The attendee has the ticket in their hand and the turnstile operates automatically. Thus we can assume steady rate of admission. Obstructions can occur if the tickets are not ready to hand or if a part of the technical system fails. The following diagram depicts a relatively constant flow of people at a rate 20 per minute over an observation period of 7 minutes.

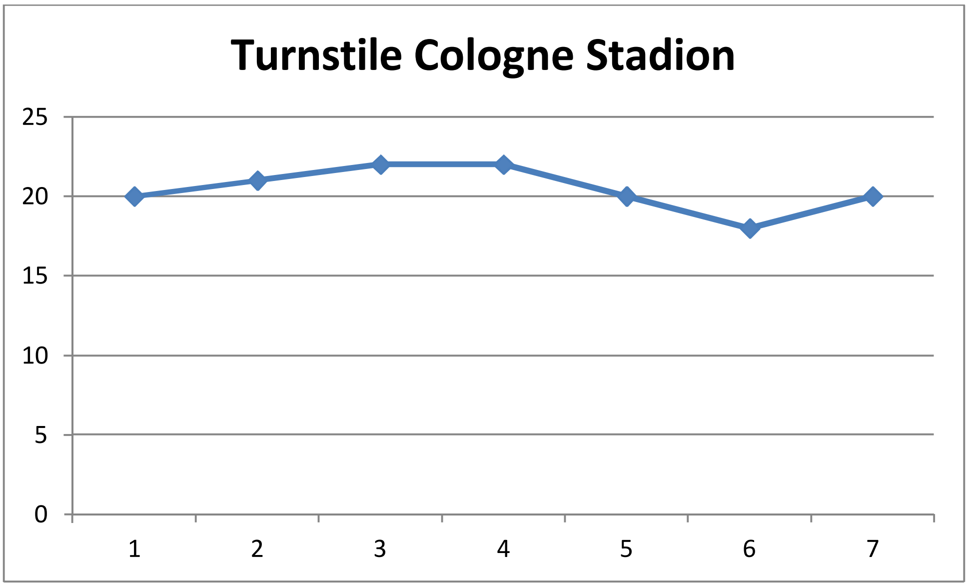


Figure 3: Pedestrian flow through a turnstile (number of people per minute versus time in minutes).

5.2. Pedestrian flows without counter flows

More complex yet simplier structured pedestrian flows occur at the end of an event. This kind of event can take place in a venue or at an outdoor site. Given that their main objective is to watch the event, attendees do not display any distinct flow characteristics during the event itself. When the event finishes visitors move towards public transportation stops or car parks. The peak pedestrian flow often occurs when dispersal begins, and is brought about by people moving quickly in order to be the first to reach their transport. After this the flow of people proceeds steadily and generally decreases at a constant rate.

The flow of people during Cologne’s 2010 musical fireworks (‘Kölner Lichter’) serves as an example. Attendees were observed as they poured out from the public grounds to the east of the Rhein in the direction of the S-Bahn station and the main train station. Recordings were made from the Hohenzollern Bridge.

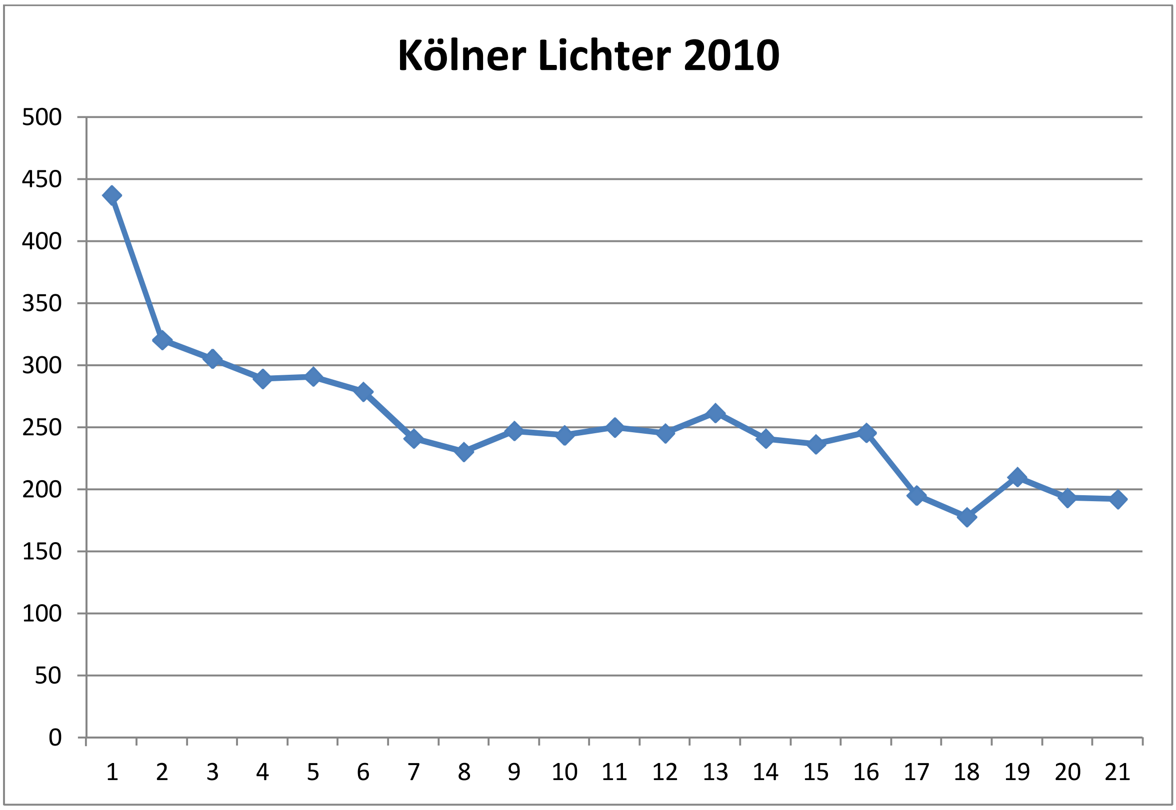


Figure 4: Pedestrian flows at the end of the 'Kölner Lichter' event (number of people per minute versus time in minutes).

Over the course of 20 minutes, the behaviour of around 5,300 people was observed as they dispersed. The pedestrian flow analysis shows no abnormalities. The exit from the grounds proceeds smoothly with steadily decreasing numbers. The pedestrian flow is firmly controlled when the event finishes. All crossroads and paths are cordoned off using barricades manned by staff. Although this results in a slightly longer route for attendees, it produces an extremely steady flow of people, which means that there is a more equally weighted flow of people into the train stations.

5.3 Pedestrian flows with counter flows

The most complex pedestrian flows occur at events in which the attendees are able to move in counter flows. The mixture of people coming and going can present disruptions in flow behaviour for both directions.

Typical examples of events at which pedestrian flows and counter flows arise are funfairs, town fairs – from old town festivals to the "Kieler Woche" (an annual sailing event in Kiel) – as well as all events that have an ongoing program. Typical counter flows do not develop with low crowd densities of under 1 p/m^2 because people are still freely able to choose which way to move. Right-hand traffic begins to form when crowd density goes above 1 p/m^2. At this density the available walkway decreases by around 0.5 meters as a gap now forms at the point of physical contact between flows.

The Cranger Kirmes from 2009 is the first example of such an event. The whole showground has an area of around 110,000 meters squared. The funfair, forming the core of the grounds has a walking surface of 21,303 meters squared, through which every visitor will pass.

This area offers space for around 42,600 people at a crowd density of 2 P/m^2. With fairground rides occupying 90%, 11,000 people can fit in the rides at the same time. The following pictures give an idea of this.

Picture 9 and 10: Cranger funfair 2009. Crowd densities (2.0 and 2.5 P/m^2) in counter flows.

In contrast to a stationary crowd the density for a moving crowd is lower because the area required for step length has to be added. Even when the walking pace was very slow, the maximum observed crowd density at Crange was 2.5 P/m^2.

The walking speeds for different sizes of group in various crowd densities were measured. While the speeds clearly vary in crowd densities of up to 1.5 P/m^2, they visibly converge at densities beyond approx. 1.5 P/m^2. The individual degrees of variances (i.e. the range of choice possible) for each group decrease in crowds such as this. Even wheelchairs and pushchairs now move at the same speed as the average attendee.

The following distribution shows the walking speeds for different groups from one to six persons for low crowd densities (Crange).

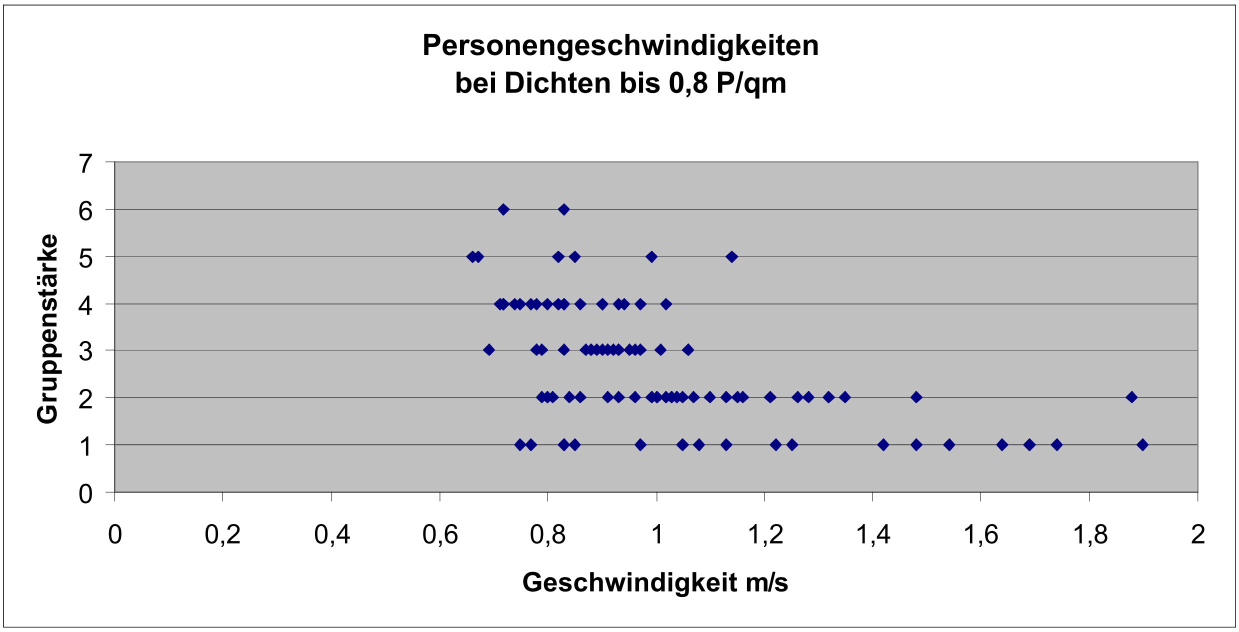


Figure 5: Measured walking speeds for different kind of groups at densities of up to 0.8 P/m^2

Group	Average walking speed. (m/s) Density up to 0.8 P/qm	Average walking speed. (m/s) Density 0.8 to 1.2 P/qm	Average walking speed. (m/s) Density 1.2 to 1.7 P/qm	Average walking speed. (m/s) Density 1.7 to 2.5 P/qm
1er	1,23	0,82	0,52	
2er	1,08	0,61	0,45	0,35
3er	0,91	0,57	0,41	0,30
4er	0,83	0,49	0,41	0,30
5er	0,84	0,55	0,40	

Table 1: Average walking speeds for various groups of people.

In order to be able to take account of groups with varying speeds in a simulation an indication of the percentage distribution of groups on the event grounds is useful. This distribution was measured (2009 and 2010).at the fun fairs at Soest and Crange.

Group	Total number Soest/Crange		Total persons Soest/Crange		%-distribution on total persons Soest/Crange	
1P	133	171	133	171	5 %	3 %
2 P Group MM	114	273	228	546	8 %	8 %
2 P Group MF	406	1057	812	2174	27 %	34 %
2 P Group FF	202	328	404	656	14 %	10 %
3 P Group	199	410	597	1230	20 %	19 %
4 P Group	129	275	516	1100	17 %	17 %
5 P Group and larger	53	119	265	595	9 %	9 %
Total	1236	2663	2955	6472		

Table 2: Percentage distribution of groups of people at a fun fair (M=Male, F=Female)

We can see that the percentage distributions at both events are roughly the same.

In 2010 studies were made over two consecutive days of the Soest “Allerheiligenkirmes” (Funfair) from the same observation point, and corresponding pedestrian flow analyses were compiled. One irregularity was the firework show on the first day of observation (Friday) at 20.00. This would have produce significant discrepancies with Saturday, as the counter flows caused by the extra event dropped accordingly for the Saturday.

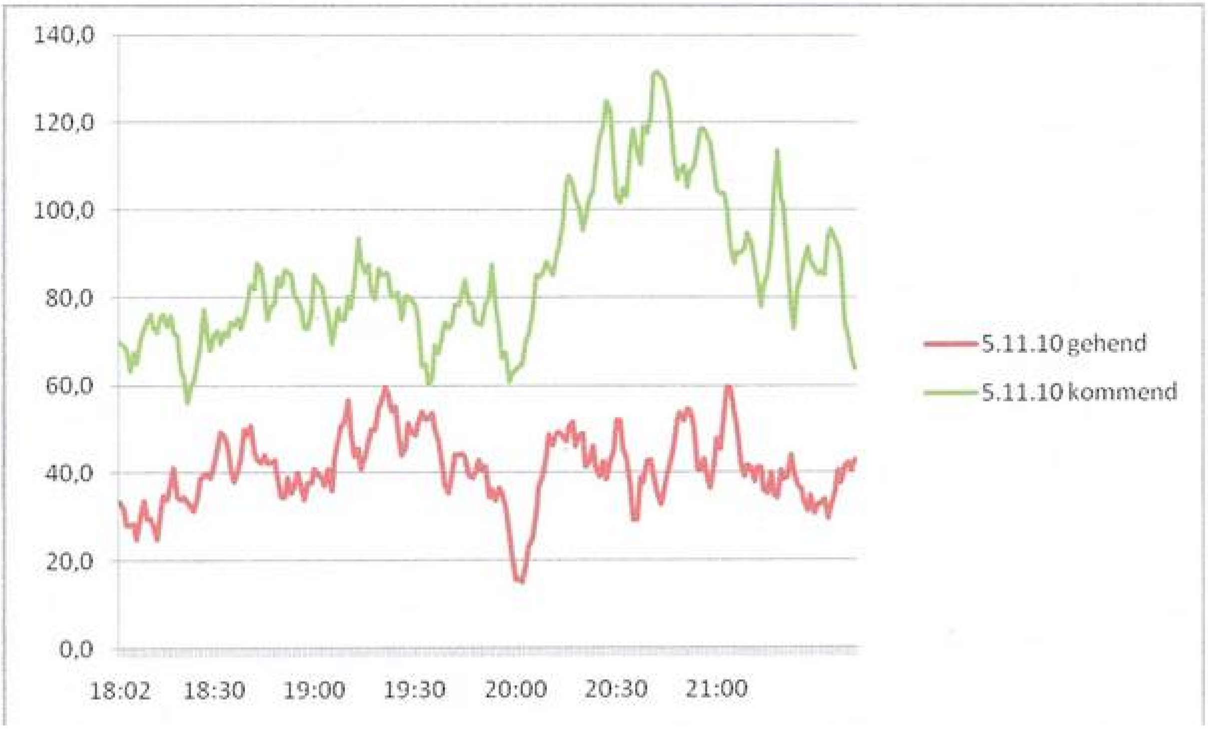


Figure 6: Pedestrian flows (Persons/minute) at the Soest Allerheiligenkirmes, 5.11.2010. (Red = going, green =coming)

The incoming flow of people is mainly the result of those travelling by public transport. The central bus station is also situated at the train station; all buses from the Soest region go there. The fireworks take place in grounds behind the train station and can be observed from the area around the bus station. The total observation period is 3.5 hours. We can clearly see the pedestrian flow (in red) increasing between 18.00 and 19.30, caused by people pouring in from the funfair towards the train station and fireworks. This flow of pedestrians was almost at a standstill from 19.50. Accordingly, when the fireworks ended at 20.30 an increased pedestrian flow in the direction of the fairground was initiated. Several peaks in incoming flows can also be seen from 20.45.

On Saturday 6.11.2010 the weather was not as wet and the number of attendees was significantly higher.

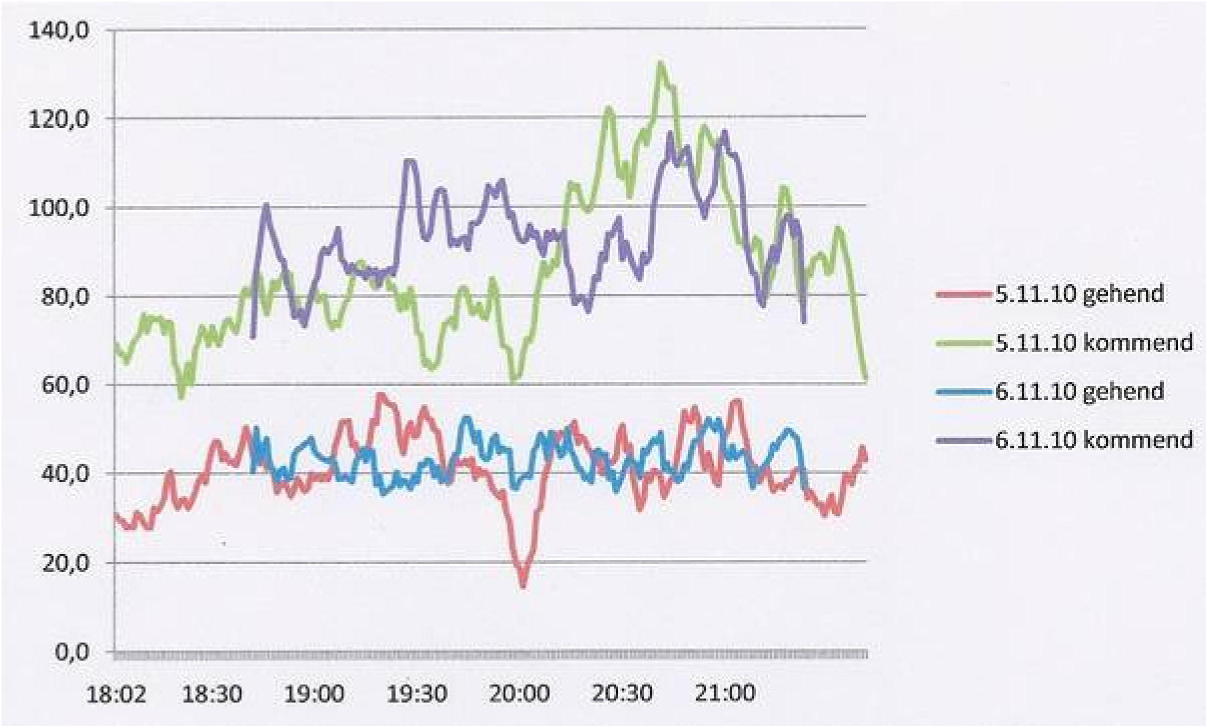


Figure 7: Pedestrian flows at the Soest Allerheiligenkirmes, 5/6.11.2010.

There was no difference between the pedestrian flows for attendees on either day of the fair. This allows a conclusion to be drawn about the structure of attendees. Pedestrian flows were measured between 18.00 and 21.30. Over this period of time the flow of people was almost identical for both days. The groups who move around consisted of curious onlookers who did not stay in one place for long. The main group of funfair visitors staid for 5 to 6 hours and did not go back until the late evening. The flow of visitors and therefore the crowds of curious onlookers were constant on both days. The increased visitor numbers can be traced back exclusively to groups who stay for a longer time.

What is noticeable about the diagram are the three practically identical peaks between 20.45 and 21.15. The light parallel shift can be attributed to the increased crowd density which also results in a slower walking speed, as 30 minutes are required to go from the station to the observation point. Here we see a ‘homemade’ problem caused by the public transportation system. A large number of buses happened to arrive at the station simultaneously at these particular points in time. This resulted in excessive numbers of visitors on the grounds, sometimes leading to congestion of the flow at narrower points. This problem can be avoided by making adjustments to the bus timetable.

The application of pedestrian flow analyses can be further clarified using the Love Parade in Duisburg in 2010 as an example. Attendees at the Love Parade were led from the train station to the event grounds via western and eastern routes. This was advantageous because people then had to walk some distance to reach the grounds. If the event were to take place right at the train station then congestion would occur at the exit of the station.

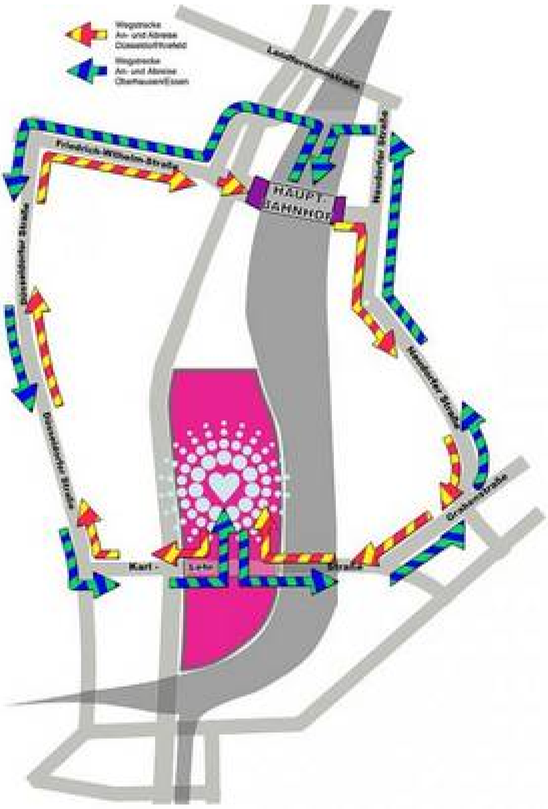


Figure 8: Love Parade flow paths (the left side corresponds to the west side).

The flow of people moving from the station’s western exit in the direction of the city was evaluated. Two own video recordings exists. The first recording documents the time period between 11.17 and 13.55 – in which approx. 40,000 people passed through the test area – and the period between 14.41 and 15.13, in which approx. 5,500 passed through.

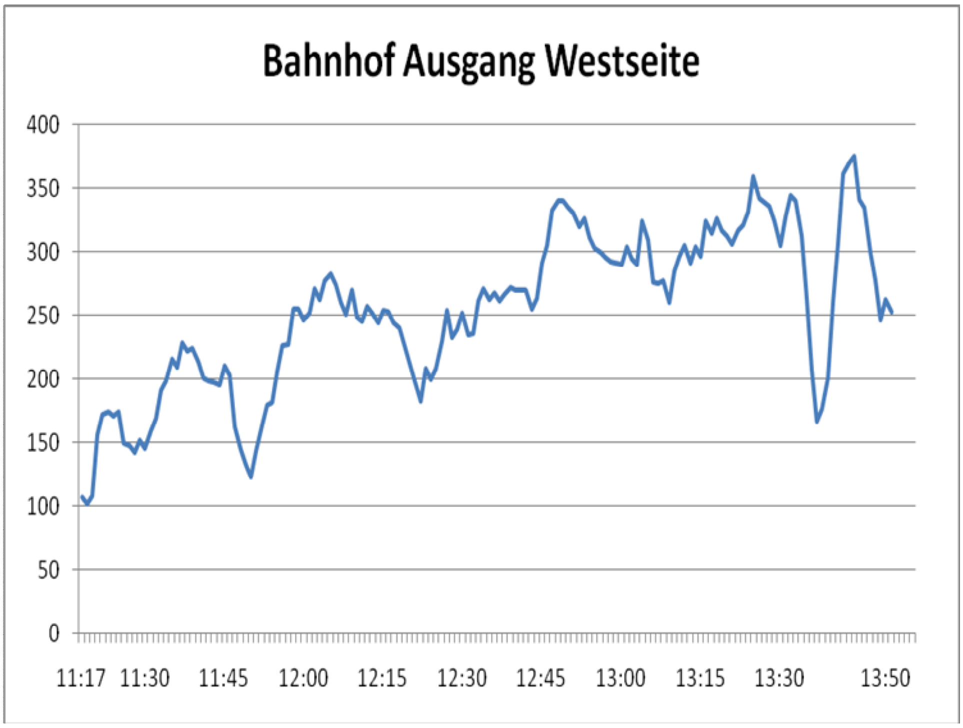


Figure 9: Pedestrian flow from the station towards town. First observation.

The average pedestrian flow increased steadily from the beginning of recording up to the start of the event at 14.00, and at 12.45 a more or less constant value was reached. The small fluctuations are no doubt down to the frequency of trains. Rather conspicuous are the two dips at 11.50 and 13.40 in which the stream of people dropped by half. The cause for this is not yet known but must lie within the system itself.

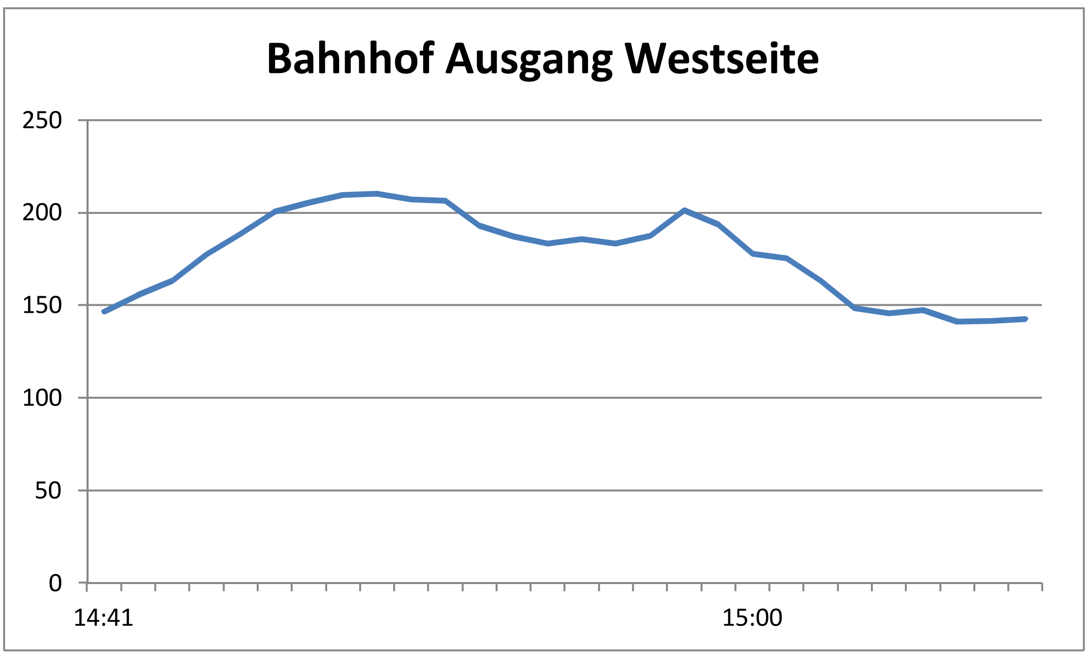


Figure 10: Pedestrian flow from the station towards town. Second observation.

The relatively steady stream of visitors is quite clear here. What differentiates it from the pedestrian flow in figure 9 however is the significantly lower average pedestrian flow value. While the average value in the first observation was around 300 people per minute, the average for this second observation was around 175 people. There must be a reason for this irregularity too. The observation log reports that at 14.40: "the west section of the station is completely full. For the time being those arriving are being led out of the station through the east side." The pedestrian flow analysis thus recognises external changes of circumstance and can account for these.

Visitors were then led to the event grounds through a west tunnel and an east tunnel. The tunnels were each equipped with security gates at the entrance, and although there were 16 gates available in all, from 13.00 only 6 were actually open.

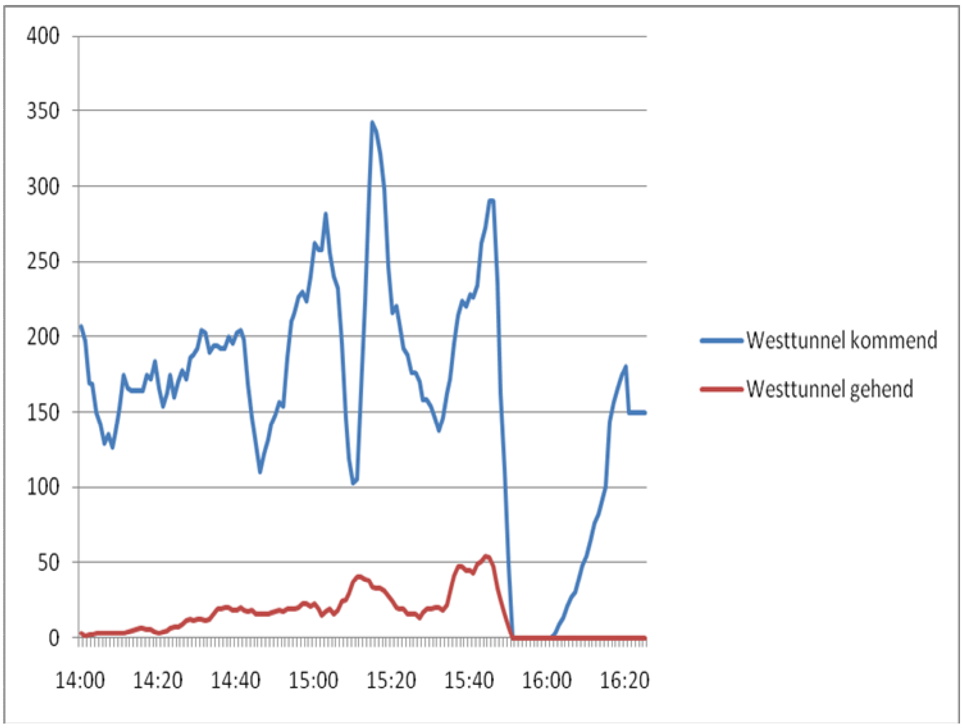


Figure 11: Pedestrian flow through the west tunnel to the event ground. (Blue = coming)

The abrupt break in pedestrian flow at 15.50 is clearly due to a police block. But even before this happens numerous irregularities can be seen in the pedestrian flow, all of which have different causes. At 14.47, for example, a police car travels from the city on to the grounds. Its crossing does not create problems but means that during this time around 400 fewer visitors are able to pass through the tunnel. 400 fewer people means an increased tailback at the gates over a space of around 200 m^2 (assuming a value of 2 p/m^2). The temporary dip at 15.15 can be traced back to the crowd manager's instruction that further gates be closed. Such an intervention was temporary though and was followed by a peak in attendees, as the gates appear to have been breached. All in all the crowd management is very variable. The pedestrian flow of going people increased continually.

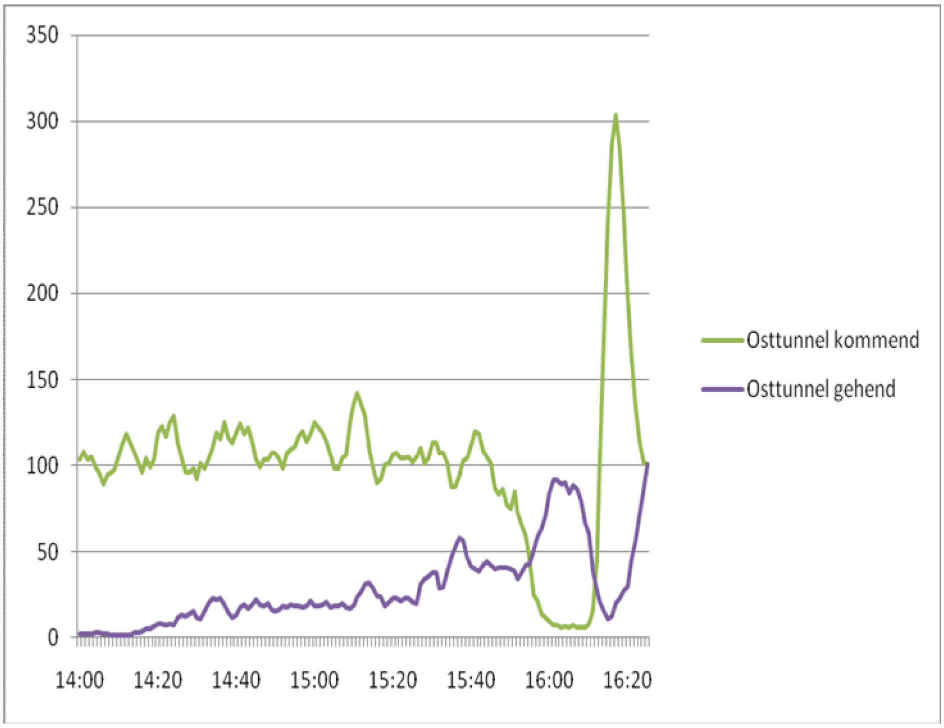


Figure 12: Pedestrian flow through the east tunnel to the event grounds.

In contrast to the west tunnel, the flow of people in the east tunnel was for the most part constant. The stream of visitors leaving was similarly steady and reached a peak at 15.14. This was when the change of guards took place at the ramp. A number of visitors used the departing vehicles to leave the grounds by walking behind them. The reason for the peak at 16.00 is that visitors leaving the grounds were still able to walk through the east tunnel at this point. The police block was located here at the tunnel entrance. Thus there was sufficient room in the tunnel for departing visitors.

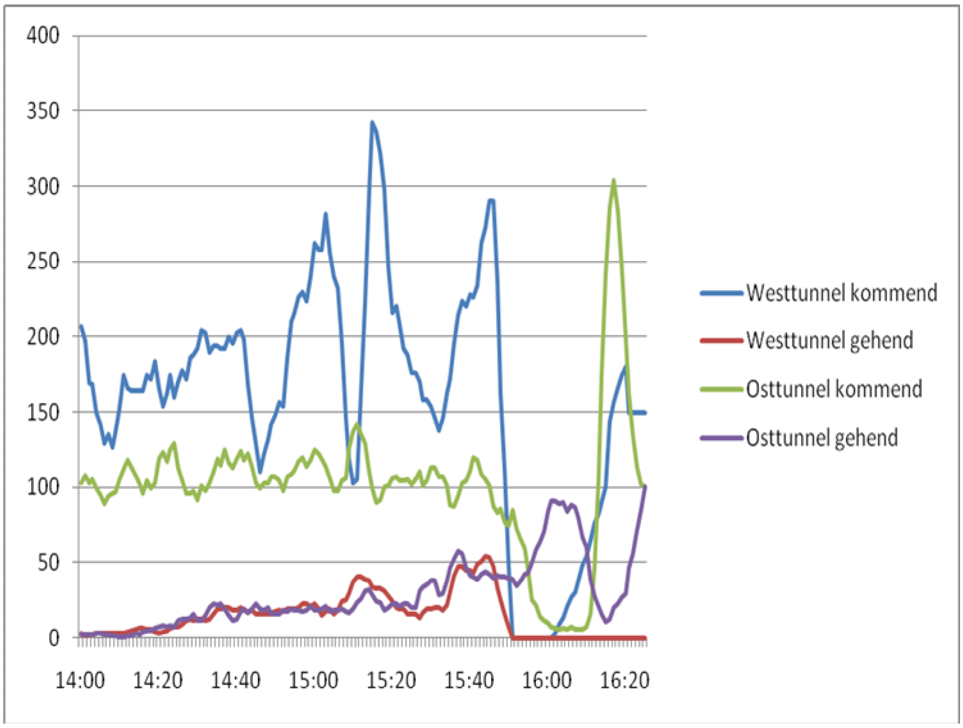


Figure 13: Pedestrian flow through the tunnels to the event grounds.

If we compare the data from both tunnels we can ascertain that the stewards at the security gates worked differently from each other. Those at the east side admitted people steadily at a relatively low flow rate. The stewards on the western side were not able to ensure the same – a steady flow of pedestrians did not come about. Looking at the pedestrian flows from the west side of the station and from the western tunnel it must be said that no coordinated crowd management or crowd control system ever existed for the whole event location (i.e. station, city, grounds). At no later than 15.00 the flow of visitors from the station was bigger than the flows that were being admitted to the grounds. This inevitably led to extensive congestion in the city area, which, in turn, brings with it potential violence and critical situations.

Fundamental to event planning, especially those that extend over a larger area, is a consideration of pedestrian flows over the whole grounds. Concentrating exclusively on the core areas of the grounds leads to misjudgements. At the same time pedestrian flows are highly dynamic processes. Circumstances at one observation point can change significantly within a short period of time. A static observation of attendees with a statement such as: “Area x has reached a capacity of 80%” does not help to produce a reaction within an appropriate time frame. A dynamic observation with a statement like: “at point x a pedestrian flow of 400 people/minute can be expected in 30 minutes” enables a prompt reaction by stewards and emergency units.

6. The “Four-Tier Model” of congestion

There are various theories regarding the formation of congestion. In most approaches experiments show the crowd density within the pedestrian flow constantly rising until congestion is formed. This is because of a continuously diminishing stride length in those walking, which ultimately makes it impossible to move further forward. These approaches thus assume that congestion will occur in pedestrian flows with a crowd density of 5 p/m^2. However, a density such as this could only be observed at events during pressure waves in crowds.

There is a preliminary stage for pedestrian flows of up to 1.5 p/m^2 in which no congestion risk exists. People demonstrate clear group behaviour, meaning that the various group sizes move at various speeds. Beyond a density of 1.5 p/m^2 the speeds of individual groups become increasingly similar to each other until they are roughly the same.

The first stage of congestion is achieved at a crowd density of approx. 2 p/m^2. Individual group behaviour has now dissipated and all are moving at the same speed. Each individual no longer has freedom of movement, meaning their actions are determined by those of the group as a whole. This stage can be recognised by the group’s walking pattern. A ‘swaying step’ is adopted, i.e. the upper body sways from right to left and the feet are no longer exclusively set in the direction of travel, meaning that the gait now incorporates sideways movements.

Unlike the first stage, disruptions occur at the second stage of congestion in a crowd density of 2 to 3 p/m^2. Disruptions include all incidents that cause the pedestrian flow to stop for a short time. The following picture shows one example, in which three people move across the pedestrian flow and in doing so bring about a short interruption to the stream of people.

Picture 11: Disruption in pedestrian flow.

There are various types of disruption possible, such as people stopping in order to communicate with members of other groups. An object can be dropped on the ground or a loudspeaker announcement can, for example, attract interest towards an attraction on the side of the pathway.

Individuals standing at the side of the pathway represent a further disruption and potential for congestion. An event that was observed over two days serves as an example of this.

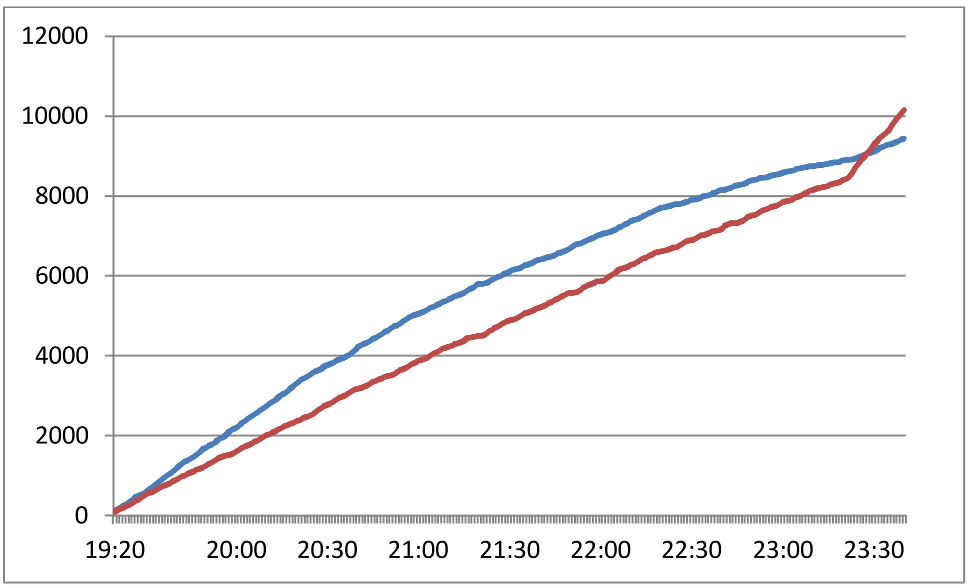


Figure 14: Total number of visitors arriving (blue) and leaving (red) over a period of time (day 1).

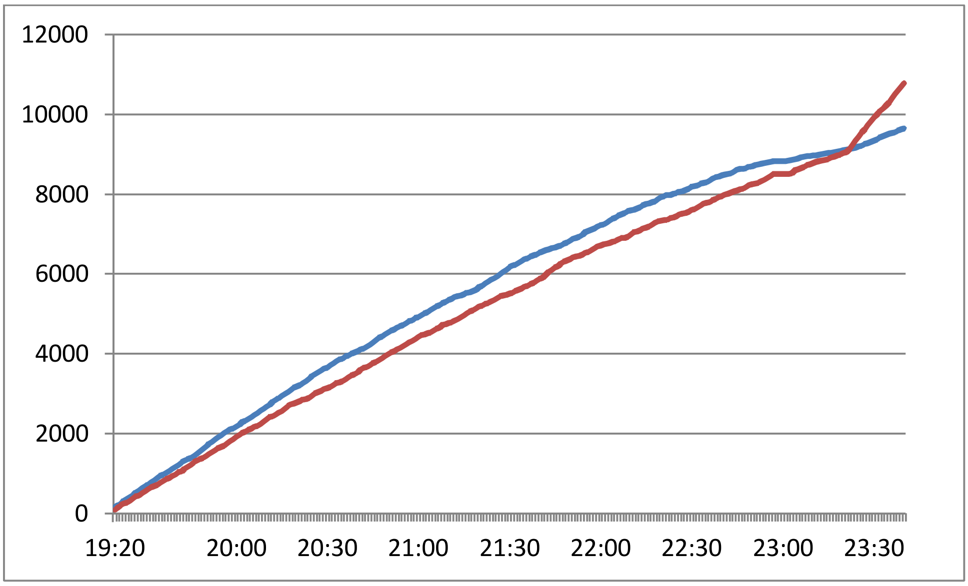


Figure 15: Total number of visitors arriving (blue) and leaving (red) over a period of time (day 2).

On both days around 9,500 people traverse the measured area towards the event over a period of 4 hours, and during this time around 10,500 people leave the grounds (attendees were already present before 19.00). In this sense the event is essentially the same on both days. Yet on one day there were only minor disruptions in the stream of people, whereas on the other day disruptions were extensive. The reason behind this is the time that visitors stayed in one place and the time they arrived on the place of the event. The discrepancy between arriving and departing attendees can be easily established in both pedestrian flows. These differences are presented in the following picture. On one day the grounds held a maximum of around 1,300 (predominantly standing) visitors, but only 500 on the other day.

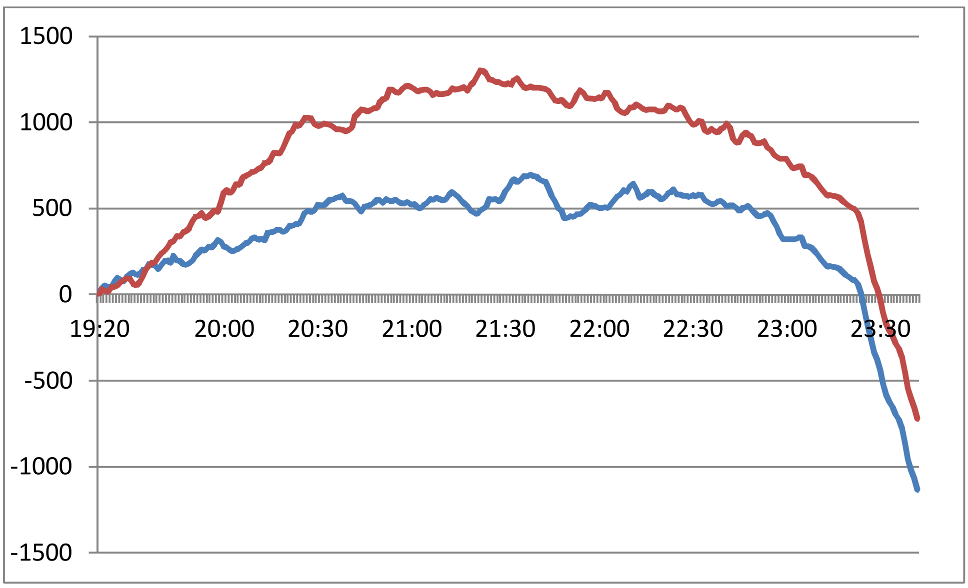


Figure 16: Discrepancies in arriving and leaving visitors.

These visitors bring about a narrowing of the available walkway, and therefore encourage congestion to build. The available walkways and their capacity are of significance here. The capacities can be calculated using a simple formula (19).

Visitors per minute = time (in seconds) * Width of walkway (m) * People per m2 * Average walking speed.

If we apply the values from Table 1 for crowd density and average walking speed then we obtain the following diagram, using, for example, a path-width of 5 meters.

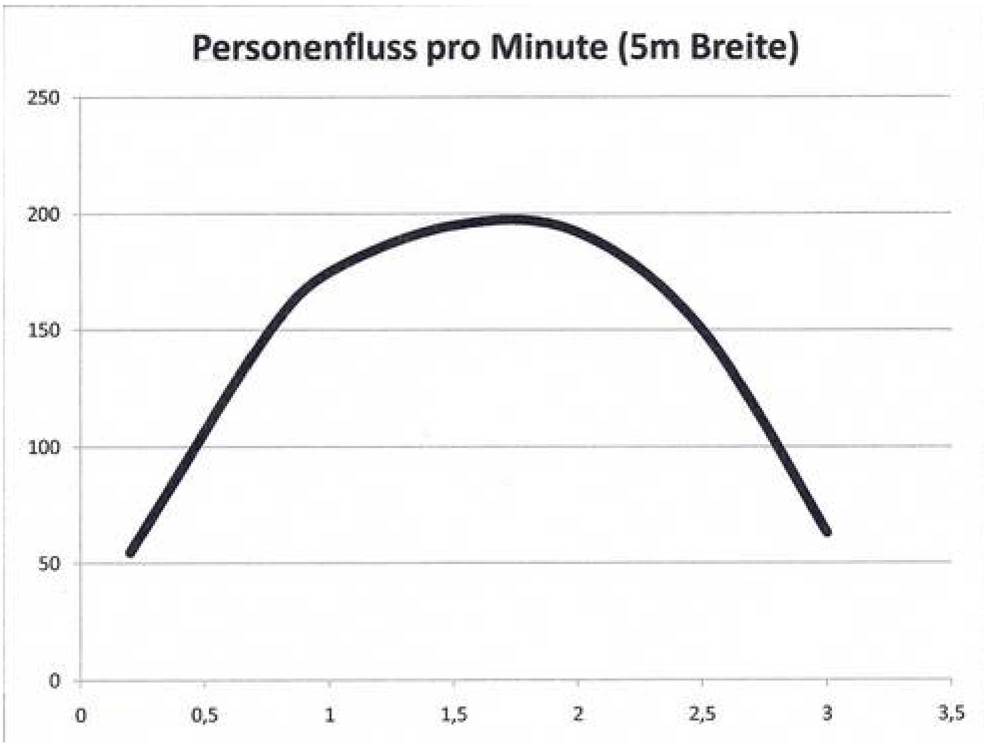


Figure 17: Pedestrian stream per minute for various crowd densities crossing a measurement line of 5 m lenght

Observations were made of walking speeds in the pedestrian stream as they occur during the normal running of an event. Higher walking speeds can be observed during an evacuation. Capacities would also increase in this case. During an event, then, a path with a width of 5 metres can contain a maximum pedestrian stream of approx. 200 people/minute, with a constant capacity across a relatively wide crowd density of between 1 to 2 P/m^2. So if a maximum value of 200 people/minute is recorded in a pedestrian flow analysis, then the available path-width on the grounds should measure at least 5 meters. During evacuation, the capacity of the walkway can almost double (approx. 350 p/min). Those attendees shown in the example who are standing and remaining in the area, reduce the available area of walkway, thereby increasing the density and ultimately encouraging a build-up of congestion.

The third stage of congestion is the partial standstill of the pedestrian flow. In itself this does not signify any risk to attendees: at various events congestion is wholly sought after and is part of the experience of the event (the implication being otherwise that the event was not well-attended). This congestion is characterised by duration (approx. 1-5 minutes) and by a standing crowd density of 3-5 p/m^2, allowing for a socially acceptable distance between people. This blockage then disperses once more. This kind of congestion forms mostly at the site of attractions or is brought about by them. The attraction itself can be any kind of ‘act’, for example a new ride at the fairground, a band at a town fair, or even a beer stand at which drinks are being sold near the walkway. Crowd migration can also be brought about when attractions cease. This is the case when the attention is turned to something else. A band takes a break, for example, or the lighting on the grounds is changed. If, for noise control purposes, the volume has to be adjusted after a certain time of day, then the potential for crowd migration must be observed in the safety model.

The following picture shows how big a stationary crowd of people can become at an attraction and what kind of influence it exerts on the available walkway.

Picture 12: Stationary crowd at a drinks stand (above the line).

Whether people accept such congestion depends firstly on the duration of the blockage and secondly quite fundamentally on the information available. For example, can those waiting clearly see the cause of the congestion, or are there other people in the way, or is it possible to make small movements forward.

If these basic conditions can no longer be adhered to, or if the congestion time exceeds the accepted time period, then this leads to the fourth stage – the critical congestion stage. Typical features in the pedestrian flow analysis are anticyclical pedestrian flows of arriving and departing people, meaning that people are either able to enter the grounds *or* leave them. The grounds are basically overcrowded. The next picture gives an example of this kind of pedestrian flow.

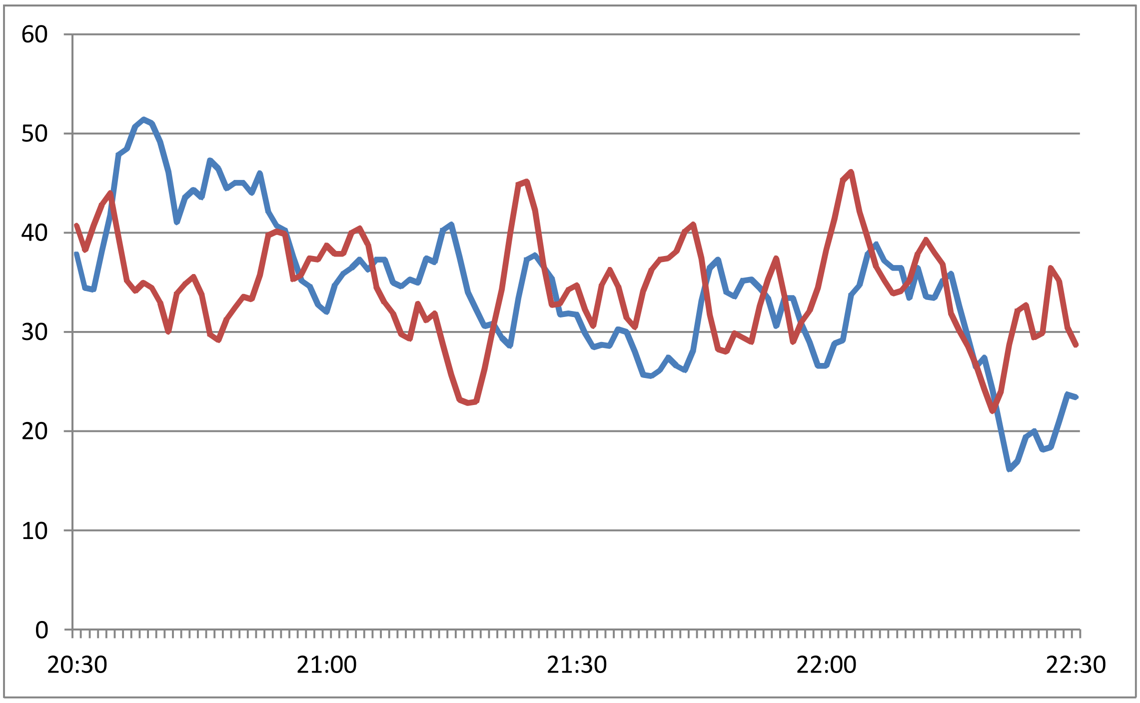


Figure 18: Anticyclical stream of people leaving and arriving. (Persons per minute)

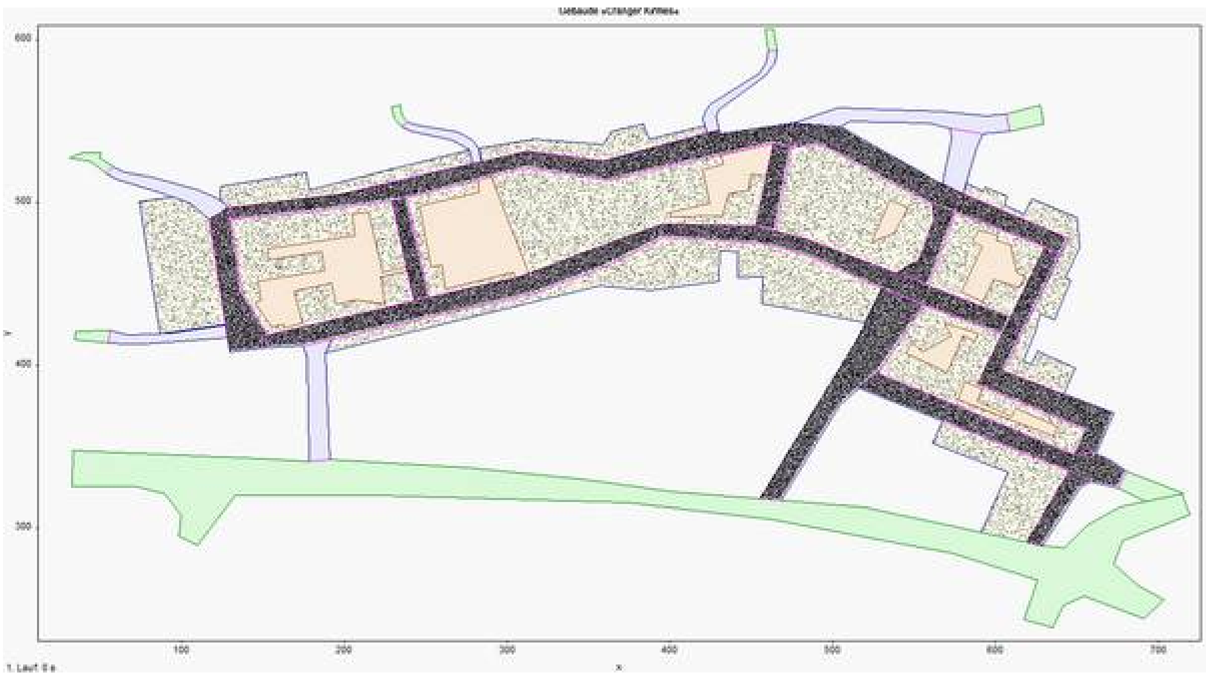
The following series of pictures illustrates what can happen in such situations. The arrow points to someone who is holding a beer mug up in the air. At first the person moves forward up to a point. Then a wave of people pushes in, which cannot be stopped or avoided. As a result of this the person is pushed backwards. If someone stumbles in a situation such as this, then it is highly likely that this will result in more people falling over and trampled on. The pictures show that the crowd density in the wave of people leaving the grounds is already at 6 p/m^2. The flow of people also shows distinct pressure waves.

Picture 13: Involuntary movement of an attendee through the counter flow.

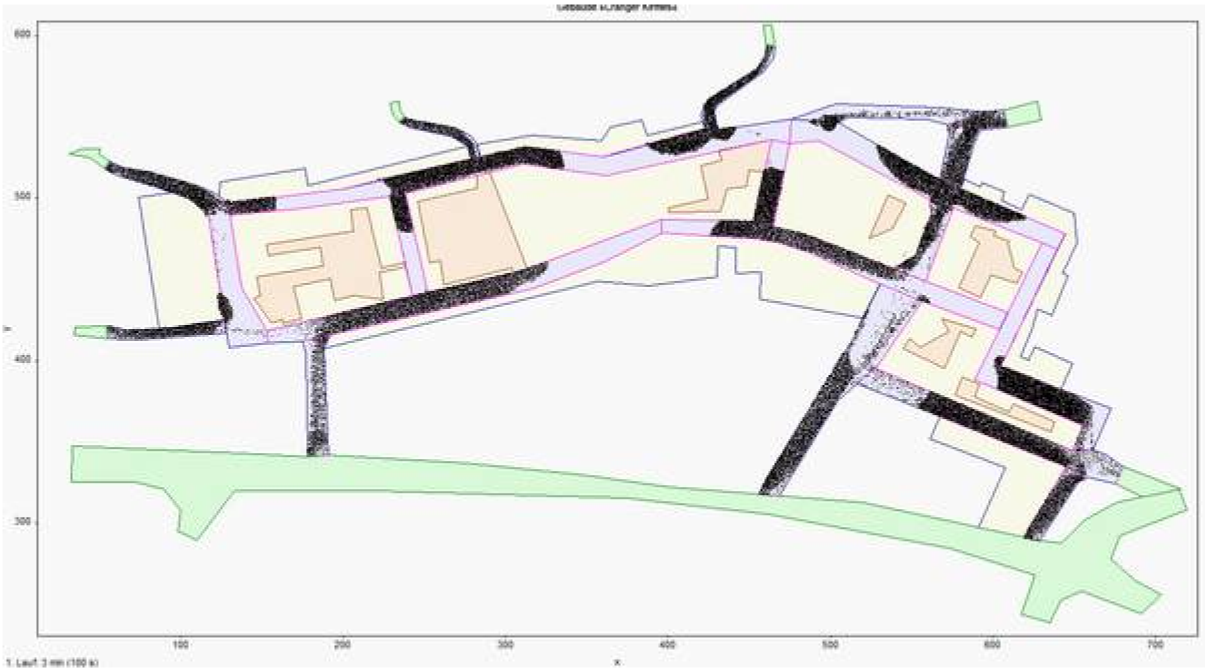
7. Pedestrian flow analyses with simulation models

The conclusions developed in sections 5 and 6 are supported by corresponding simulation calculations. For this it is necessary to implement so-called ‘microscopic evacuation models’ (also known as ‘individual models’) which describe the movements of individual people. Only by doing this can an analysis be made of situations that lead to increased crowd densities, whilst taking into consideration relevant structural environmental influences, individual features and behaviour (body size, set targets, group formation) as well as, where appropriate, organisational measures (instructions, mobile barriers etc.).

Therefore, in the context of the research project “Risks Associated with Major Public Events – Planning, Assessment, EVAcuation and Rescue Concepts (EVA),” simulation calculations with the pedestrian flow model ASERI were undertaken for a few of the events documented here. These include the well-attended, trouble-free occasions as well as hypothetical emergency situations with subsequent (partial) clearance of the affected grounds. Both of the following images are exemplary of an evacuation scenario at the Cranger Funfair. At the start there are 55,000 people on the event grounds (picture 14). Five minutes after the start of evacuation, dense pedestrian flows have formed on the streets leading away from the event grounds.



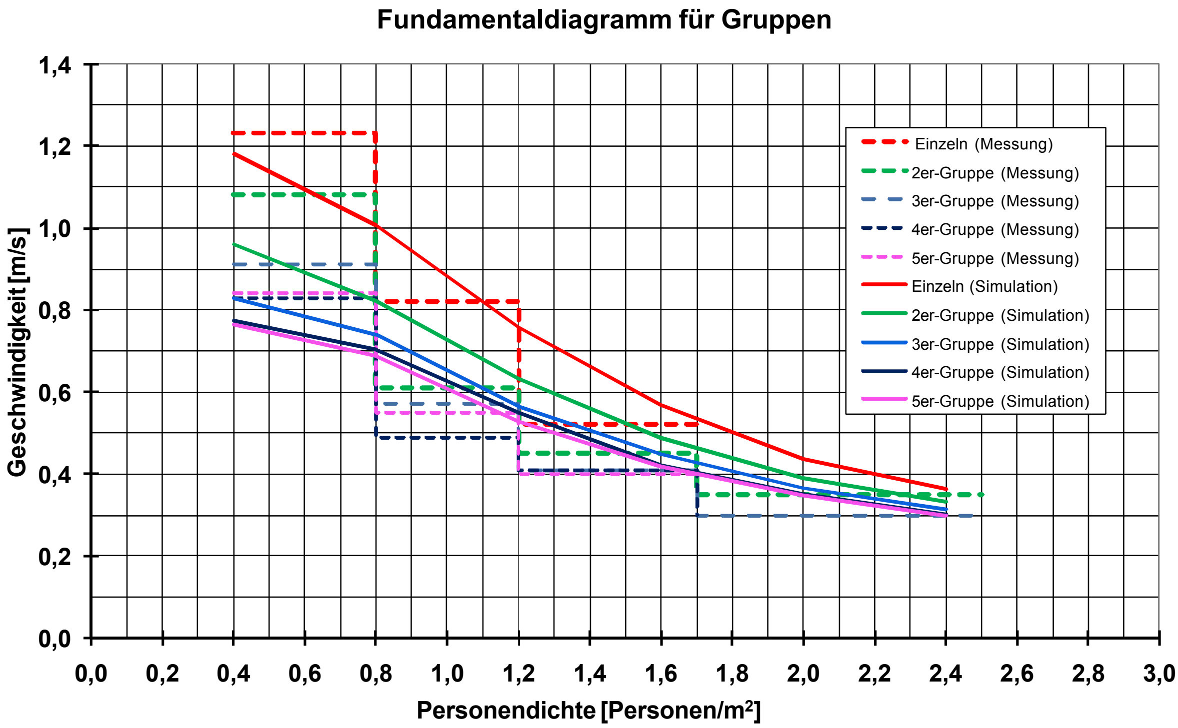
Picture 14: 55,000 people distributed around the grounds of the Cranger Funfair



Picture 15: Densification of pedestrian flows on the streets leading away from the events grounds, 5 minutes after the start of evacuation.

The issues of group formations as described in sections 5 and 6, their influence on pedestrian flows, and the phenomenon of the counter flow were also explored in the development of the ASERI pedestrian flow and evacuation model within the EVA project. Amongst other things it was possible, through numerical simulations, to confirm the importance of effective walking pace as described in section 5, or of the pedestrian stream on the person density - the so-called ‘Fundamental Diagram’ (Picture 16).

The types of social relations between group members are of significance when determining the degree of group cohesion. The ASERI model includes the following types of relations: mutually positive (friends, couples), mutually negative, asymmetrical (e.g. parents – child or superior – inferior) and neutral. The type of relationship determines the interpersonal distance that will be tolerated before the group disintegrates or splits up. A good accordance with empirical data was achieved for a relationship pattern of 50% mutually positive and 50% neutral correlation.



Picture 16: Fundamental diagram (simulation and observation) for various group sizes.

In the planning and preparation phase of an event simulation models can offer an important contribution to recognising and avoiding bottleneck and congestion situations, through assessing the risk potential of narrow points and through improving pedestrian flows in terms of efficient crowd management. The use of on-site simulation programmes which take place during an event and continuously update projections using recorded data is still in the research and development phase at this time.

8. Behaviour of rescue workers in pedestrian flows

A bachelor thesis by Knopp (12) – from which the following is cited – examines under what conditions a third party can reach people in crowds in a medical emergency as quickly as possible and without risk.

The literature provides details of maximum walking speeds in various crowd densities. According to Weidmann, a density of 1.75 p/m^2 produces a maximum speed of 0.7 m/s. Fruin says that this speed is also possible at a density of 2.04 p/m^2 (13). The behaviour of pedestrians in a crowd is, however, different from that of a rescue team. Pedestrians have a tendency to avoid physical contact with others for as long as possible. A rescue team, on the other hand, will create space for themselves if necessary. They require more space because they bring equipment with them (emergency rucksack, possibly a stretcher).

Recordings were carried out on the last Monday of 'Karneval' in Cologne in 2010 to analyse the speed of a rescue team. To determine the speed, a three-man rescue team equipped with emergency bag traversed crowds of people; the distance was then measured in relation to the time taken. The speed of the rescue team was hereby calculated. In addition, the crowd density was gauged in order to make a statement about the speed in relation to crowd density. It was possible to move through the crowd at a density of 1.5-2 p/m^2 without difficulty. One reason for the easy progression is that additional pedestrian flows had formed in the rescue team's direction of travel. Moving forwards was more difficult in higher crowd densities and it was impossible to avoid contact with other people. The following table lists the results of the measurements.

Distance (m)	Duration (Min)	Speed (m/s)	Density (P/m^2)
120	2:36	0,80	1,5 – 2,0
120	4:12	0,48	2,0 – 3,0
110	4:36	0,40	2,0 – 3,0
100	4:54	0,34	> 3,0

Table 2: Rescue team speed depending on crowd density.

In most cases the public quickly made space for the rescue teams, making progression through the crowd speedier. If a stationary crowd density of 2 p/m^2 is assumed when calculating the size of the guarded area for development planning purposes, then this results in a rescue team speed of 0.77 m/s or 46 m/min. If the crowd density for a more compacted audience is 3 p/m^2, then the rescue team will reach a speed of 0.42 m/s, or 25 m/min.

If a crowd density of 4 p/m^2 is assumed for highly compacted audiences, this results in a maximum speed of 0.27 m/s or 16 m/min for the rescue team.

Taking the recorded data from the Cranger Funfair as a basis we see a rescue team speed of approx. 0.35 to 0.40 m/s or 20 to 25 m/min within a moving group of people.

Given that a relatively high crowd density does not consistently occur over a long distance, response times and accessible distances can be calculated at a value of 25 meters per minute.

Emergency vehicles travel without problem through crowds of up to 1 p/m^2 at speeds of between 6 and 10 km/h or 100 to 170 m/min. Numerous people use the space behind the moving vehicle in order to increase their own walking speed. At a crowd density of approx. 1.5 p/m^2 the speed is still around 3.5 km/h or 60 m/min. When the crowd density goes beyond around 1.5 p/m^2 an emergency vehicle will advance more slowly than a rescue team. In addition and according to the type of event, the emergency vehicle poses a potential risk to those attendees who are under the influence of alcohol. Beyond this crowd density there is no advantage to using an emergency or police vehicle over using a team on foot.

9. Assessing first aid services and rescue service reinforcements

The following observations are taken from a publication (Knopp, P and Schmidt, J.) (14) from the vfdb homepage. The calculations of examples can also be found here. The software for the Cologne Algorithm is also available here as a free download.
http://www.vfdb.de/Veroeffentlichungen.159.0.html.

In order to carry out an assessment of first aid and rescue service provision at a major event it makes sense to use an algorithm. Algorithms and their associated checklists offer the advantage of standardising procedure as well as establishing a minimum level and minimum quality in planning.

The following will compare the Cologne Algorithm (published in 2006) (16) and the algorithm according to Klaus Maurer (published in 1994, revised in 1999) (17).

Algorithm according to Klaus Maurer

The most prevalent and well-known publication is Klaus Maurer's algorithm, which Maurer developed in the 1990s and is based on a points system. With the help of specific supporting tables, the user is able to calculate an overall risk for an event by using a score system. In the following the necessary requirements for the medical services can be deduced using another table (15, 18).

Klaus Maurer categorises the risk factors of major events in the following five groups:

- Number of people (permitted and actual)
- The event location in enclosed spaces or outdoors
- The potential for risk according to the type of event
- Participation of well-known figures, with security precautions
- Consideration for police intelligence (17)

The permitted and actual attendances are fundamental factors in the level of risk created by a major event. The risk is described by judging the maximum number of visitors permitted, something that depends on the event location. In assessing risk by using the event space the maximum number of people permitted is calculated by looking at structural requirements, seating, permitted sitting and standing areas, or alternatively with 4 people per square meter in outside areas. In the following an allocation of points is given. The points are assigned here as follows:

Up to 500 people	1 point
Up to 1,000 people	2 points
Up to 1,500 people	3 points
Up to 3,000 people	4 points
Up to 6,000 people	5 points
Up to 10,000 people	6 points
Up to 20,000 people	7 points

For each additional 10,000 people the points score increases by 1 point. If the event takes place in a building then the calculated points will be doubled.

The risk, which itself arises from the number of people present, is described through calculating the number of actual or expected attendees. This attendance can be estimated by looking at: the number of tickets sold, figures based on past experience, or the available space (there are 2 people per square meter here). One point is assigned for every 500 attendees.

In order to then adapt the risk potential to the type of event taking place, an assessment factor is assigned, which adjusts the risk to the particular event through multiplying this factor.
For the attendance of prominent figures with additional security precautions, a score of 10 points will be assigned for every 5 people.
Should additional police intelligence be available concerning the propensity to violence amongst attendees then an additional 10 points will once again be added (17).

After all risk factors are compiled then the overall risk of the event can be calculated. The necessary rescue services will subsequently be evaluated against the overall risk using an overview.

The advantages of Klaus Maurer's algorithm are that this algorithm is easy to use, verifiable and reproducible. However, the algorithm is inflexible, making it difficult to incorporate individual experience and therefore leading to uncertainties in experienced users.

The spatial dimensions of an event cannot be incorporated into the calculation, making the planning of parades or processions more difficult. Furthermore spatial factors such as sections of buildings are not taken into consideration, meaning that the necessary reinforcement of medical services is not being taken into account (15).

Cologne Algorithm

The Cologne Algorithm builds on the method of requirements planning, which is based on the three steps of establishing safety objectives, development planning (security areas) and reinforcement planning (security). Reinforcement planning is based on empirical data as it is in Klaus Maurer's algorithm and is therefore easier to use than the normal statistical rescue services' requirements planning calculation.

In order to be able to estimate the frequency of medical and emergency provision it is assumed in the Cologne Algorithm that on average two medical assistances will be necessary for every 10 hours of event time and every 1,000 attendees (2% per 10 hours). One fifth of these cases requires emergency rescue to avoid potentially serious damage to health (0.4% per 10 hours). Of these emergency cases 10% require emergency medical care to prevent life-threatening illnesses (0.04% per 10 hours).

These guidelines were calculated using major public events (such as carnivals, the Love Parade, church congresses etc) and involve an typical engineering safety margin. As with Klaus Maurer's algorithm these guidelines can be adjusted to the event and situation by multiplying risk factors. However, the risk factors have been expanded to include consideration of weather conditions, mass phenomena, and overcrowding. It is also easy to incorporate individual experiences of prior events here.

Determining a safety objective should ensure that a maximum access time is not exceeded in emergencies. In Cologne the maximum time for a paramedic and assistant to reach the location should be 5 minutes (apart from the maximum response time of corresponding ambulance regulations). Doing this guarantees that basic life-saving measures are taken within a given response time and ensures the efficiency of the rescue services through medical teams treating minor illnesses and injuries.

The following two methods will be put into use in the Cologne Algorithm. Firstly a risk assessment is carried out, which is based on statistical research. Secondly prevention planning comes. This has its origins in engineering methods of requirements planning and is a simple means of determining the amount of parallel services. As mentioned above, two further steps in development planning (protection area/response time model) and reinforcement planning (frequency model) occur after the establishment of safety objectives. The following steps are therefore necessary for thorough planning:

1. Necessity test
2. Development planning: response time model
3. Reinforcement planning: frequency model
4. Irregularities
5. Management organisation

10. Examples of use

Outdoor events often involve security gates, which serve to count the number of people, thus limiting attendee numbers; or the gates are there to assist in checking baggage and tickets. In most cases these gates have a width of 60 cm (sometimes 50 cm). The number of gates and security staff occupying them has a significant effect in keeping disturbance to a minimum on admission to the event grounds.

Theoretically a security gate has a maximum output of approx. 4,000 people per hour (p/h). Readings from events are rarely available or published. The previously mentioned ticket machine in the football stadium had a maximum output of 1,200 p/h. For a calculation taking into consideration security staff it can be assumed that admissions will be reduced to 25%, meaning the output sinks to 1,000 p/h. This capacity can be increased by boosting staff numbers. At large events with numerous entrances a steward can redirect people to available gates using a megaphone. Two rows of stewards can be placed at the gates. This means that male stewards, for example, check only male attendees and their baggage directly at the entrance. Female attendees pass through, and after a certain distance are checked by female staff.

The number of security gates must always be consistent with the number of people expected in order to prevent waiting times of more than a few minutes. Should visitor numbers be higher than expected for a particular period then appropriate alternative areas should be made available in front of the security gates. It is also important to maintain communication with attendees. Announcements such as “the waiting time is now approximately 15 minutes” provide information and thus help avoid crowding.

At some events, such as public screenings of football games, the permitted crowd density of 2 p/m^2 can sometimes be exceeded even though a significant number of people are not yet through security. Essentially situations like this should be avoided by, for example, public transport announcements made in advance, advising, “Area X is already full. No further people can be permitted inside the area.” One difficulty with those waiting to be allowed in is that the public viewing area looks empty in places. The people inside the area tend to position themselves at the screen, making the areas behind appear fairly empty. This leads to unrest amongst those waiting for entry. The risk assessment must then determine which poses the lesser risk: crowding in front of the security gates, or a higher crowd density in the grounds. Strictly speaking the viewing grounds can hold a crowd density of 2.5 p/m^2 without any problems (depending on the width of escape and rescue routes). In this case allowing more people to be gradually admitted to the grounds would be the safest solution.

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Picture verification:

Picture 1, Quelle Feuerwehr Köln, bearbeitet durch vfdb

Picture 2, Quelle Feuerwehr Köln, bearbeitet durch vfdb

Picture 3, Quelle vfdb

Picture 4, Quelle vfdb

Picture 5, Quelle Feuerwehr Dortmund, bearbeitet durch vfdb

Picture 6, Videomitschnitt Loveparade 2011, bearbeitet durch FhG-ICT

Picture 7, Quelle vfdb

Picture 8, Quelle vfdb

Picture 9 und 10, Quelle vfdb

Picture 11, Quelle vfdb

Picture 12, Quelle vfdb

Picture 13, Quelle vfdb