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Abstract

This study covers data from 18 evacuation situations in different building types ranging from a single hospital ward to a stadium. Twelve of the cases were ordinary evacuation drills, four were real fire alarms and the remaining two were normal but congested situations. The data were collected in Finland, starting in autumn 2007 and finishing in autumn 2010. The data gathered are designed for the buildings' safety and security staff, the fire authorities, the fire safety engineers and the model developers.

The results obtained from the evacuation situations are represented using quantitative and general approaches to link similar data together. The original data from the single evacuation cases are also represented individually.

Several distributions were formed to quantify different time intervals of the whole evacuation process. The distributions were pre-movement times, total evacuation times, and walking speeds on smooth and inclined surfaces. The congested situations were investigated using correlations between the walking speeds and crowd densities.

In the general part, the alarm systems, the pre-evacuation actions and the differences between the real fire alarms and the drills were monitored to reach conclusions about the reactions of the people and the safety staff. The behavioural aspects of humans were also analysed. The evacuation phase was investigated in terms of the exit routes and the people's door selection routines.

Preface

This report was conducted in the project 'Data collection and analysis of evacuation situations' (*Koeaineiston kerääminen ja analysointi poistumistilanteista – EVACDATA*). The purpose of this work was to produce empirical data on evacuation situations in Finland in terms of both quantitative and qualitative aspects. The gathered data can be used in work on the buildings' safety and by the security staff, fire authorities, fire safety engineers and model developers.

This work has been funded by the Finnish Fire Protection Fund, the Ministry of the Environment, the Ministry of the Interior, the Finnish Work Environment Fund and VTT Technical Research Centre of Finland. The project steering group had members from the above-mentioned funding and research organisations as well as from the following rescue service regions: Helsinki, Kanta-Häme, Keski-Uusimaa, Länsi-Uusimaa, Pohjanmaa, Pirkanmaa and Varsinais-Suomi. The support from these rescue service regions was essential to the successful implementation of the evacuation experiments, and it is therefore greatly acknowledged.

The cooperation with the various organisations that have been involved in the planning and execution phases of the observed fire drills in the different locations, and the parties that have been kind enough to provide recordings from surveillance camera systems after real evacuation events are also acknowledged.

Contents

Appendix A: Description of evacuation drills and real fire alarms

1. Introduction

An evacuation situation in any building involves many risks. The building's geometry and the behaviour and possible disabilities of the evacuees all have an effect on the success of the evacuation. The use of experimental data is a good objective way of attempting to characterise the evacuation process.

A modern construction design in the area of fire safety engineering needs developed tools to determine the safety level of different solutions quantitatively. One important question is: Do the people have enough time to evacuate before lethal conditions occur inside the building? The performance-based approach, which enables the design of large and complex solutions, relies strongly on numerical modelling of the fire and evacuation processes. As the tools, e.g., computational models, for these analyses are developed, the information on evacuation situations is essential. The evaluations made through analyses of fire safety engineering need information about the methods used, and they have to be valid.

Experimental data from real evacuation scenarios are hard to obtain, as real evacuation situations occur infrequently, and the amount of information from these events accumulates slowly. In addition, the quantitative parameters may be partially missing when the demand for analyses or assessments of the scenarios comes late. In the future, the saving of essential data in a specific database, case by case, would ease the work afterwards. The data from evacuation drills offer many more opportunities to monitor and observe both the qualitative and the quantitative reactions of evacuees. The controlled test series also offers favourable opportunities to test hypotheses that can arise during real fire alarms.

In this study, the experimental data on evacuation drills and real evacuation scenarios are gathered and analysed in terms of quantitative and general observations.

2. Experimental methods

The measurements of an evacuation situation can be made using several devices. In practice, the aim and hypothesis define the level of the selected instruments. The rough division of device types can also be performed when the amount of available installation time is known before the drill. The user also has to be aware of the differences and usability of a number of monitoring methods in different circumstances.

Before any evacuation experiment was carried out, the existence of this study was introduced to the persons responsible for the evacuation drill. The introduction letter included the background, aim of the study, timetable, control group involved in the study and confidential aspects. The first meetings, at which the exact plan and goals of the drill were specified, were held soon after the introduction.

2.1 Video cameras

The evacuation drills were monitored with digital video cameras and, in some cases, surveillance cameras. The recordings were later analysed in detail. In the case of a real fire alarm, recordings from the surveillance cameras installed in the building were used.

The number of cameras providing coverage of the main exits (not all exits), corridors and some specific areas, such as large open spaces, stairways, classrooms, etc., varied between three and six. The video cameras were compact and therefore quick to install at the venue. The cameras were either installed on top of objects or fastened to the ceiling so that the view was high enough not to be obstructed by the crowd. As the data storage medium of the cameras was a memory card, handling and editing was easier than for digital video cassettes.

The cameras have already been found to be very useful monitoring devices in a previous study carried out by Hostikka et al. (2007). Compared with, for example, the identification sensors, the video cameras are clearly more usable: sensors reveal nothing about the evacuees' social activity and other behavioural aspects during evacuation. In the analysing phase of the video records, the recognition of a single evacuee at different locations inside the building is usually the key to understanding and measuring different events. The post-processing of information obtained from videos includes several time-consuming manual processes however.

One clear advantage of video records is the audio track, which is usually missing in surveillance camera recordings. The audio track helps to fix the exact time of a fire alarm. Surveillance cameras within a particular building may have different time stamps because the cameras are running under different loops and servers that are not synchronised. Surveillance cameras with motion detecting programmes also produce some breaks that may disrupt the evaluation of the whole timeline.

2.2 Evaccounter

The people from the videos were counted using the Evaccounter developed by Hostikka et al. (2007). The Evaccounter is a MATLAB-based program that allows the exact times of different events shown in the video to be saved. This is done by recording the keyboard pressing times while the user watches the video. Quantities like flow rates through doorways, walking speeds and reaction times are the most typical measurements. The Evaccounter also allows events from slow motion videos to be counted. Figure 1 shows the user interface of the Evaccounter.

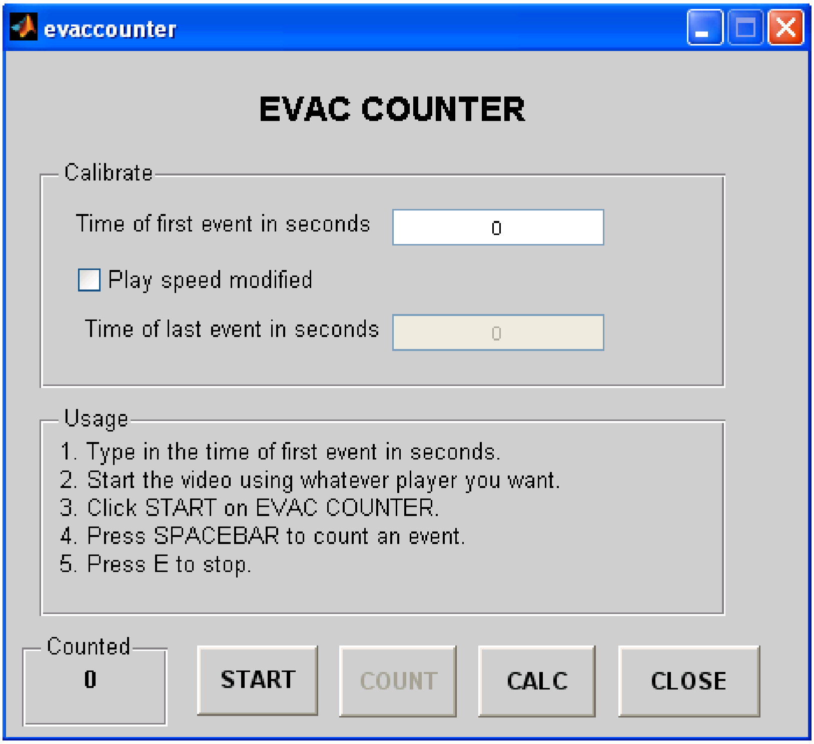

Figure 1. The user interface of the Evaccounter.

3. Evacuation drills and real fire alarms

The evacuation cases analysed in this study took place in Finland between the end of 2008 and the end of 2010. A couple of evacuation drills carried out in 2007 were also included. All the evacuation cases included in this study are listed in Table 1. The detailed descriptions of the evacuation cases are presented in Appendix A. The information on each evacuation case is presented in a similar form starting with the background of the evacuation situation and then showing the building description, results and observations. There are some exceptions in which there was little material from the evacuation scenario compared with the other cases. In all, the evacuation cases were diverse, ranging from an evacuation of a few patients from a hospital ward to thousands of evacuees in a stadium.

In all the cases, the results and observations that are shown protect the personal integrity of the individuals. This is done by not showing any photographs or screen capture photos of the evacuation situations. The building geometries are shown partially or with rough sketches.

Table 1. A list of the evacuation cases. The number of people is an approximation (i.e., not the number of people counted).

No.	Case	City	Date	No. of people	Building	Type
1	A	Helsinki	10/2007	800	college	drill
2	B	Helsinki	10/2007	200	college	drill
3	C	Espoo	8/2008	150	supermarket	real
4	D	Espoo	9/2008	30	supermarket	real
5	E	Espoo	10/2008	100	shopping centre	drill
6	F	Ylöjärvi	10/2008	500	compreh. school	real
7	G	Helsinki	11/2008	6	hospital	drill
8	H	Valkeakoski	12/2008	80	factory	drill
9	I	Helsinki	10/2008	300	three offices	drill
10	J	Mynämäki	11/2008	650	compreh. school	drill
11	N	Vaasa	4/2009	200	church	drill
12	O	Kerava	5/2009	200	factory	drill
13	Q	Tampere	10/2009	100	spec. school	drill
14	R	Helsinki	11/2009	hundreds	bus terminal	real
15	S	Espoo	1/2010	thousands	stadium	normal
16	T	Helsinki	2/2010	thousands	stadium	normal
17	U	Helsinki	4/2010	200	cinema	drill
18	V	Espoo	3/2010	100	door selection test	drill

4. Quantitative observations of evacuation situations

4.1 General

The evacuation cases all differed from each other by, at least, the geometry of the building and the number of people evacuating the building. Some similarities were nonetheless found in the type of person, the alarm method, building type, etc. The data that are similar and the results in this chapter are taken from the evacuation cases presented in Appendix A.

The evacuation process includes several series of events from the time of fire detection to the situation when the evacuation is complete. Figure 2 shows the whole evacuation process (Proulx, 2008). Each of the events has its own time intervals distributed over a range based on the responses of technical instruments or human actions. In this study, the latter is monitored in detail with a view to forming distributions that represent the events.

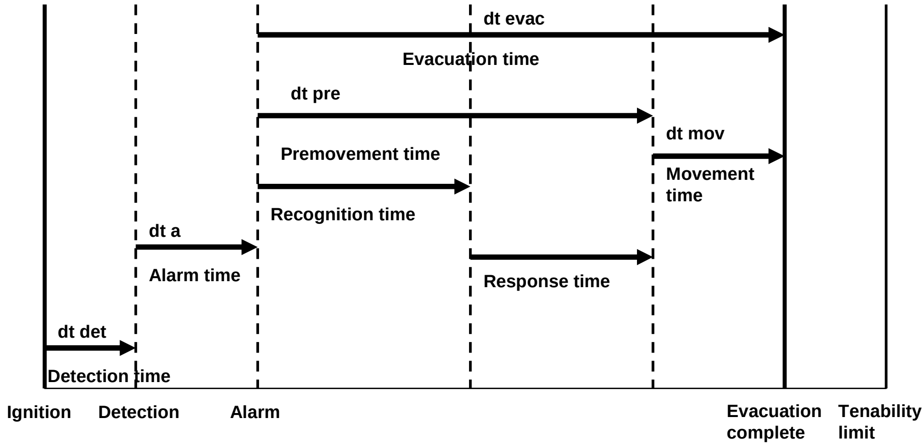

Figure 2. The evacuation process divided into detection, alarm, pre-movement and movement times (Proulx, 2008).

4.2 Pre-movement times

In this study, the pre-movement time means that the people have been alerted to a fire alarm or noticed the situation in some other way (smoke, alerted by others, etc.) and the time between the alarm and the movement phase is measured (see Figure 2). In this study, the typical reactions or responses to an alarm included changing the direction of movement, standing up and starting to move, collecting things, standing and watching what was happening, and dressing in outerwear.

Figure 3 shows different pre-movement time distributions in different open space scenarios. In Figure 3a, young school children (Case U) reacted by standing up and starting to move after being shown an evacuation video on a screen in a cinema. In Figure 3b, pupils inside a classroom heard the headmistress's evacuation announcement through a PA system and reacted by standing up and starting to move towards the door while the announcement was still running. In Figure 3c, the people inside a church (mostly students from an upper level comprehensive school) stood up while the priest gave the order to evacuate.

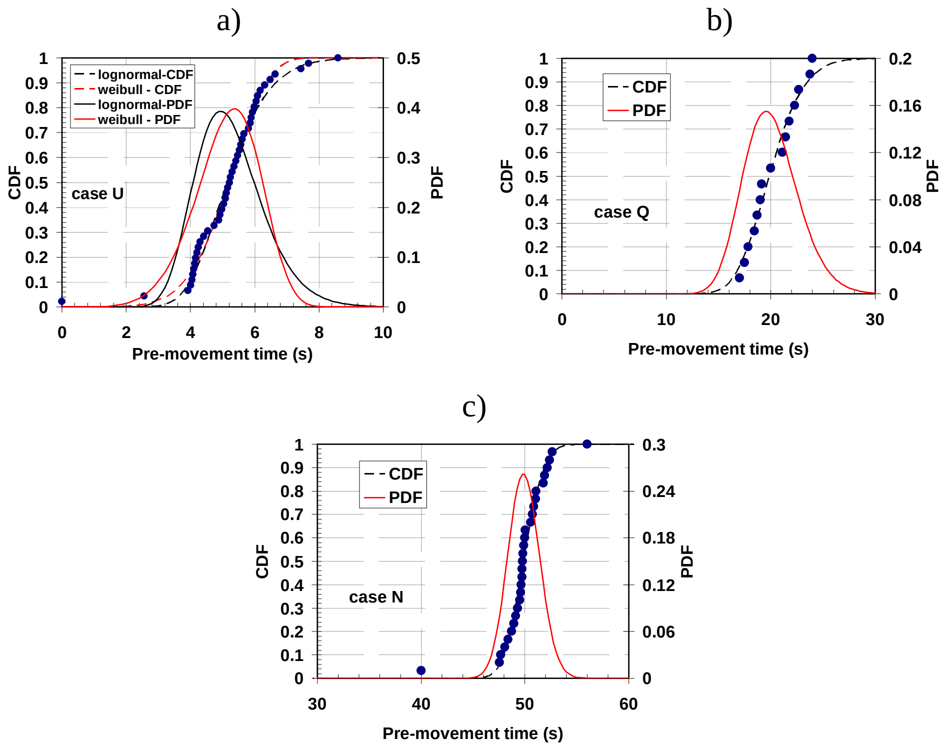

Figure 3. Reaction times in selected evacuation scenarios: a) a cinema, b) a special school and c) a church. The fitter distributions and their parameters are: a) $\mu = 1.63$ and $\sigma = 0.20$ for the log-normal distribution[1], and $\alpha = 5.90$ and $\beta = 5.53$ for the Weibull distribution[2], b) $\mu = 2.99$ and $\sigma = 0.13$ (log-normal) and c) $\mu = 3.90$ and $\sigma = 0.03$ (log-normal).

As seen from Figure 3, the pre-movement times in a room and in a large open space were quite short. The people tended to start moving before the whole evacuation announcement had finished. A good voice message or announcement should be short and commanding so that the main information (to exit the building) comes up quickly. Another important activator for reacting to an alarm in an

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1 $PDF = \frac{1}{x\sigma\sqrt{2\pi}} e^{-(\ln x-\mu)^2 / 2\sigma^2}$ and $CDF = \frac{1}{2}\left[1+erf\left(\frac{\ln x-\mu}{\sigma\sqrt{2}}\right)\right]$

2 $PDF = \frac{\alpha}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1} e^{-\left(x/\beta\right)^{\alpha}}$ and $CDF = 1-e^{-\left(x/\beta\right)^{\alpha}}$

open, crowded space (or room) is people waiting until someone else makes the first move. Soon after this, everyone follows (group behaviour). These three evacuation scenarios were all drills, so this affected the people's minds and their sensitivity level beforehand.

A very sudden reaction was also seen in the case of a hospital ward evacuation (Case G), when the first nurses were in the corridor within 10 s of the alarm bell. This was mostly influenced by awareness of the evacuation drill.

A good comparison of evacuating a school building with a real fire alarm shows that the reaction time distribution is wider (see Case F), with pre-movement times from 6 s to 76 s. This is mostly because the fire alarm is an unforeseen event and surprises some of the pupils who start to look for their friends and for more information.

A long pre-movement time was also seen in Cases C and R, in which the role of the security staff giving the evacuation orders was significant. In Case C, the people did not know about the evacuation until the security staff told them individually. The same happened in Case R, with those who did not follow the evacuation orders being asked to leave by the security staff. Case C was not threatening to the customers inside the shop, but in Case R, smoke was present and should have launched the evacuation.

In Cases H and I, the people were either sitting in their offices at the time of the alarm or walking towards their offices after noticing the fire alarm. Those who were walking towards their offices were probably picking up their outerwear or shutting down their computers. The distribution of these pre-movement times is shown in Figure 4. It should be mentioned that in Case H, three people went to their offices from elsewhere, so the movement phase of these people included travel via their offices.

In winter, in particular, the pre-movement time is likely to include a dressing phase, which, in its simplest form, could just be collecting outerwear and putting it on until going outside. In our study, Cases J and Q included events in which the pupils dressed or put on their shoes (pupils are normally without their shoes during lessons). These events were within a range of 10 s to 20 s when the pupils put their shoes on. When collecting outerwear, the range was 2 s to 5 s for the pupils and 15 s to 40 s for the teachers, respectively. In schools, dressing is well practised daily, and pupils usually know where their outerwear is, unlike the teachers who may have to collect some outerwear.

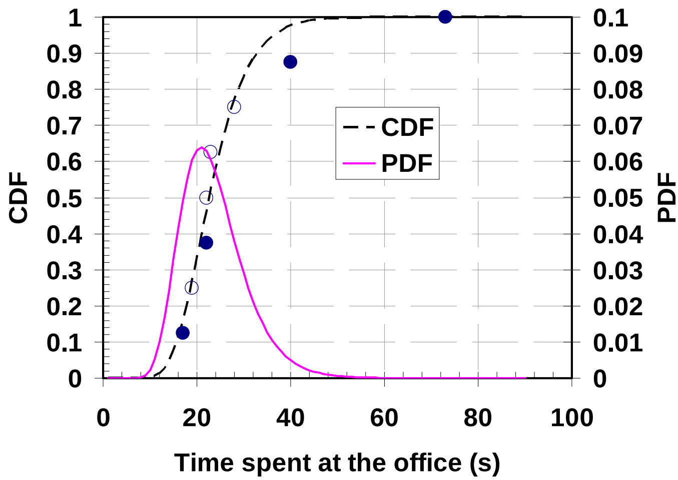

Figure 4. The log-normal distribution for the time spent in the office after the fire alarm. The open symbols are from Case I and the closed ones from Case H, respectively. The log-normal distribution parameters are $\mu = 3.12$ and $\sigma = 0.28$.

4.3 Evacuation time

Here, the evacuation time or total evacuation time includes the pre-movement time and the movement time. As seen previously, the pre-movement time includes several events, some of which are more likely to occur in a certain building type. The movement time relates to the walking speed and travel distance. In Finland, the travel distances are based on building regulations or performance-based fire engineering (RakMK 2002).

4.3.1 Evacuation time from a single room

The evacuation cases held in schools or colleges were compiled and the relation between the number of people and the evacuation time is shown in Figure 5. As seen in Figure 5a, the number of people (pupils and teachers) varies from 10 to 25 and the evacuation time varies from 0.2 min to 1.6 min (13 s to 98 s) until the room is empty. The quickest time was in Case J in which the comprehensive schoolchildren evacuated after the evacuation announcement (if the time is calculated from the beginning of the evacuation announcement, the evacuation time would be approximately 2 min longer). Case N represents the evacuation time of adults from the crypt of the church. The median value for the evacuation time of a single room is 0.74 min (44 s) (see Figure 5b).

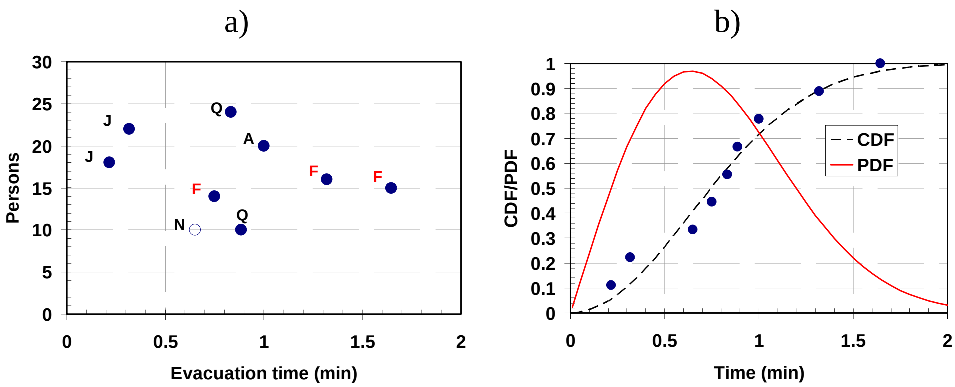

Figure 5. a) Number of people in a single room vs. evacuation time and b) cumulative density (CDF) and probability density (PDF) functions of the Weibull distribution (α = 2.02 β = 0.89) showing the evacuation time from a single room.

4.3.2 Evacuation time from a building

When looking at the evacuation situation on a scale of the whole building, the number of people versus the total evacuation time (out or to safety) is shown in Figure 6. Figure 6a shows the evacuation time for all the people, including the safety organisation members who were often the last to evacuate the building. In Figure 6b, 95% of the evacuees are counted. This represents the evacuation time of ordinary people (everyone except safety staff members). As seen, one data point exceeds the time of 12 min in Case O in which the evacuation was carried out inside the premises of a factory. In Case O, the reason for the long time is the long travel distance to the meeting point. Case O is excluded from the log-normal distribution data points shown in Figures 6c and 6d. The median value of the total evacuation time for all the evacuated people is 4.3 min (257 s) (Figure 6c). The corresponding value for 95 % of the evacuees is 3.3 min (198 s) (Figure 6d).

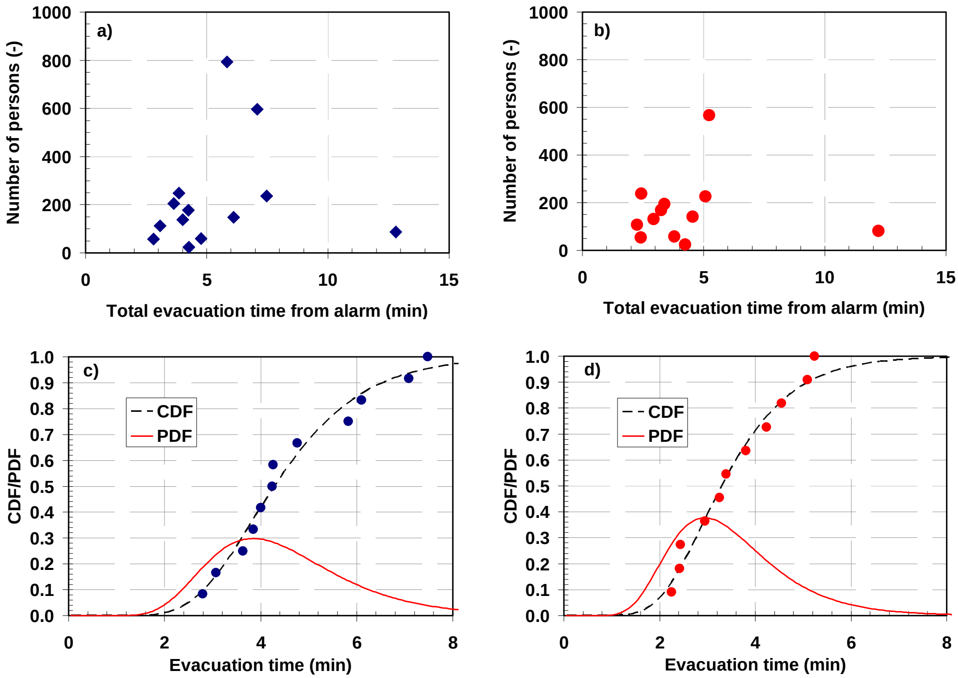

Figure 6. Total evacuation time for a) all people and b) 95% of the evacuated people. The log-normal distributions of evacuation time (excluding Case O for which the evacuation time was 12 min) for c) all people and d) 95% of the evacuated people. The log-normal parameters for c) are $\mu = 1.45$ and $\sigma = 0.32$ and for d) $\mu = 1.19$ and $\sigma = 0.33$.

The data points represented in Figure 6 are linked to certain evacuation cases shown in Table 2.

Table 2. Total evacuation time in different evacuation cases. The left side includes all the evacuees and the right side 95% of the evacuees, respectively.

Case	Total evac. time (all) [min]	Number of evacuees [-]	Total evac. time (95%) [min]	Number of evacuees [-]
A	7.1	596	5.2	566
B	6.1	148	4.5	141
C	7.5	237	5.1	225
F	3.8	249	2.4	237
H	4.8	60	3.8	57
I – office a	2.8	57	2.4	54
I – office b	4.3	24	4.2	23
I – office c	4.2	177	3.3	168
J	3.6	204	3.4	194
N	4.0	137	2.9	130
O	12.8	86	12.2	82
Q	3.1	112	2.2	106
S	5.8	793	-	-

A comparison of real and fire drill situations is made in Figure 7. The curves represent the evacuation cases of school buildings. The growth rate of curves F and J are quite similar, but the special school differs from these. The total evacuation time is longer in the real Case F than in the others. This is mostly due to the staff in Case F checking for longer that everyone is out of the building, and this can be seen from the long tail of the curve. It was notable that the special school pupils (Case Q) needed more guidance and assistance than was observed in Cases J and F. This produces evacuation times that are about twice as long with approximately 100 pupils.

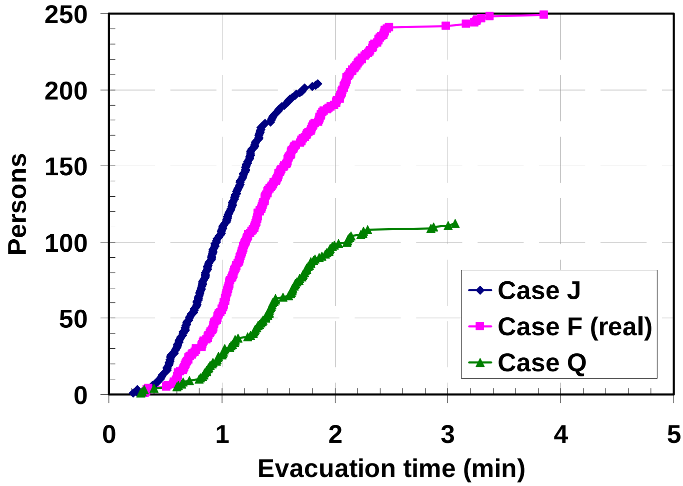

Figure 7. A comparison of evacuation times between drills and a real case in a school. The evacuation time (x-axis) starts from the fire alarm. The number of people coming out of the building is shown on the y-axis.

4.4 Walking speed

4.4.1 Horizontal surface

The horizontal walking speeds observed in the evacuation drills were mostly cases in which adults walked along corridors. Figure 8 demonstrates different situations in which the walking speeds differ. Figure 8a shows a normal situation (Cases A, O and V) in which people are not walking in congested corridors but at their own target speed. Figure 8b shows the walking speed of children evacuating a cinema (Case U). Figure 8c shows walking speeds in a situation in which people have a goal to achieve. In this particular case, the goal was to enter a classroom as quickly as possible (see Case V). The median values for normal situations are 1.3 m/s (adults), 1.5 m/s (children) and 2.1 m/s (‘goal–oriented’).

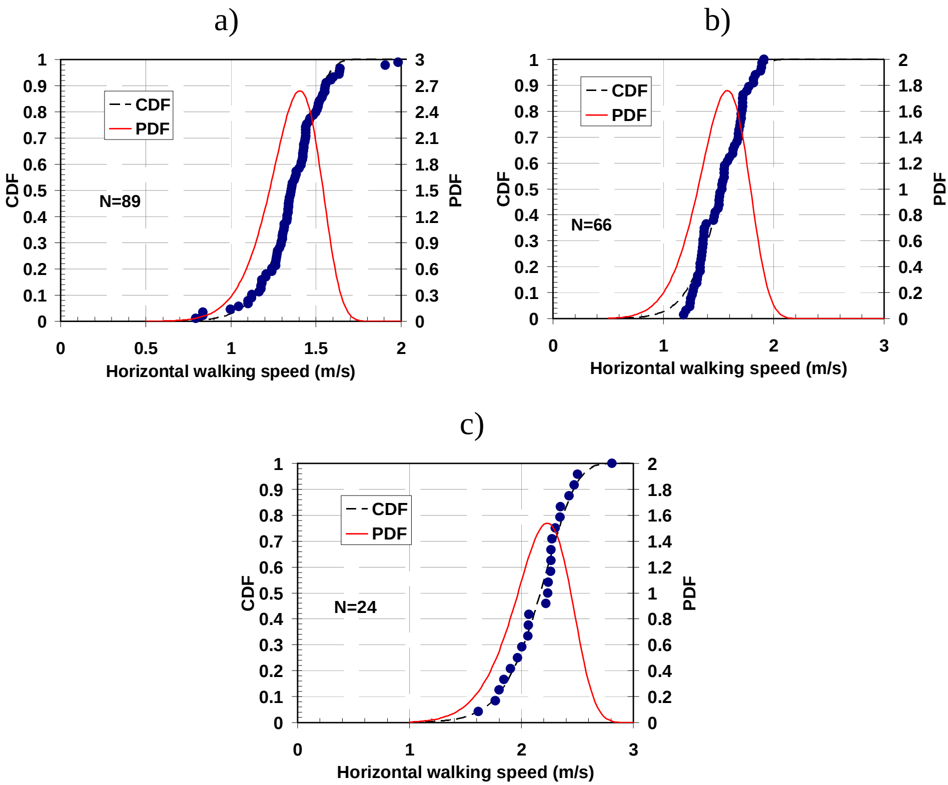

Figure 8. Walking speeds of a) adults, b) children in a normal situation, and c) the walking speed of adult students after receiving orders to walk fast to achieve a goal. The Weibull distribution parameters are a) α = 9.39, β = 2.25, b) α = 7.62, β = 1.60 and c) α = 10.14, β = 1.41.

4.4.2 Inclined surface

Walking speeds on inclined surfaces, either upwards or downwards, are usually related in situations in which the evacuation route includes stairs. For underground structures, the evacuation is carried out in an upward direction, the same direction as that of the smoke.

In a few of the evacuation cases, the evacuation route included stairs, which were easy to monitor. The representative inclined walking speed values are measured along the slope of the stairs, i.e., not in the horizontal direction. Case O had small stairs inside the factory area that crossed the manufacturing line. The median value for the walking speeds was 0.55 m/s (Figure 9a).

In Case S, people used the stairs, moving in a downward direction, after an ice hockey game. The inclined speeds for these were between 1…2 pers./m^2 crowd density. The median value of the downward speed along the inclined surface was 0.64 m/s (Figure 9b).

The third case, U, was an evacuation drill in a cinema with primary school children. The speed upwards, along the incline, is shown in (Figure 9c). These values are taken in small crowd densities (below 1 pers./m^2) with a median value of 1.1 m/s.

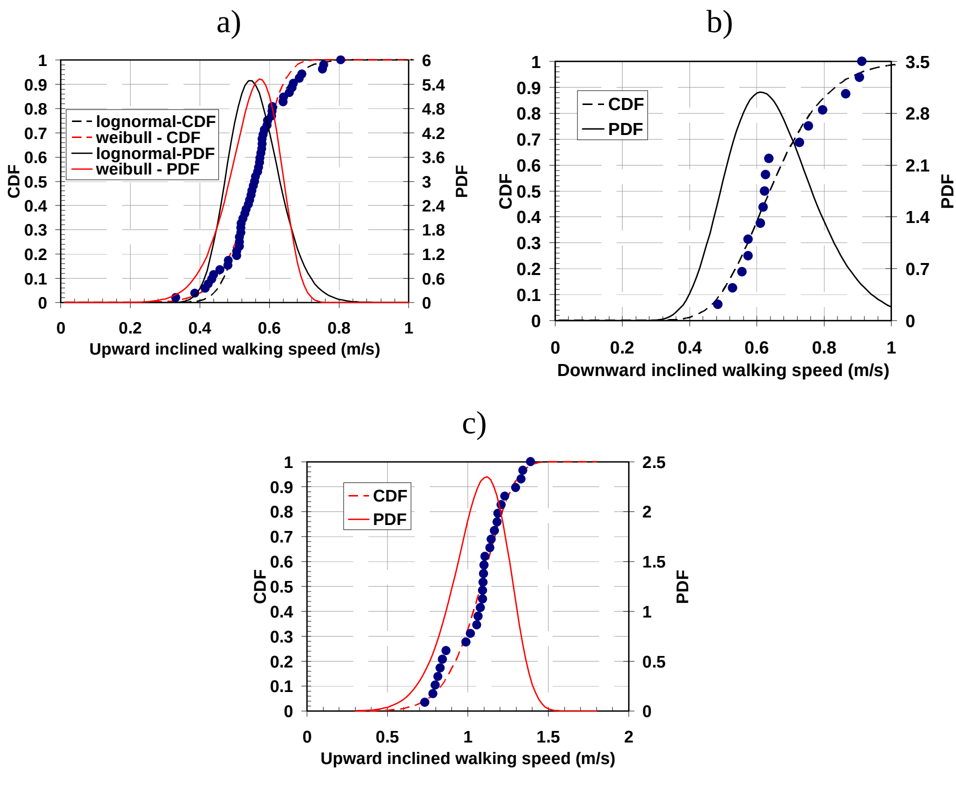

Figure 9. Walking speeds of adults in: a) upward (29°) and b) downward (27°) inclined directions and c) upward (24°) walking speeds of children. The log-normal distribution parameters are a) μ = -0.58 and σ = 0.13, and b) μ = -0.44 and σ = 0.20. The Weibull distribution parameters are a) α = 8.67, β = 0.58, and b) α = 7.20, β = 1.13

4.4.3 Congested situations

The walking speed usually decreases with increasing crowd density. Such situations can be seen at, for example, concerts, ice hockey games and any crowded public event. In this study, the congested walking speed values were monitored for Cases S, T and U (the stadiums and the cinema). Figure 10a shows the horizontal walking speed values as a function of the crowd density. These values were monitored in a stadium in which a concert and an ice hockey game were held. The walking speed is shown to decrease to a value of approximately 0.3 m/s when the crowd density is about 2.5 pers./m^2. The walking speeds upward and downward along stairs are shown in Figures 10b and 10c, respectively. The values are calculated along the slope of the stairs. The Case S data include mostly adults and the data points in Case U represent children.

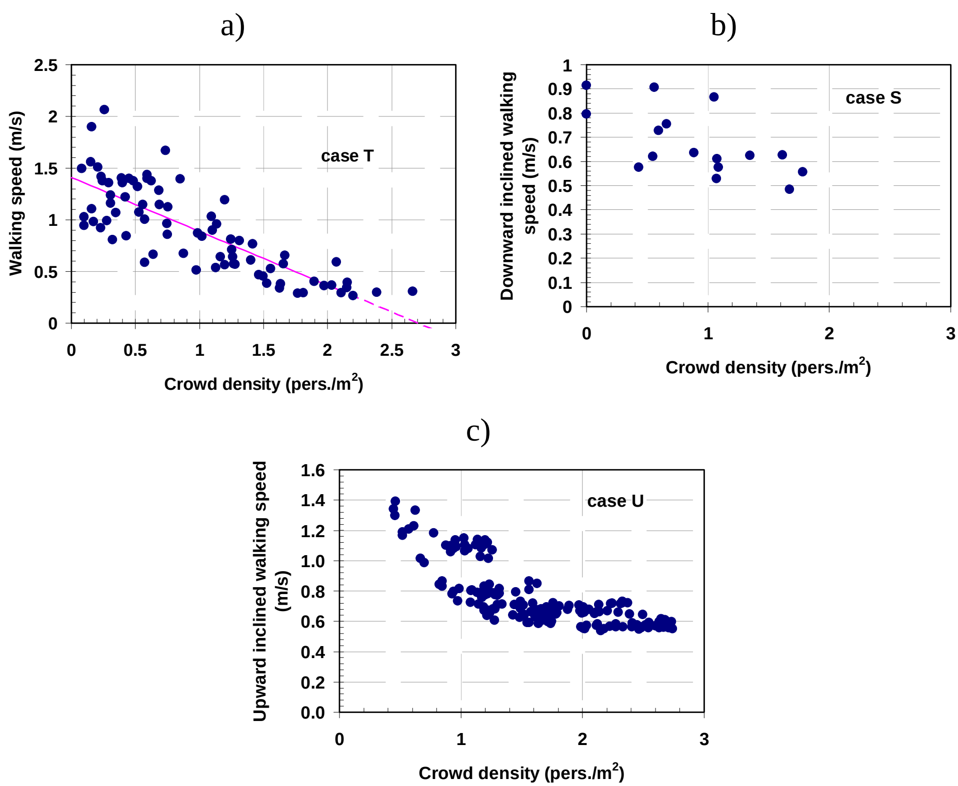

Figure 10. Walking speed versus crowd density curves obtained from Cases S, T (the stadiums) and U (the cinema). The linear fit curve parameters are a) y = -0.52x + 1.40.

4.5 Flow rates

Several evacuation scenarios included a dense crowd moving through doorways or corridors. The flow rates *J* are determined by:

$$J = \frac{\Delta N}{\Delta t}, \tag{1}$$

where ΔN is the number of counted people over some control line (e.g., doorway) in a certain time interval Δt [s].

Figure 11 shows the flow rate values gathered from different evacuation situations for this work. All of the flow rate values represent situations in which there was congestion or the doorway was exited in a queue. The flow rate is calculated by taking the slope for the evacuated persons vs. the evacuating time curve. The data points covering the fit curves were taken over 20…100 persons.

As seen from Figure 11, the flow rates between the doors with effective widths of 0.7–2.0 m are in roughly the same range. With the 5-m wide corridors, the flow rate increases by an approximate factor of two. The trend line shows that human flow increases by approximately one person per second when doubling the door width. The flow rate is affected by several parameters, e.g., width of opening, walking speed, crowd density and dimensions of the torso.

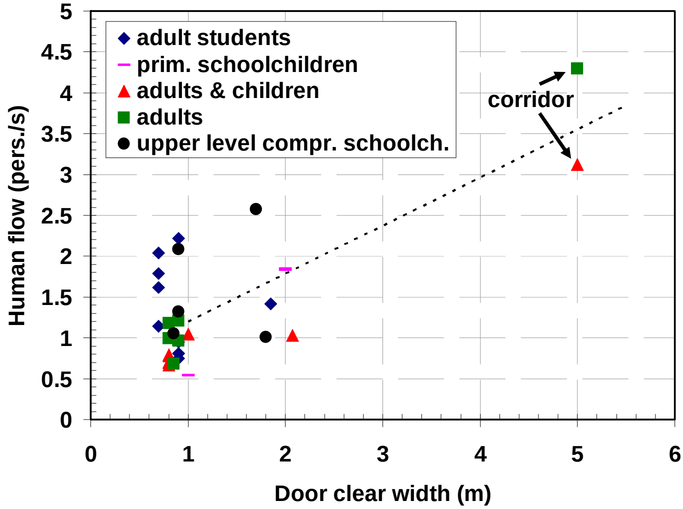

Figure 11. Flow rate as a function of opening width. The fit curve parameters are y = 0.59x + 0.60.

Table 3 represents all the data points relating to the human flows observed in the evacuation drills or real fire alarms shown in Figure 11. The door mode, representing whether the door was opened beforehand by the staff (= 1) or just opened by the moving people (= 2), is also shown in Table 3. The specific flow is calculated by dividing the flow rate values with the clear opening width *w* [m]. Thus, we calculate the specific flow rate J_s [pers.·m^{-1}·s^{-1}] in Equation (2):

$$J_s = \frac{J}{w} = \frac{\Delta N / \Delta t}{w} . \qquad (2)$$

Table 3. Specific flow values in different evacuation situations.

No.	Case	Comment	Door	Door clear width [m]	Human flow [pers./m]	Specific flow [pers.·m^{-1}·s^{-1}]	Type of person	Door mode (1 or 2)*
1	A		4b	0.9	0.805	0.895	adult students	2
2	A		4c	0.9	0.808	0.898	adult students	2
3	A		4d	0.9	0.749	0.832	adult students	2
4	A		5	1.85	1.417	0.766	adult students	2
5	B		main door	0.9	0.953	1.059	adult students	2
6	V	normal	doors 1&2	0.7	1.142	1.631	adult students	1
7	V	own interest	doors 1&2	0.7	2.043	2.919	adult students	1
8	V	group interest	doors 1&2	0.7	1.790	2.557	adult students	1
9	V	normal **	door 2	0.7	1.619	2.313	adult students	1
10	V	normal **	door 2	0.9	2.220	2.466	adult students	1
11	I		office c – door 1	0.9	0.965	1.072	adults	1
12	I		office c – door 2	0.9	1.207	1.341	adults	1
13	I		office a	0.85	0.680	0.800	adults	2
14	T	concert	corridor	5.0	4.295	0.859	adults	-
15	T	concert	door 3	0.8	1.180	1.475	adults	1
16	T	concert	door 7	0.8	0.994	1.242	adults	1
17	S	ice hockey game	door 1	1.0	1.046	1.046	adults & children	1
18	S	ice hockey game	door 3	2.07	1.029	0.497	adults & children	1
19	T	ice hockey game	corridor	5.0	3.121	0.624	adults & children	-
20	T	ice hockey game	door 3	0.8	0.778	0.973	adults & children	1
21	T	ice hockey game	door 4	0.8	0.669	0.837	adults & children	2
22	T	ice hockey game	door 5	0.8	0.697	0.872	adults & children	2
23	T	ice hockey game	door 7	0.8	0.705	0.881	adults & children	2
24	T	ice hockey game	door 8	0.8	0.796	0.995	adults & children	1
25	J		door 1	2.0	1.836	0.918	prim. schoolchildren	2
26	J		door 2	2.0	1.849	0.924	prim. schoolchildren	2
27	Q		door A	1.0	0.545	0.545	prim. schoolchildren	2
28	F		door 3	0.85	1.050	1.235	upper level compr. schoolch.	1
29	F		door 1– right	0.9	1.320	1.467	upper level compr. schoolch.	2
30	F		door 2	0.9	2.086	2.317	upper level compr. schoolch.	1
31	N		door A	1.7	2.573	1.514	upper level compr. schoolch.	2
32	N		door B	1.8	1.012	0.562	upper level compr. schoolch.	2

* 1 = opened by the staff or just an opening without a door leaf, 2 = opened by the people walking
** Extra human flow measurements for which the direction of movement was the opposite of tests nos. 6, 7 and 8.

The log-normal cumulative distribution function for all the data points shown in Table 3 can be seen in Figure12. The median value for the specific flow rate for all the data is 1.03 pers.$\cdot$s$^{-1}\cdot$m^{-1}.

If we divide the data into two groups in accordance with the door mode, we see that the specific flow median is 1.38 pers.$\cdot$s$^{-1}\cdot$m^{-1} in the case of door mode = 1 and 0.86 pers.$\cdot$s$^{-1}\cdot$m^{-1} in the case of door mode = 2, respectively. So, the clear opening width (door mode = 1) produces higher specific flow rates than the case in which each individual has to keep the door leaf open when walking in line through the door (door mode = 2).

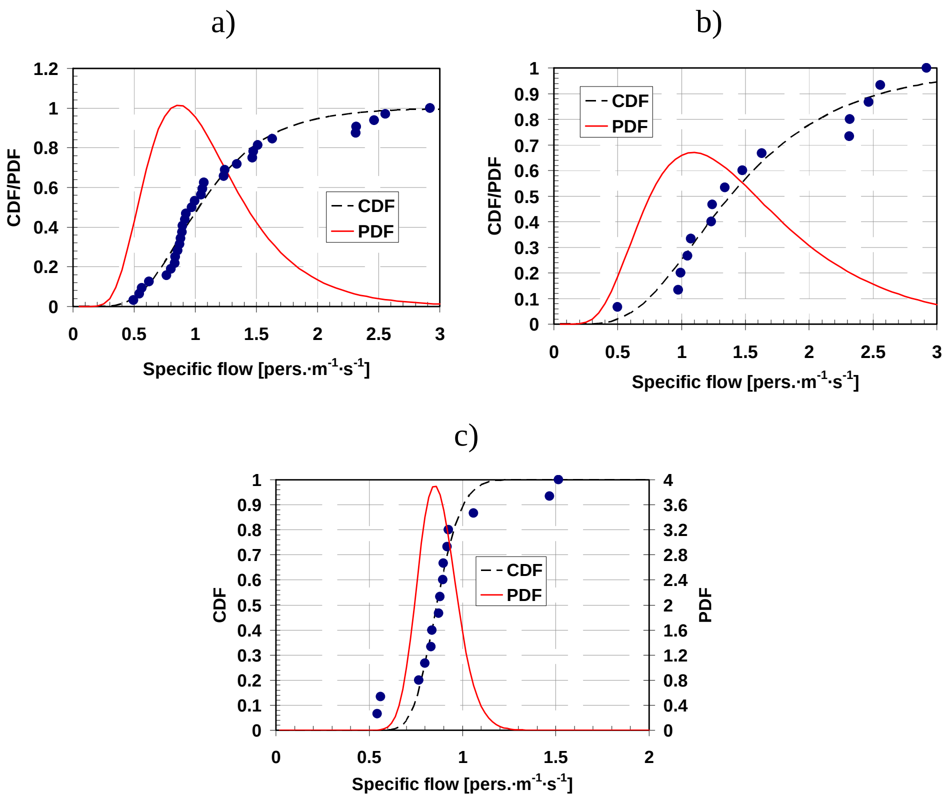

Figure 12. Log-normal cumulative distribution (CDF) and probability density (PDF) function of specific flows: a) all cases, b) when the door mode = 1 and c) when the door mode = 2. The log-normal distribution parameters are a) $\mu = 0.028$ and $\sigma = 0.416$, b) $\mu = -0.146$ and $\sigma = 0.119$ and c) $\mu = 0.322$ and $\sigma = 0.485$. The door modes are 1 = opened by the staff or just an opening without a door leaf, 2 = opened by the people walking.

The use of the total door width capacity is often under its dimensioned value and this causes extra evacuation time. One simplified example is shown in Figure 13 in which the different specific flow values are 1.38 pers.$\cdot s^{-1} \cdot m^{-1}$ and 0.86 pers.$\cdot s^{-1} \cdot m^{-1}$ (door modes 1 and 2), and different usage (100%, 66% and 33%) of the total door width produces different evacuation times (here the time of people travelling through the door openings).

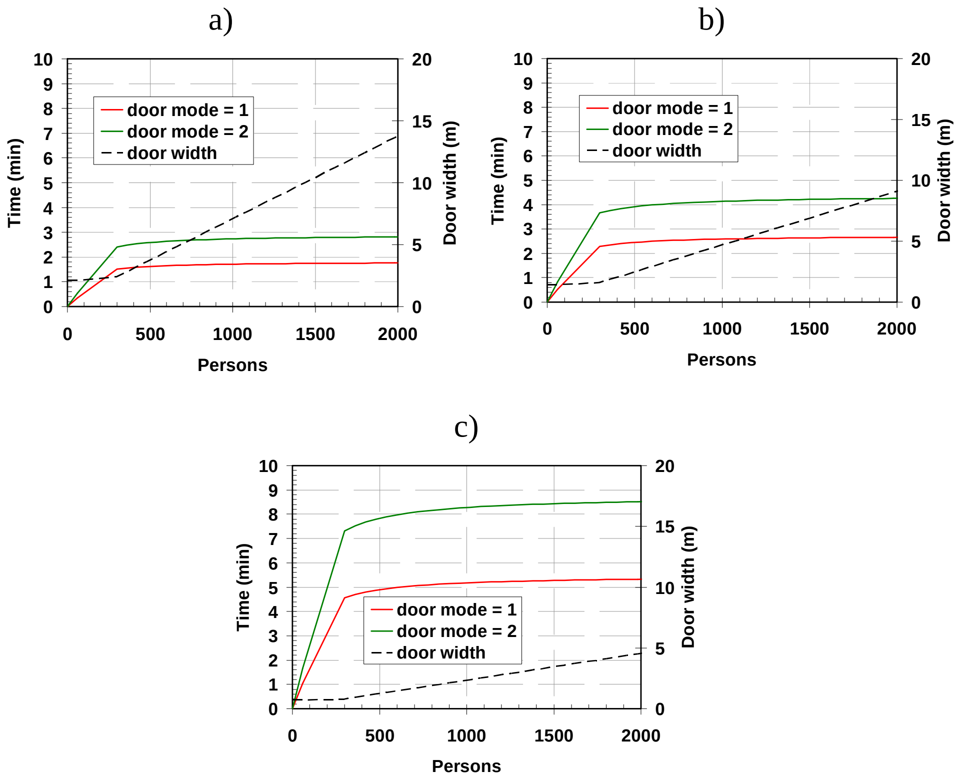

Figure 13. Effect of the usage of the total door width at the evacuation time. Figure a) 100%, b) 66% and c) 33% of the used door width capacity. The door modes are 1 = opened by the staff or just an opening without a door leaf, 2 = opened by the people walking.

Figure 13 also shows that the specific flow is the main factor limiting the evacuation time (i.e., the evacuation time saturates at a certain level).

The same behaviour can easily be seen when modifying Equation (2):

$$t_{evac} = \frac{N}{\chi \cdot J_s \cdot w(N)} = \frac{N}{\chi \cdot J_s \cdot \left(kN + w_{\min}\right)} = \frac{1}{\chi \cdot J_s \cdot \left(k + \frac{w_{\min}}{N}\right)} \tag{3}$$

$$\Rightarrow t_{evac} \approx \frac{1}{\chi \cdot J_s \cdot k}, \text{ when N >> 0}$$

where χ represents the effectiveness factor for the usage of the total door width (e.g., 50% means half of the available capacity is used). The total door width increases with the number of people. According to the national building code of Finland, the door width should be increased by 0.4 m for every 60 people after 120 people, with a minimum width of w_{min}. k [m] represents the slope 0.4 m/60 pers. (1/150) of the people vs. door width relation.

Thus, using Equation (3), we notice that the evacuation time is limited only by the specific flow:

$$t_{evac} = \frac{1}{\chi \cdot J_s \cdot k} = \frac{1/k}{\chi \cdot J_s} = \frac{150}{\chi \cdot J_s} \text{(s)}. \tag{4}$$

If the usage of the total door width is 100% and the specific flow is 1 pers.$\cdot$s$^{-1}\cdot$m^{-1}, we get an evacuation time of 150 s (2.5 min). This means that using the Finnish building codes, we produce the same evacuation time for all building sizes (excluding the pre-movement time and the movement time in the corridors until the end of the queue is reached) when N is large (if N $\geq$ 500 the error is 10% or less).

As the crowd density increases, the specific flow starts to decrease. This relation is shown in Figure 14. The crowd density and the specific flow seem to be higher on stairs (Figures 14b and 14c) than on a smooth surface (Figure 14a). In addition, some differences were found between the maximum specific flow values for adults (Figures 14a and 14b) and children (Figure14c).

Here, the crowd density ρ_c [pers./m^2] is calculated using Equation (5):

$$\rho_c = J \cdot \frac{1}{v} \cdot \frac{1}{w} = \frac{\Delta N}{\Delta t} \cdot \frac{1}{v} \cdot \frac{1}{w}, \tag{5}$$

where v [m/s] is the walking speed (horizontal or inclined surface) of humans.

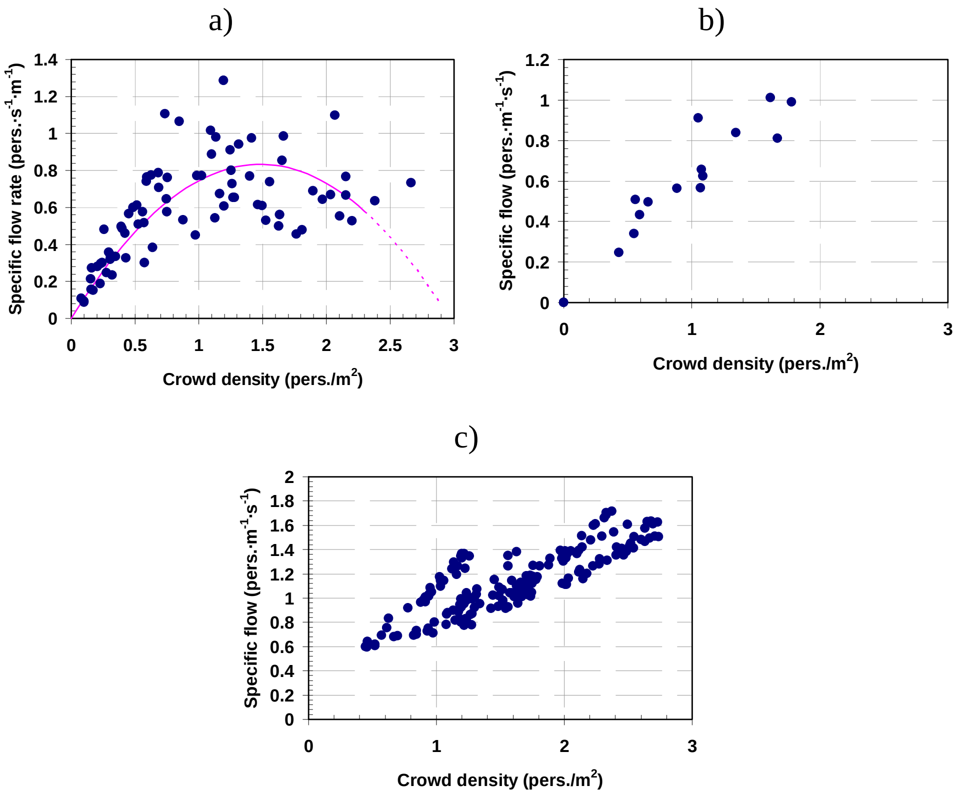

Figure 14. Specific flow as a function of crowd density: a) Case T, b) Case S and c) Case U. The fit curve parameters in a) are $y = -0.37x^2 + 1.12$. The surface and the direction of movement are as follows: a) smooth surface, b) downward (adults) and c) upward (children).

4.6 Discussion of quantitative observations

The different results of evacuation cases gathered in Sections 4.2–4.5 represent mainly the situations observed in evacuation drills. The point in time at which the evacuation drills would be carried out was usually known in advance, which explains some of the results seen for the pre-movement times. The courage and decision-making are further highlighted in a drill, and the evacuation may be launched by a much smaller amount of information than in a real case.

The pre-movement times are calculated in open spaces (classrooms, church, etc.), however, with evacuation drills being representative values. The people have a fairly easy task to start the evacuation procedure by standing up and starting to move using the simple geometry to find the exit. In our study, all this happened within 10 s…20 s of the first person standing up. In a comparison with the evacuation time of single classrooms in a real case and drills, no remarkable difference was found. This also indicates that the pre-movement times were in the same range for both situations.

Although the exact recognition times were not measured, it seems that the clearer the announcement, the smaller the deviation of the pre-movement distribution. Nonetheless, the short announcement has to include the required information to launch the evacuation.

The real cases showed longer pre-movement times because there was no preparation or awareness of the forthcoming event. This was seen in the people's behaviours and in the need to find information. The investigation increased in complex buildings (corridors, between shelves), and most of the people did not start to evacuate until two signals had been perceived. In one case, three signals were needed to clear the area completely.

Differences in specific flows were also noticed, depending on whether the door was opened by the staff or the moving people themselves. An important factor in limiting the evacuation time is not the available capacity of the exit doors but the usage of the exit doors.

Some observations were made of the motivational aspects of humans when people were instructed to walk faster than usual to achieve a goal. This provided better information on the situation as the people were motivated and acted altruistically or egoistically. The test series showed, among other things, an increase of at least 60% in both walking speeds and specific flows compared with normal evacuation drill data.

The normal events in stadiums showed that there was congestion during normal movement. These cases were good demonstrations of how well the dimensioning works in practice and how the extra constructions affect the crowd movement. Simple correlations were made between the specific flow and the crowd density on both the smooth and the inclined surface. From these, the results obtained from the inclined surface (the stairs) showed higher crowd densities for the same specific flows.

5. General observations of the evacuation scenarios

5.1 Alarm systems

The difference in evacuation scenarios as well as alarm systems was noticed. The most common alarm signal combination was an announcement and an alarm bell. The announcement was given both manually and automatically from recordings. The alarm bell signal varied from an ordinary bell ringing to a continuous signal. Large buildings, e.g., shopping centres and vocational high schools, usually had the newest alarm systems with automatic voice guidance. Older and smaller buildings, e.g., a church, primary and special schools, had manual PA systems. In some cases, the alarm system was implemented differently using the short message service (text messages) because the evacuation scenario differed from the normal fire alarm drill. In the case of the cinema evacuation drill, along with the alarm bell, which is the method usually used to alert people to danger, a new alarm method was tested. A video was shown on the cinema screen advising people to exit the premises using the emergency exits. This video was shown prior to the fire alarm bell in one of the cinema halls to see how people would react to the video. (The future plan was to have the evacuation video and fire alarm bell side by side as simultaneous means of alarming.)

The door selection tests were implemented without using any alarm systems in the building. This was feasible because of the nature of the tests. A simple whistle was used by the test organiser to give a start signal for each of the tests.

Table 4 represents the alarm systems used in the evacuation scenarios.

Table 4. A list of different alarm types in the evacuation scenarios.

Case	No. of people	Building type	Type	Type of alarm system
A	800	college	drill	fire bell and voice message over PA system
B	200	college	drill	fire bell and voice message over PA system
C	150	supermarket	real	first the public voice message over the PA ‘checking the situation’ and then announcements by the walking security staff
D	30	supermarket	real	voice message over PA system
E	100	shopping centre	drill	voice message over PA system and fire bell
F	500	comprehensive school	real	announcement over PA system and fire bell
G	6	hospital	drill	headmaster’s announcement over PA system and fire bell
H	80	factory	drill	text messages and verbal announcements by the staff
I	300	three offices	drill	voice message over PA system and fire bell
J	650	comprehensive school	drill	the orders to evacuate were given during the morning assembly over the PA system
N	200	church	drill	orders given by the priest and fire bell
O	200	factory	drill	text messages and verbal announcements by the staff
Q	100	special school	drill	orders given by the headmistress over the PA system
R	hundreds	public building	real	voice message over the PA system
S	thousands	stadium	normal	-
T	thousands	stadium	normal	-
U	200	cinema	drill	exit video, orders given by the safety organisation members and alarm bell
V	100	door selection test	drill	a whistle

The two factories had text message systems. In both cases, the first message was sent to the safety organisation members, the smaller group, and the second message concerned the staff. It was noted that the first message information also went out to most of the staff members before the second was sent. This usually meant that the staff received the second message while they were evacuating or had evacuated themselves. In Cases A, B and I, the combination of the fire bell and voice message started with the fire bell. After approximately one minute (in Case I, the duration was 90 s), the fire bell stopped and the voice guidance started. The first acts of the people would have been more effective if the alarm had begun with an informative voice message or if the duration of the alarm bell phase had been shorter. In some cases, the people said that the fire bell and the voice guidance had been operating simultaneously so the message had not been heard well.

5.2 Surveillance camera installations

Varying numbers of video cameras were used in the evacuation drills, depending largely on the layout of the premises and the goal of the observations. Typical points of interest were passages, staircases and places where door openings or physical obstacles might influence the movement of people.

In the real evacuation cases, permission to acquire and use, for the purpose of this work, recordings of the building's own surveillance cameras was received from the security organisation of the building administration and other relevant security authorities.

In all the cases in which people were recorded or surveillance camera recordings were issued, all legal and ethical obligations were followed. The consent of the participants (or in the case of minors, also their guardians) was obtained in advance. If data that could identify their objects were acquired or stored, the Person Register Law and its confines and demands were followed and complied with. Data falling under confidentiality contracts were handled in adherence with the mutual agreement of the issuer and all transferable obligations.

The main differences between normal video camera recordings and the surveillance camera recordings were discussed earlier in Section 2.1. As the material from surveillance camera recordings usually last for one or two weeks, the predefined procedure to gather the material quickly is essential.

5.3 Pre-evacuation actions

5.3.1 Reaction to alarm

How evident the danger is, how easily and what kind of information is available and how well the expected course of action is in line with a person's preferences and expectations partly define the course of the person's actions. The tendency to avoid/minimise uncertainty often governs people's actions.

In drills or situation in which the danger is not apparent, people usually behave seemingly rationally from the view of expected logical actions and curiosity. Conflicting information and observations, contradicting situations and guidance from that which is expected cause confusion and make decisions difficult.

The reaction to fire alarms depends largely on the building type. In schools, the manual announcements over PA systems are given daily and the responses to these are short. In shopping centres, the announcements are often commercial and, in the case of fire, the alarm announcement does not necessarily launch the evacuation to the extent that was expected. The two-phased evacuation announcements may also confuse people and give the expression that the danger has not struck suddenly or the people may not notice the difference between the first and second announcements.

In complex geometries, such as offices and shops and between shelves where people do not see each other, the range of reaction times is wide. In these cases, the security staff or safety organisation usually has to make the effort to go through the whole area. In areas where other people are present and they can see each other well, the reaction to the alarm happens simultaneously with someone making the first move.

In general, manual voice alarming seems to be more effective than automatic systems. There are still some weak points in manual announcements that can affect the reaction to the alarm. Spoken messages have low repeatability and the content should be short and include only the essential matter.

The difference between real fire alarms and evacuation drills is seen as some kind of disobedience in the reaction to the alarm signal. Almost none of the fire drill cases had anyone inside the building after a few minutes, but in the real cases, there were always (even in schools) a few (or more) people who were just curious or for some other reason did not react to the alarm signal(s). A good example is Case R (the bus terminal).

In fire drills, when people had prior knowledge of the drill and maybe about the evacuation routes to be used, the preparedness resulted in fast reactions. The prior knowledge also produced expectations in people's minds, however, and could lead to confusion. In the cinema fire drill (Case U), for example, the participants had a detailed view of the course of the drill and the overlapping means of alarm to be used. It seems that some of the participants were confused because the actions, especially in the way the alarm was given, differed from those they were expecting – they did not start to evacuate despite some confused movement. It seemed that on a minority's initiative, part of the group decided to wait for further instruction by the staff and not react to the alarm bell.

5.3.2 First actions after the fire alarm

After perceiving the fire alarm, the typical reactions varied greatly between the different evacuation cases. In the previous section, 5.3.1, it was noted, especially in the real cases, that there were always people who stayed inside the premises regardless of the alarm. In the supermarket, Cases C and D, some people continued shopping after being given orders to evacuate. In both cases, the situation was estimated to be safe, so that people could walk through the cash desks (to pay for their purchases). In Case C, congestion formed in front of the area of the cash desks because shopping trolleys partially blocked the route. In Case D, the distribution of the time spent at the cash desk per customer was calculated. These examples show that normal evacuation through cash desks can last for a long time and produce unexpected congestion.

In the third real case, F, the surveillance cameras inside the school revealed that most of the reactions consisted of the way the pupils walked in corridors and suddenly changed their directions or started to follow others. The adults hesitated more than the pupils in their decision to leave the building.

The fourth real fire alarm (Case R) showed that even in a real situation, when people saw the smoke (through the glass in this particular case), people did not start to evacuate until the other signal or voice announcement was given.

In the evacuation drills, when unexpectedness was in evidence, people did not seek more information and did not wonder about the situation but started to walk almost immediately towards the exits (e.g., Cases I, N and Q). If the evacuation drill were the first one to be held in building, then the awareness would be understandable. Only one partially unannounced drill was held (Case H) and it clearly showed the need for additional information among the people.

Two demonstrations were seen on how people communicated with each other and started to evacuate in such a situation when the primary alarm system failed or was deliberately not used (Cases H and O).

5.3.3 Group behaviour

The group behaviour was mostly seen when, for example, a security person, colleague, small group of people or a safety organisation member advised or gave orders to evacuees. If, in these situations, the minority was the security person or safety organisation member, the orders were obeyed well. In Case A, the situation outside the building was laborious to the safety organisation member who was giving orders to hundreds of people to move to the meeting place. In this particular case, the number of evacuees was too large for one safety person to handle.

The situation usually clears up when people start to follow the moving crowd (the majority). At the moment of seeking information, any ideas are welcome and even a small group can lead a mass of people (the minority). One specific case was seen inside an office building (Case I, office b) when three women had the idea of using a specific route to evacuate and a group of approximately ten people followed them.

In schools, the authority of the teachers may not be sufficient when giving orders, for example, to dress when the moving phase was on (Case J).

In large open spaces where people sit on their chairs, the group behaviour is easily seen when someone launches a chain reaction, e.g., by standing up, the others follow. The same following behaviour can be seen in doorways, with people liking to use the same door as the person in front of them.

5.3.4 Staff's action

The role and status of a person influences that person's reactions and actions in an emergency situation and even in planned drill. The duties and tasks preceding the onset of the situation mostly influence the behaviour of the person. Staff often have roles and responsibilities in the case of unexpected situations, in addition to their normal duties.

In some places, it is common for one person to have different roles or duties and responsibilities from day to day or at different shifts, especially in places with few staff, when employees may circulate some duties. This can lead to confusion with regard to which actions to take when something unexpected happens or when the outcome of a well-planned action turns out to be something other than expected.

In the cinema fire drill (Case U), interesting observations were made of the staff's action. First, the number of staff was quite small, and the staff worked in different roles depending on who was on duty and for which roles he or she has been trained. The role of training, including in emergency situations, seemed to be highly respected. One observation was that the staff who were given new responsibilities at work and the opportunity to train for a new role in this drill did remarkably well in the procedures that followed, acted fast and proactively and seemed to be more alert. The more experienced employees showed good routines in handling their duties, but they were more prone to adjust slowly to unexpected situations and seemed to act more strictly according to their well-learned routines and tasks. Thus, the conflict of prioritisation of assigned roles in an unexpected event sometimes seemed to be resolved more slowly.

The laborious work of the staff or security staff was seen in the public buildings (Cases C, D and R) in which the people were not aware of the situation or just did not follow the evacuation call. In these cases, the best response depended largely on the size of the safety organisation group.

The value of guidance by people in offices on different floors is significant. First, the fire brigade needs information (in the same way as in any other evacuation case) on whether anyone is still inside the building. The safety staff members give the best assessment in this situation. Second, if any of the people are not familiar with the stairs or exits, the guidance of safety staff is essential.

The main danger is the fire inside the building, but other risks may be faced outside. The traffic on the streets beside the buildings may be heavy, and this could cause harm or be dangerous in congested situations when moving to the meeting place. The safety persons are usually the last to evacuate the building, and there is no guidance for the first evacuees.

5.4 Evacuation phase

5.4.1 General

The evacuation phase starts after people have perceived the alarm and made their decisions to evacuate the building. The time of the evacuation, or moving phase, depends on the walking speeds (or crowd density) and the travelling distances of the humans. These parameters are adjusted by the route and door selection decisions that people make while they are evacuating. The route selection depends on several factors, such as familiarity with the building, visibility of exit signs, minority-majority aspects (guidance, following others), threat of fire, etc. The door selection is the last to affect the whole process and it controls the human flow through the doorways. This chapter demonstrates some observations made in the evacuation drills on the view of the evacuation phase.

5.4.2 Exit route selection

As the monitored areas were mainly the main doorways, not all the usage of exits was measured. Nonetheless, the observations showed that the majority of the evacuees inside the building evacuated through the main doors, the same doors through which they walked in. The exit routes were therefore the normal routes for the evacuees. If the evacuation drill was meant for the staff, the main entrance was not the only exit to be used (Cases E and I). The staff and, especially, the safety organisation members should familiarise themselves with the use of alternative exits. A good example of this was seen in the real Case H, in which the teacher led the pupils out of the exit door of the building. In addition, in Case A the safety organisation member opened the exit door of the staircase, which was immediately used by evacuees.

The routine use of a stadium was seen with the ice hockey game spectators who normally exited the stadium through several doors, as they knew the geometry of the stadium well.

In some circumstances, the evacuation route becomes the normal route, or the route varies because people collect their things before evacuating the building. This kind of behaviour was seen in Cases H and Q (the factory and the special school, respectively).

5.4.3 Door selection and capacity of exit routes

The door selection and usage of the doors are an important factor that directly affects the evacuation time of the building. The observations made of the evacuation drills and real fire alarms showed that people tend to follow each other and walk in a line through pre-opened doorways. This is probably because people think they are moving and that is good enough for them, and a short time of congestion will not change their minds. When someone opens an extra door, he or she is certain to be followed by several people. Even in a case of double-leaf doors, quite often only one leaf is used.

Hardly anyone uses the latches of the exit doors during evacuation drills or in real cases. People normally use the same routes they use on a daily basis. In some cases, people do not know if they are allowed to use the exit doors during the drill because the latch is covered with a plastic shield that has to be removed or broken in order to use the exit door.

Figure 15 represents an example of a normal situation in a stadium (Case T). The theoretical capacity of eight door leaves is shown with a dashed line and the realised curves after an ice hockey game (red) and a concert (black) with solid lines, respectively. Although the number of people walking towards the main door is similar in the two latter cases, the use of the eight door leaves differs significantly between the cases. The spectators of the ice hockey game are experienced in using more door leaves than the people at the concert. They both remain under the theoretical curve with values of 62% for the ice hockey game and 29% for the concert (100% represents the theoretical value).

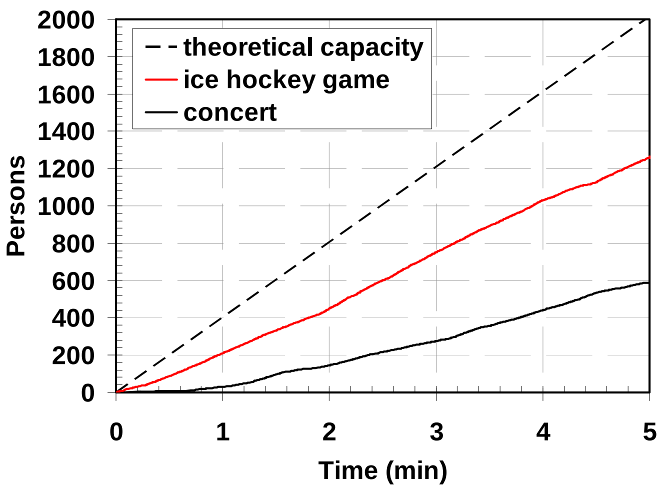

Figure 15. Usage of the main door in a normal situation in Case T. The theoretical curve is calculated using a door width of 6.4 m and 1.05 pers.$\cdot$m$^{-1}\cdot$s^{-1} specific flow values.

Factors such as the physical arrangement of the alternative exits, obstructions and capacity of passages, visibility and composition of the crowd, together with the context in which the people face the need to decide between alternatives, influence the outcome of the efficiency of the flow against the theoretical optimum.

One demonstration of using the exit doors and the effect of geometry was seen in Case B in which the students chose the first door that came their way. Using the door required people to turn 90 degrees to the right. Another door was located in the same line as the first one, but no one used it, for the apparent reason that the first door was located on the side of the ‘indoor track’.

5.5 Actions in the meeting place

Although the actions in meeting places were not the focus of our study, some observations were still made. The meeting places were located outside the buildings in every case except Case O, in which the meeting place was inside the factory.

In general, the locations of the meeting places were well known or found (except for a couple of cases). This was mostly due to the guidance of the safety organisation members. In some cases, the role of the fire brigade was taken into account and the assessment of the situation was given at the meeting place. The content of this information was not monitored. (After the drills, the observers usually demonstrated to people how to act correctly in real situations when the fire fighters needed information on whether anyone was still inside the building.)

In Case A, the people did not move to the meeting place until the safety organisation member ordered them to do so. The people would have wanted to stay near the main entrance, which would have caused congestion, as it occasionally did. The same happened in Case B when the students stood in front of the main entrance throughout the evacuation process.

The role of the safety organisation member inside the building is as important as guiding people in the doorways to the meeting place.

5.6 Feedback on the participants and the organisers

After the evacuation drills, feedback meetings were held. The participants in the meeting were usually the safety organisation members and the observers (mostly fire authorities). In two cases (E and N), the evacuees also participated in the feedback meeting.

Infrequently, the evaluation of success was measured using time criteria or any other criteria. Otherwise, the evaluation of success was based on the observers' findings and the feedback of the safety organisation members.

The most common feedback concerned alarm signal audibility or lack of information (Cases A, G, I and O). The voice message, in particular, was not heard well in different parts of buildings. In a few cases, the lack of yellow waistcoats on safety staff increased the sensation of ignorance among the evacuating people.

The feedback meetings were important events to give instructions to safety staff to handle different 'what if' cases that came to their mind.

6. Summary

This study covers 18 evacuation situations in different types of buildings. Twelve cases were normal evacuation drills, four were real fire alarms and the remaining two cases were normal but congested situations. The data gathered are designed for the buildings' safety and the security staff, the fire authorities, the fire safety engineers and the model developers.

6.1 Quantitative observations

Several distributions were formed to quantify different time intervals of the whole evacuation process. The distributions were pre-movement times, total evacuation times and walking speeds on smooth and inclined surfaces. The congested situations were investigated using correlations between walking speeds and crowd densities.

The pre-movement time calculations showed that a short announcement could produce small deviations in the pre-movement time distribution. Nonetheless, the short announcement has to include the desired information to launch the evacuation.

Differences in specific flows were also noted when the door was opened by the staff or the moving people themselves. Another significant factor in limiting the evacuation time is not the available capacity of the exit doors but the usage of the exit doors.

Some observations were made on the motivational aspects of humans when people were instructed to walk faster than usual to achieve a goal. This provided better information on a situation in which people were motivated and acting altruistically or egoistically. The test series showed, among other things, an increase of at least 60% in both the walking speeds and the specific flows compared with the normal evacuation drill data.

6.2 Qualitative observations

General differences between the evacuation drills and the real fire alarms were observed. One clear difference is that courage and decision-making are highlighted more in a drill. The evacuation may also be launched by a much smaller amount of information than in a real case. This is because there is awareness and knowledge of the forthcoming drill. The real cases showed longer pre-movement times because there was no preparation or awareness of the forthcoming event. This was recognised in the people's behaviour and the need to look for information. Most of the people did not start to evacuate until two signals had been perceived.

The staff assisting with the drills reacted and acted efficiently. In addition to the knowledge of the drill, they also had clear roles and duties in the drills. They also often possessed more insight into the planned course of action. The real fire alarms were different in that the staff also had to adapt to the unexpected situation and look for information. The alarm situation and the cause of it needed to be resolved. The staff have predefined roles for emergencies, but the stress and sometimes unpredictable behaviour of people increase the staff's workload.

In the drills, the assisting staff worked more independently. One reason is that they already had most of the information they needed to carry out their work. Often, they also had a good assumption of how people would react and what routes would be used, etc. In real alarm situations, it was observed that the staff tended to work in groups. This could be a way of sharing information and planning actions. When the source of the alarm was known, the staff also went on the scene to 'confirm' the cause. In these cases, many seemingly irrational ways of acting could be caused by the need to obtain information and confirm beliefs. The various degrees of uncertainty among all people in an emergency situation affect all phases of the evacuation.

The drills and real alarms took place in public buildings, work places, etc. One notable fact is that when there are people in these types of buildings, there is usually also significant movement in and out of the buildings. This means that from the time of an alarm, there may be people entering the premises, not knowing about the emergency. This could be observed in several of the drills and, especially, in the real fire alarm cases. Before the staff are able to prevent people entering the parts of the building under evacuation, there can be a significant flow of people entering the area. This puts more people in danger and blocks evacuation routes.

This leads to the general observation that in both drills and real cases, the actions of the staff seemed to focus on the incidents and people inside and close to the area of the emergency. It was difficult for the staff to reach doors or gathering areas because of the crowds. Often it seemed that the thoughts behind the evacuation worked from the inside out, forgetting that, at the same time, effective efforts should be directed at controlling the entrances and exit routes and preparing safe areas where exiting people could gather without obstructing exit routes. Alarms and notifications are also only available inside the affected area. There is of course a downside of more extensive notification of emergencies, as it may attract more people to the danger area.

Similar elements of behaviour can be observed in drills and real emergencies. Depending on the situation, some phenomena prevail and certain elements may be absent. When observing pre-evacuation and evacuation actions, the amount of information available affects behaviour and decision-making. This information may be prior knowledge gathered by observing the surroundings. If the exit route is visible or clearly indicates where it leads, it may be preferable. Doors that are already open may be preferable to closed ones. People also tend to follow others' example. One notable difference between the observed drills and the real emergency situations was that whereas the people participating in the drills were clearly oriented to perform the evacuation task, in the real cases people had primary tasks contradicting with the enforced actions caused by the unexpected alarm. People could be in the middle of shopping, trying to catch a bus, going home, doing a work-related task, etc. People tended to achieve this primary goal even if they were starting to become aware of the unexpected situation. The level of perceived danger, amount of relevant information available and effectiveness of the actions of the staff affect the time it takes a person to resolve this contradiction.

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Appendix A: Description of evacuation drills and real fire alarms

A1. Case A: A vocational high school

Background

The evacuation drill in the vocational high school building in Helsinki was held in October 2007. The evacuation drill started at about 9 am. Based on our observations, there were about 600 students and staff inside the building. The real number of participants may have been even higher, as not all the exits were monitored. The evacuation drill was announced in advance to the safety staff and the students. The students knew the week and the staff the exact date of the planned drill.

Building description

The geometry of the building near the main exits is shown in Figure 16. The meeting place was located outside, near the main exits. The monitored areas outside were the main door (route 4) and the door next to it (route 5). Inside the building, fixed surveillance camera installations (routes 1–3) were used to monitor the evacuation drill. Routes 3 and 5 are the ways out from staircase A at ground level. People normally use route 3, but, in emergencies, route 5 can also be used.

The main door divides the merging flows from routes 1–3 into four separate flows (see Figure 16) marked as 4a, 4b, 4c and 4d, respectively. Doors 4b, 4c and 4d are normally used as the entrance and door 4a only in emergencies. In order to use the emergency door 4a, the latch has to be turned to open the lock.

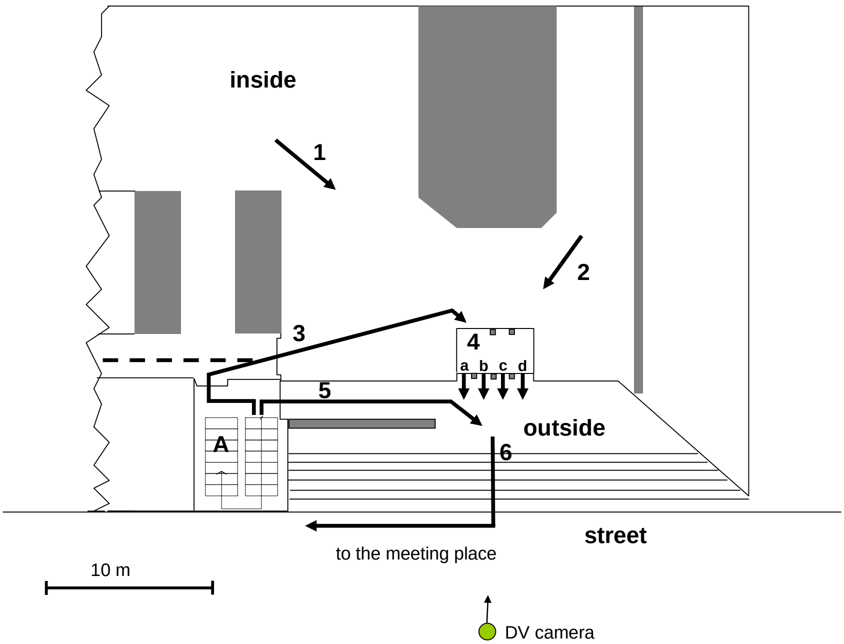


Figure 16. A floor plan of the vocational high school (Case A). The main exit routes used during the evacuation are shown with arrows nos. 1–6.

Results

The rate of evacuated people was counted from the videos using the Evaccounter described in Section 2.2. The numbers of people evacuated through different main routes were:

Route 1: In the first 6 min after the alarm, approximately 160 people walked across the atrium heading for the exit.

Route 2: Within 1.5 min of the alarm, approximately 60 people were evacuated from the building. Two of the evacuees showed some unexpected behaviour. During the evacuation, one person stopped inside the main door and waited for about 20 s before exiting, and another tried to walk against the crowd flow making an extra 80 m detour, which extended the evacuation time for this person by about 2 min.

Route 3: As seen in Figure 16, at ground level, people have two choices to walk out: route 3 and route 5, i.e., the normal or the emergency route, respectively. During the evacuation drill, in the first 2 min 30 s, people came out through route 3. After this, apparently due to a safety organisation member, the others were advised to use emergency route 5. In all, approximately 150–200 persons were evacuated from the building using route 3. About 30 of them came from the direction of the cafeteria (dashed line in Figure 16).

The surveillance camera video material next to route 3 was used to measure the crowd flows through the doorway of staircase A. The door had double-leaved and during the first 2 min, people used only one leaf until someone pulled the bolt to open the other leaf. Figure 17 illustrates the crowd flows in these situations. During the period in Figure 17, there was congestion in the doorway.

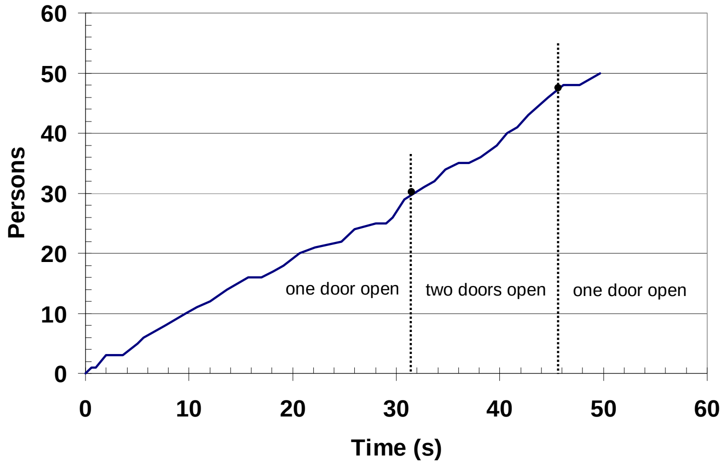


Figure 17. Number of persons walking out from staircase A along route 3 using either one or two leaves of the doorway. The curve starts rising after the congestion begins.

Interestingly, the crowd flow (persons/s) remains fairly steady regardless of the number of open door leaves, as seen in Figure 17. The flow rate and specific flow rate values with different door widths are presented in Table 5.

Table 5. Flow rate and specific flow rate values with different door widths.

Doorway width (m)	**Flow rate (persons·s^{-1})**	**Specific flow rate (persons·s^{-1}·m^{-1})**
0.9	0.89	0.98
1.85	1.19	0.64

<u>Route 4</u>: Within the first 4 min of the alarm, approximately 350 persons were evacuated from the building. The rest of the evacuees exited the building after 7 min of the alarm. They were mostly people belonging to the building's security organisation. Figure 18 shows the number of evacuated persons through doors 4a–4d as a function of time. Door 4a is normally closed and locked but can easily be opened from the inside. During the drill, nobody exited through door 4a however.

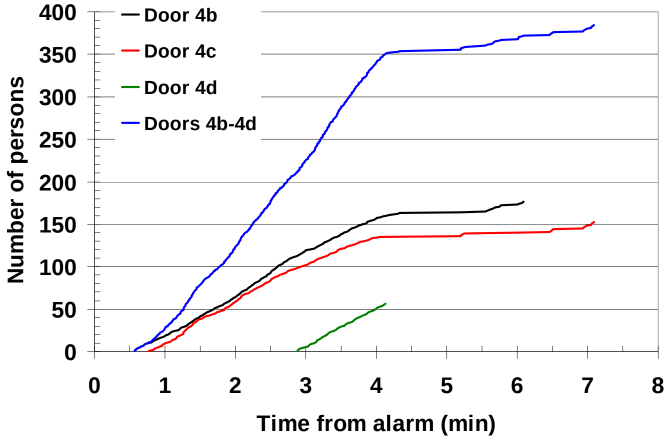


Figure 18. Number of persons evacuated through doors 4a–4d.

<u>Route 5</u>: The first people evacuated from the building through route 5 after 2 min 40 s of the alarm. Within 5 min of the alarm, about 200 people were evacuated through this route. Figure 19 shows the number of people evacuated through route 5 as a function of time.

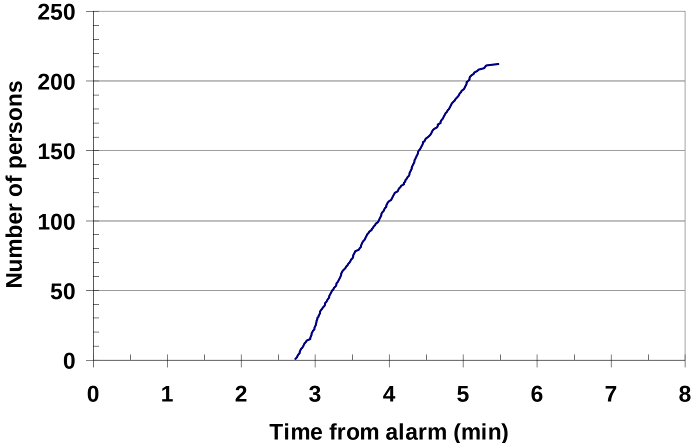


Figure 19. Number of people using route 5 as a function of time.

Route 6: Through doors 4a–4d and 5, 596 people were evacuated within 7 min 5 s. The flow rate was at its highest after about 3 min of the alarm (Figure 20).

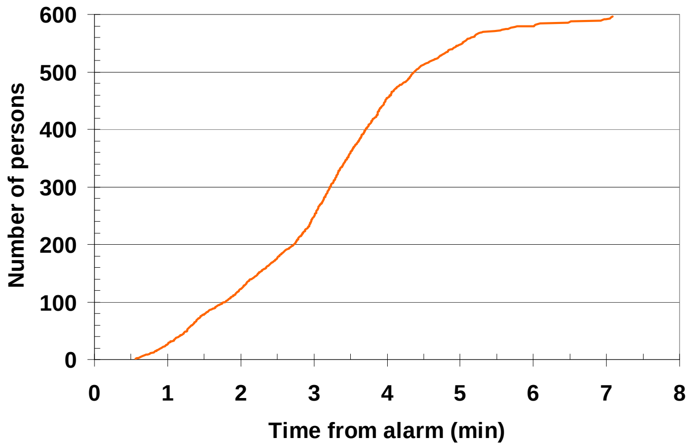


Figure 20. Number of people using route 6 as a function of time.

Figure 21a shows that, at its highest, the value of the crowd flow rate through doors 4b–4d was about 1.35 persons/s, while the maximum flow rate out from staircase A was about 2.5 persons/s. The higher value is due to the wider exit for staircase A. The specific flow rates (determined per door width [persons$\cdot$s^{-1}m^{-1}])

in Figure 21b are at the same level (about 1.5 persons·s^{-1}m^{-1}) however. The cumulative distribution function of specific flow rate is presented in Figure 21c. Figure 21c shows that the lower quartile (25%) of the specific flow rate is 0.8 persons·s^{-1}m^{-1}, the median (50%) 0.9 persons·s^{-1}m^{-1} and the upper quartile (75 %) 1.0 persons·s^{-1}m^{-1}.

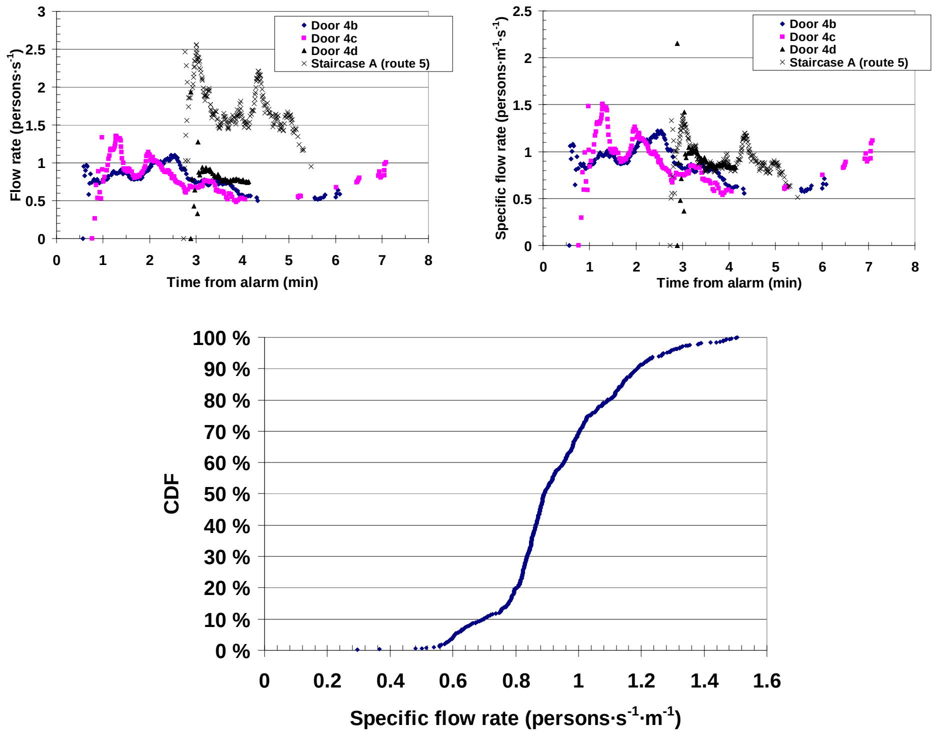


Figure 21. a) Crowd flow rate, b) specific flow rate through doors 4b–4d and staircase A (route 5) and c) cumulative distribution function of the specific flow rate.

The walking speeds (in the atrium, along route 1) calculated from videotapes are presented in Figure 22. The monitored path length was about 10 m. It was not possible to calculate the walking speeds of all evacuated persons walking through the atrium. The results are presented separately for individuals and groups (at least two people). As seen in Figure 22, there was no significant difference between these two groups.

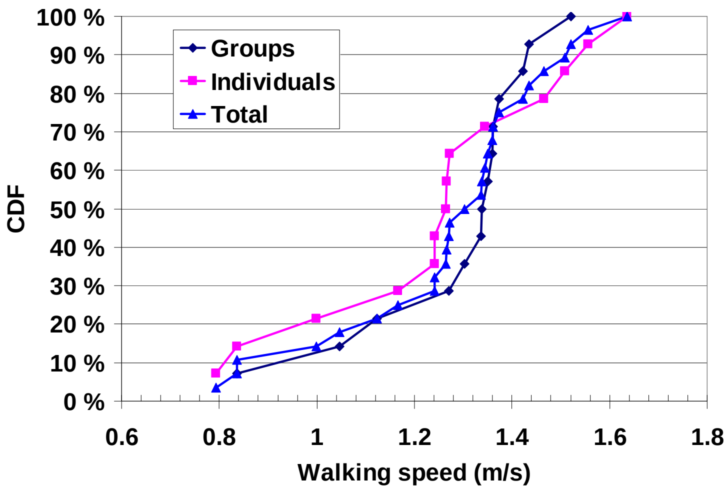


Figure 22. Cumulative distribution of walking speeds.

Observations

The feedback meeting was held after the drill and the following observations were made by the safety organisation members:

- In staircase A, there was congestion on the third and fourth floors, as most people apparently wanted to go out through the main exit.
- On the fifth floor, people were guided to staircase B where there was no congestion at all.
- The evacuees would have liked the local security organisation to use megaphones to guide them (for example, to move further away from the exits).
- A busy road near the main exit can be an additional element of danger to the evacuees. The organised guidance of local security staff may be used to reduce this risk.
- The announcements could not be heard in the corridors of different floors, but they could be heard in the staircases and the basement.

Route 5 was used because a member of the safety staff opened the door in staircase A and showed the route to the people. Until then, the normal route 3 inside the building was used.

A2. Case B: A vocational high school

Background

The high school building was in the same city block in Helsinki as the building presented in Case A. The evacuation drill was held in October 2007. Based on our observations, there were about 200 students and staff inside the building. The real number of participants could have been greater as not all the exits were monitored. The evacuation drill was announced to the safety staff and students in advance. The students knew the week and the staff the exact date of the planned drill.

Building description

The building has five floors and, in this case, two video cameras and one surveillance camera were used to monitor the area of the main entrance; see Figure 23. The focus was on monitoring the doorway flows and the door selection routines of the people.

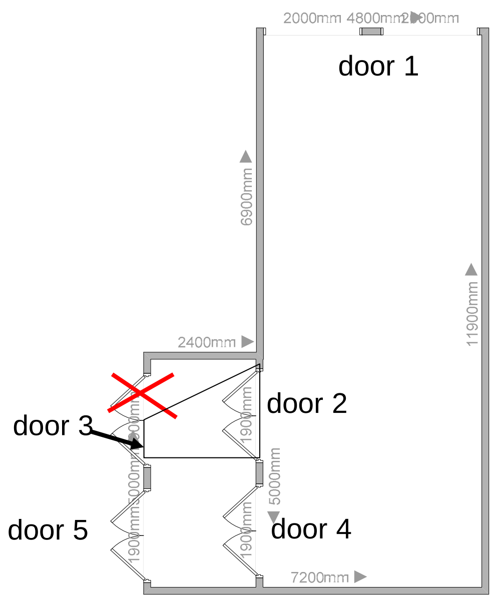


Figure 23. The monitored main entrance. The atrium is next to door 1, and the outer doors are doors 3 and 5.

Results

The rate of evacuating people was counted from the videos using the Evaccounter described in Section 2.2.

The camera was installed in the atrium, through which 148 persons evacuated within 6 min 6 s of the alarm. The number of persons as a function of time is presented in Figure 24.

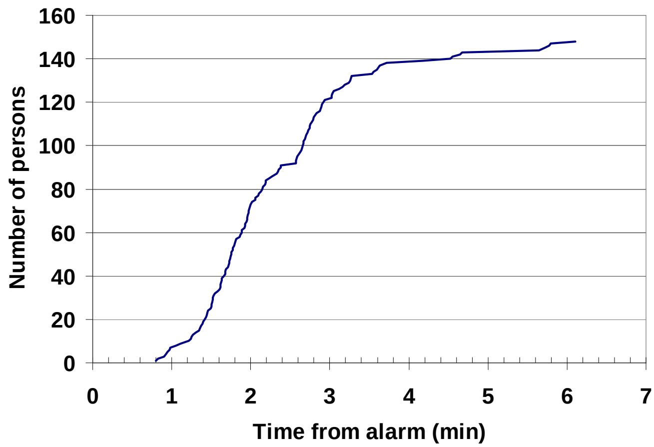


Figure 24. Number of people evacuated through door 1 (the atrium) as a function of time.

Some investigation was carried out to obtain information on the queue formation. Figure 25 shows the first 77 people who evacuated through doors 1–3. As shown, the human flow (slope of the curves) decreases at doors 2 and 3 compared with the flow through door 1. This is due to the queuing that forms because of the entrance tambour (the space between doors 2 and 3) and the narrow outer door 3. It was also noted that no one used both door leaves of door 3, probably because the other leaf was the emergency door, although it could be opened from inside by pulling the latch. The human flow values (30–70 people) for doors 2 and 3 were about 1.08 pers.$\cdot$s^{-1} and 1.00 pers.$\cdot$s^{-1}, respectively. The flow for door 1 was 1.46 pers.$\cdot$s^{-1}.

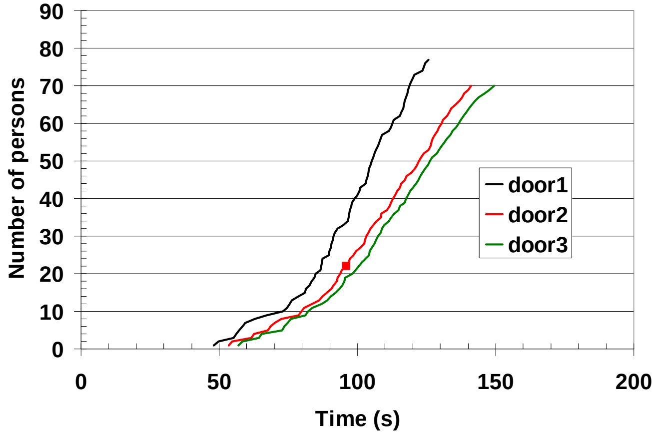


Figure 25. The first 77 persons evacuated through doors 1–3. The queuing effect can be seen from the slopes of the curves. The dot on the curve for ‘door 2’ is the point at which the other leaf of door 2 was opened.

From the data in Figure 25, we can estimate the queuing formation between doors 1 and 2, as people queued in line and waited for their turn to step into the entrance tambour. The queue formed very fast: within one minute, about 26 persons were queuing.

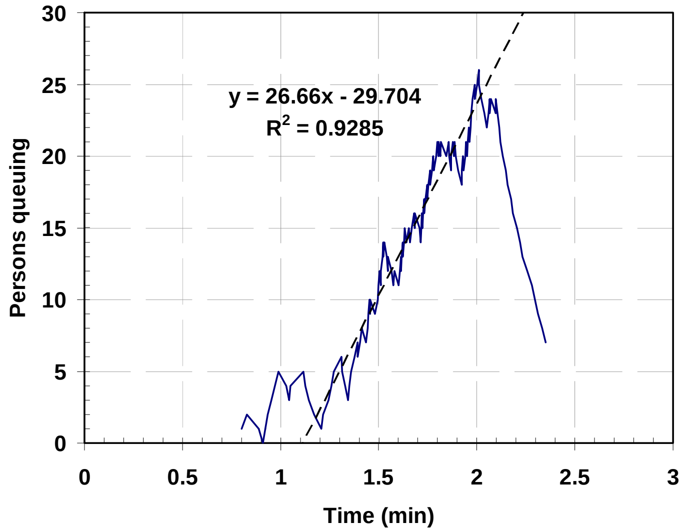


Figure 26. Number of queuing persons between door 1 and door 2. The linear trend shows the growth rate of the queue.

The crowd density inside the entrance tambour can be calculated by estimating the surface area that was effectively used between doors 2 and 3 (see Figure 23). Figure 27 shows the almost linear dependence of walking speed and crowd density.

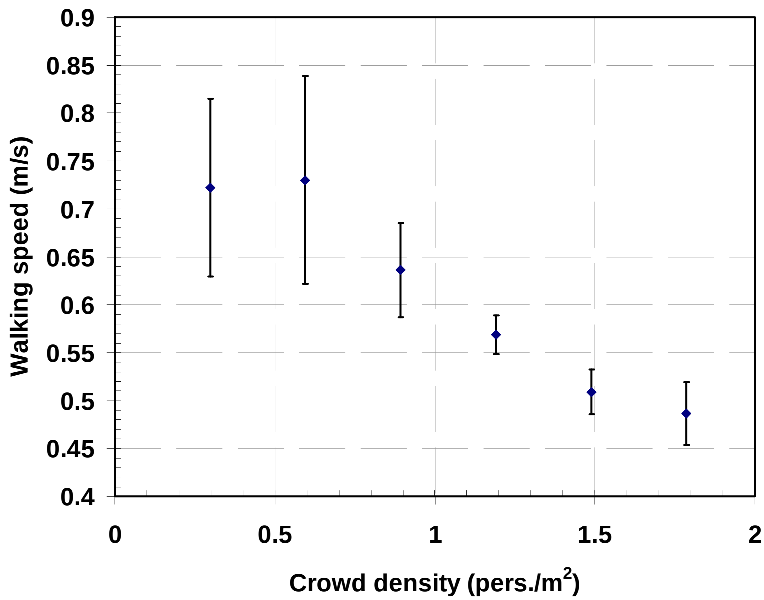


Figure 27. The dependence of walking speed and crowd density inside the entrance tambour. The error bars represent the standard error of the mean.

Figure 28 shows the dependence of the specific flow and the crowd density. As shown, the specific flow increases to a value of about 1.1–1.2 pers.·s^{-1}·m^{-1}. The capacity of the entrance tambour does not limit the specific flow within this range of crowd density.

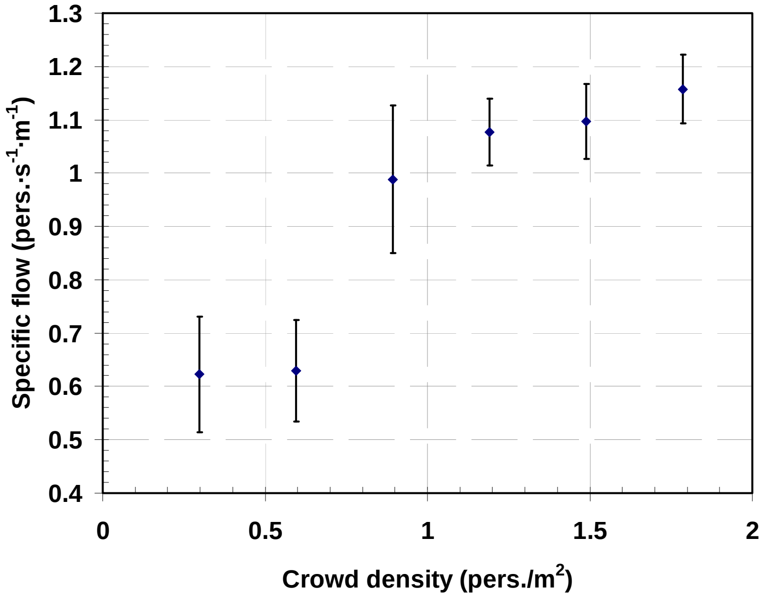


Figure 28. The dependence of specific flow and crowd density inside the entrance tambour. The error bars represent the standard error of the mean.

Figure 29 shows that the crowd flow rate was about 0.4 persons/s lower as the evacuees came out from the building during the drill compared with the flow rate as they went back in after the drill. The reference point was door 1. The natural explanation is that people went back inside in larger and more compact groups than they came out.

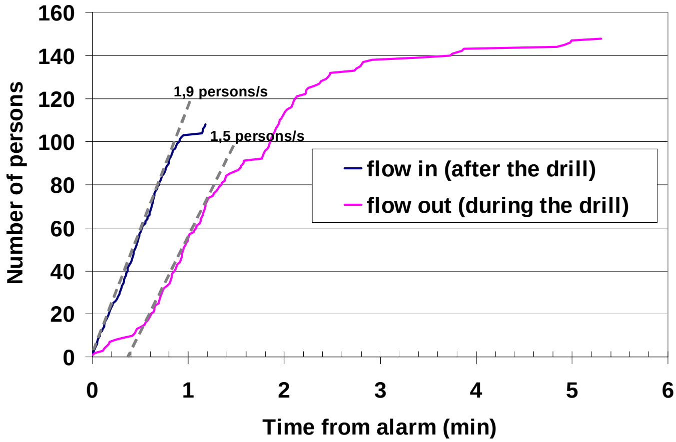


Figure 29. Number of people as a function of time as people come out during the drill and go back in after the drill. The time of the 'flow out' curve is shifted back by about 1 min.

Observations

The main observation of this evacuation drill was that less than 10% of the evacuees used doors 4 and 5. Doors 4 and 5 were similar to doors 2 and 3. At least seven of those who used doors 4 and 5 seemed to clock themselves out with the time-card device that was located near doors 4 and 5. This may be the reason they picked these doors. Other people who used doors 2 and 3 seemed to follow people and used pre-opened doors.

After the fire drill, the safety staff gave some feedback:

- Except for staircase C and near the main exit inside the building, the announcements could be heard well.
- There were no local security staff on the fourth floor.
- Some of the information boards were installed at the wrong angle (90°), so it was difficult for evacuees to orient themselves and move in the right direction.
- Outside the building, there was no guidance for the evacuees.

A3. Case C: A supermarket inside a shopping centre

Background

In this case, the fire alarm was real. A frozen sprinkler nozzle in a supermarket of a large shopping centre raised the alarm. In the beginning, the voice instructions through the PA system were, 'we are investigating the situation…' and orders to evacuate the building were not given at that time. It took about 13 min from the sprinkler activation until the fire brigade arrived and ordered the security staff to start the evacuation. The decision by the fire authorities was not to evacuate the whole shopping centre, just the supermarket where the frozen sprinkler caused the alarm. The security staff inside the building communicated through radiotelephones after the evacuation order was given. After that, they started to guide people out of the building.

Building description

Figure 30 illustrates the floor plan of the supermarket where the real fire alarm occurred. Normally, people entered through automatic swing doors on both sides of the supermarket (routes C1c and C2c). Inside the supermarket, there are two main corridors (corridors 1 and 2) and several smaller corridors (all marked as route C3) between the shelves.

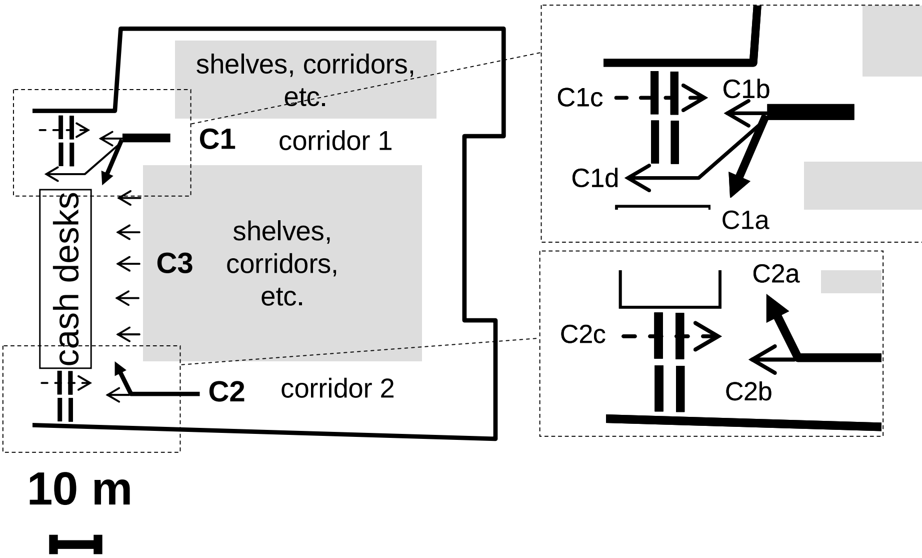


Figure 30. A schematic floor plan of the supermarket inside the large shopping centre. On the right side, the arrows represent different walking routes of evacuated people. The dashed arrows, C1c and C2c, show the normal routes to the supermarket.

Results

During the evacuation, people walked mostly through the main corridors 1 and 2; see Figure 31. About 190 people came through corridors 1 and 2. About 40 people came through the area of shelves where the narrow corridors are. It was noted that about 30 people came into the shop while the evacuation was on. This is understandable because they did not know that the security staff had given orders inside the shop before the evacuation. The staff noticed the situation and blocked the entry.

a) b)

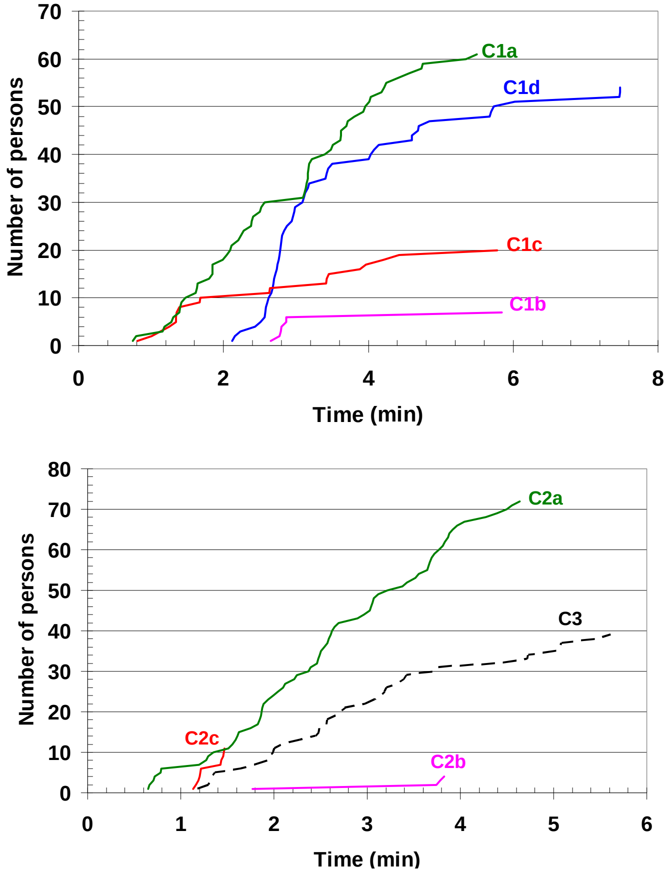


Figure 31. Results of supermarket evacuation. The explanation of notations is shown in Figure 30.

Observations

This case was an example of the walking security staff giving the evacuation orders to every customer they met in the shop. A couple of videos showed that the orders were given close to the people. After the orders (lasting 5 s–10 s per case), the customers started to move towards the cash desks. The orders had to be given to every customer, one at a time, so the total time to cover all the people took a relatively long time. Some of the customers were putting goods in their shopping trolleys while moving towards the cash desks and being evacuated. At 3 min–4 min, the shopping trolleys congested the area near the cash desks and the security staff had to give orders to bypass the cash desks without purchases.

A4. Case D: A department store

Background

This case was a real fire alarm inside a department store (part of a larger shopping centre). Two lights were smoking because of an electrical failure. A staff member raised the alarm and called the fire department. The security staff checked the situation and switched off the power to the lights (a power cut) inside the department store. The store had emergency lighting so people could see and move. Soon after that, the security staff started to investigate the light failure more closely by carrying equipment such as ladders and driving the truck closer to the venue.

The alarm was raised at noon on a working day so the store was not full of customers. According to the security staff's estimations, there were about 30 people inside the department store at the time of the alarm.

The first announcement inside the store was given at the same time as the lights were switched off. The announcement only applied to the power cut and no smoke or fire was mentioned. The fire brigade arrived at the scene about 12 min after the power cut and the instructions to evacuate the store were given over the PA.

Building description

The examination of the evacuation situation was carried out using two surveillance camera videos; see Figure 32. One was taken on the spot and the other near the cash desks. The video taken on the spot does not show many normal customers or their movements but contains mostly the security staff's and staff's actions. Both videos started about 1 min before the time of the power cut.

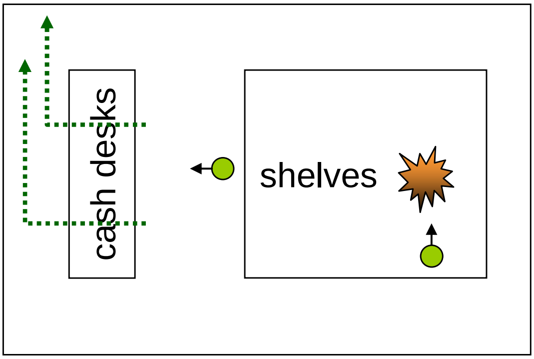


Figure 32. Floor plan of the department store. The two circles show the surveillance camera locations.

Results

Most of the events during the evacuation are observed from the surveillance camera near the cash desks. The zero point of the fire alarm is the time of the manual power cut. Thus, all the events and evacuated people shown here were monitored and counted after the power cut. The evacuation time (when the instructions to evacuate were given) is assumed to be the same as that when the fire brigade arrived (12 min).

Figure 33 shows the evacuated customers from the department store. All the evacuees were allowed to exit through the cash desks after the evacuation request. As shown in Figure 33, most of the customers had time to leave the building before the fire brigade arrived. The videos show that there was no difference in the customers' behaviour after the time the evacuation request was given. The flow rate also remained the same during the 25 min evacuation.

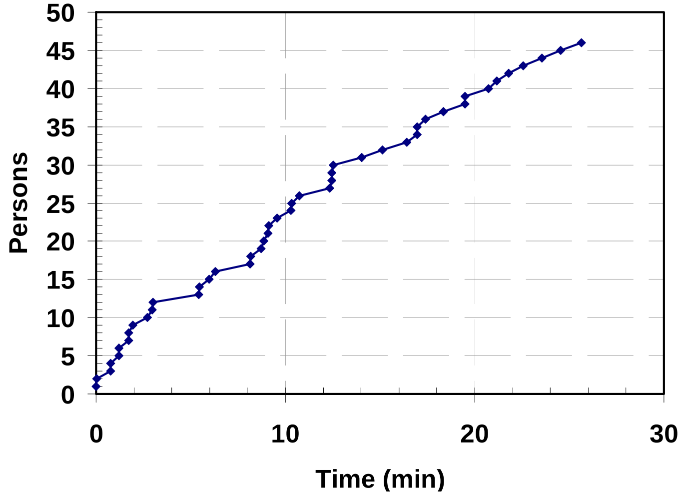


Figure 33. Number of evacuated customers after the power cut. At the time of 12 min, the fire brigade arrived and at the time of 21 min, the cash desks were closed.

Figure 34 shows the time distribution for an individual customer spending time at the cash desk. The time is calculated over the period when the customer puts his or her purchases on the desk until the next customer does so. This is the same as the time the cashier spends working with one customer. The distribution in Figure 34 also gives the information about the queuing time at the cash desks. For example, the median of the distribution is about 40 s, and multiplying it by the number of customers gives the upper limit estimation for the queuing time at the cash desks as well as the time the store is empty for further actions. If the situation is threatening, the evacuation naturally has to be carried out without stopping at the cash desks.

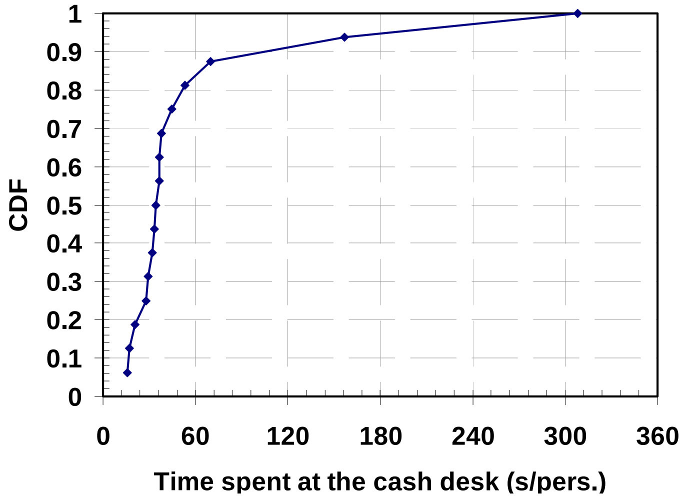


Figure 34. The distribution for the time spent at the cash desk when paying for the purchases.

Observations

Before the fire brigade arrived on the scene, one customer came into the store at the time of 7 min after the power cut. Soon after that, the main entrance was closed so new customers could not come in. The staff behaved more actively after the evacuation request (12 min after the power cut), probably because they were told to check the department store for customers. At the time of 21 min after the power cut, the cash desks were closed and the cashiers were guided to go out. One staff member stood in the corridor guiding the rest of the customers out. It was clear, however, that the majority of the staff was inside the building for a whole 45-min episode. The reason for this was probably that the situation was deemed safe and that there was no reason to evacuate them.

A5. Case E: A shopping centre

Background

This is the same building as that of evacuation Case C. At this time, the evacuation was a drill and covered the whole shopping centre and its staff. The drill was held in the autumn at dawn before the shopping centre opened for customers. The number of volunteers was estimated at about 100, which was believed to be 10% of the normal number of staff. The staff had practised the locations of exits and exit routes before the drill.

Building description

The building consists of three floors, and the supermarkets are on the lowest floor (see Figure 35), most of the small shops are on the second floor and the rest are situated on the third floor. The main doors and exits from the first and second floors lead straight to street level (a stepped building). Most of the exits on the first floor are locating in the area of the two supermarkets.

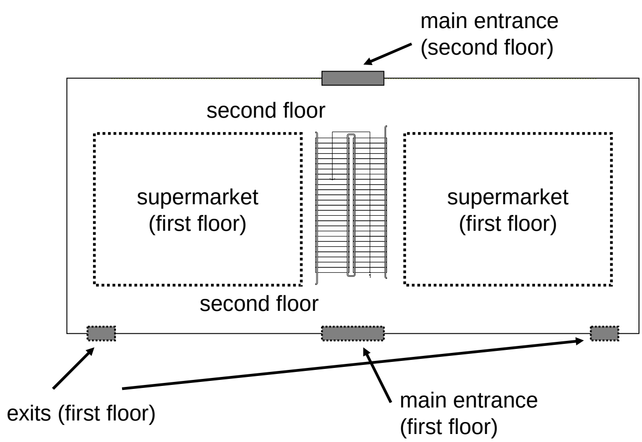


Figure 35. Floor plan of the first and second floors of the shopping centre.

Results

The monitoring focused on the main entrance on the first floor and the main corridor on the second floor inside the building. The number of persons on the second and third floors was quite low, about 10–20, meaning that most of the participants were staff at the supermarkets on the first floor.

The request to evacuate the building was in two phases, and the first public announcement contained information about the investigation of the cause of the fire alarm and orders not to use lifts for safety reasons. After 1 min 27 s of the first announcement, the actual request to evacuate was given.

Figure 36 shows the evacuated persons through the main entrance on the first floor. The first five persons used the exit door next to the main doors but the rest used the main doors. The five exit users seemed to walk straight to the exit doors without trying to use the normal doors.

About 100 persons were evacuated from the shopping centre in 4 min during the drill. Of these, a substantial number of people, about 80, used the exit doors on the first floor. All 80 persons were staff at the supermarkets who knew the location of the exits.

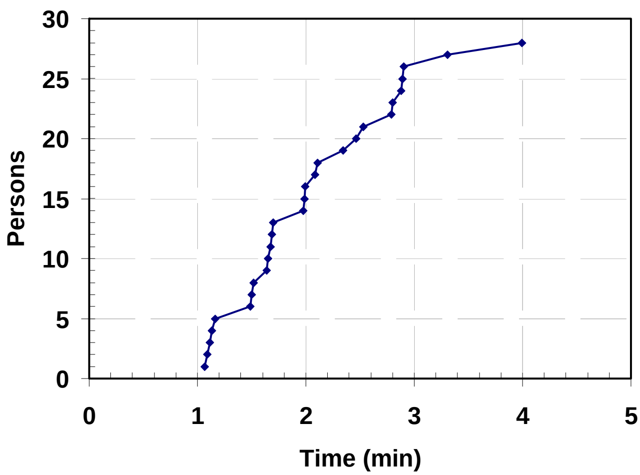


Figure 36. Number of evacuated persons through the main entrance on the first floor.

Observations

The few people who started to evacuate from the second floor did not use the main door on the second floor, although it would have been shorter than walking down the stairs and through the first floor. The total number of evacuees was very low on the second floor and most of the shops did not take part in the evacuation drill.

A6. Case F: A comprehensive school

Background

This case was a real fire alarm. The reason for the alarm was a smouldering light switch in a classroom and the fire detector was activated. The classroom was empty at the time, but in the other classrooms, lessons were going on.

The staff extinguished the fire using a portable fire extinguisher and started the evacuation. The request was given manually over a PA system, while the alarm bells were ringing. All the people were successfully evacuated before the fire brigade arrived.

Video material showed that A few people were walking along corridors at the time the alarm was raised. The school normally has about 500 pupils.

Building description

The floor plan of the building is shown in Figure 37. The building has three floors of which the two lowest have exits. Figure 37 shows the three exits that were used most during the evacuation. Doors 1 and 2 are normally used during breaks. The geometry of doors 1 and 2 is typical: the inner double-leaf door is normally unlocked, whereas the other outer leaf is locked but can be opened from the inside by using the bolt. Door 3 is not used in normal situations.

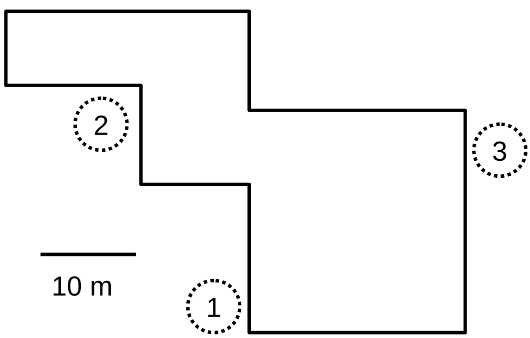


Figure 37. A simplified illustration of the comprehensive school floor plan. The evacuation took place mostly through doors 1–3 shown above.

Results

The number of evacuated people is shown in Figure 38. Most of the people used the main door (door 1). Door 2 is also familiar to the pupils in their daily activities, which can be seen from the number of evacuees using it. The effect of the normal (right-hand traffic) use of door 1 is also seen in the evacuation scenario as about 90 pupils used the right side and about 30 pupils used the left side of door 1. The last people evacuated were the staff members.

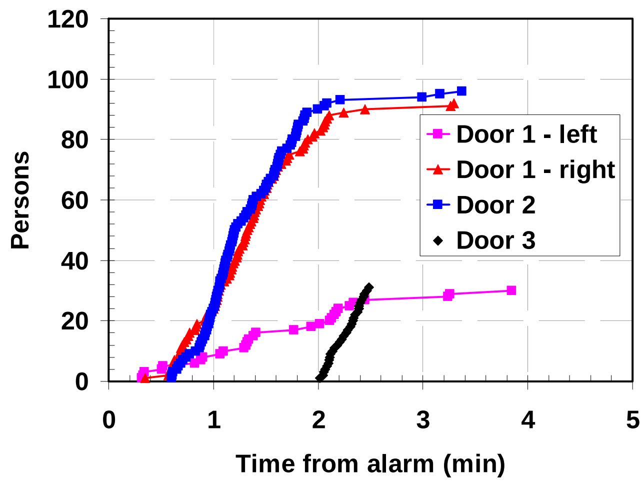


Figure 38. Number of persons as a function of evacuation time.

The specific flow rates for doors 1–3 are presented in Figure 39. As shown, the maximum flow rates are in the range of 2–2.8 pers.$\cdot m^{-1} \cdot s^{-1}$. The specific flow rates for door 2 are very high because the pupils only used one leaf of the double-leaved door, although both could be unlocked from the inside. From the video, it could be seen that the crowd occasionally formed congestion that could have been cleared by opening the other leaf.

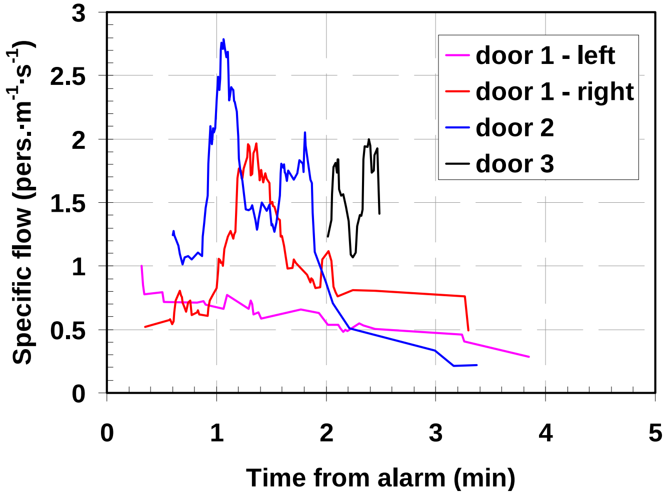


Figure 39. Specific flow results measured for doors 1–3.

Figure 40 shows the pre-movement times inside the comprehensive school. The pre-movement time estimations were performed by analysing the video material recorded inside the comprehensive school. The pupils who were walking along the corridors as the alarm was raised had the shortest pre-movement times (0…20 s). Typical reactions to the alarm were to change the walking direction or to start walking towards the exit.

Observed pre-movement times between 20…40 s were cases when pupils sat and observed other pupils' reactions before deciding on their own actions.

The longest pre-movement times were for the pupils who waited for their friends with whom they wanted to evacuate and one man who finished his ongoing work before he started to evacuate.

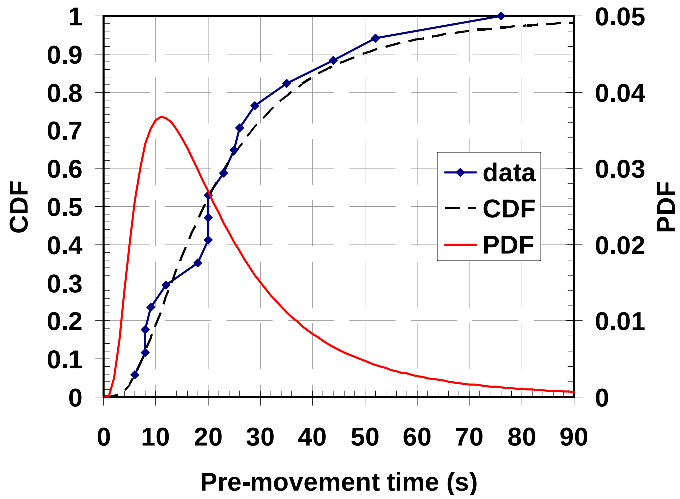


Figure 40. Pre-movement times during the comprehensive school evacuation. The log-normal distribution parameters are μ = 2.96 and σ = 0.74 (median = 19 s).

Observations

The exact time of the alarm was difficult to measure because the surveillance cameras do not save audio, which would have made it easier to fix the alarm time. The time of the fire alarm was defined by watching the reactions of pupils on the videos and using the time estimations given by the teachers at the school. The surveillance camera installation covered the whole building (except the classrooms), so the pre-movement times and reactions were clearly seen. It was notable that not the whole capacity of available door width was used effectively.

A7. Case G: A hospital ward

Background

An evacuation drill was carried out in a hospital ward. Figure 41 illustrates the floor plan of the evacuation drill. Ward No. 2 has beds for 25 patients, but the drill focused only on single room evacuation. Room no. 2 had six patients who could not move by themselves and needed help with evacuation. One bed was simulated to be on fire, and the fire had to be extinguished. At the time the alarm went off, Ward No. 2 had three nurses, simulating the number of nursing staff at night. The evacuation drill was planned so that the nurses in Ward No. 5 attended the evacuation as soon as they noticed the alarm and located its origin.

The nurses who took part in the drill in Ward No. 2 were given instructions in their room N (see Figure 41) about the patients' condition one hour before the alarm took place. The nurses knew the exact day of the drill but did not know the exact time or room in which the fire and patients would be located.

The alarm was raised by activating the smoke detector in room no. 2. Soon after that, the alarm bell went off in the hospital and 30 s after the alarm bell, the announcement of the evacuation drill was made. The announcement included information about the location of the fire, so the nurses in Ward No. 5 easily found the origin of the fire and went to help. All the patients were in their beds during the evacuation, so the nurses pushed the beds and patients out of the room.

Building description

The hospital has several floors but only one floor was evacuated. The camera installations were carried out about two hours before the drill. All four cameras were used to monitor the drill. One camera was in the stairwell, one in the corridor and two were located in room no. 2.

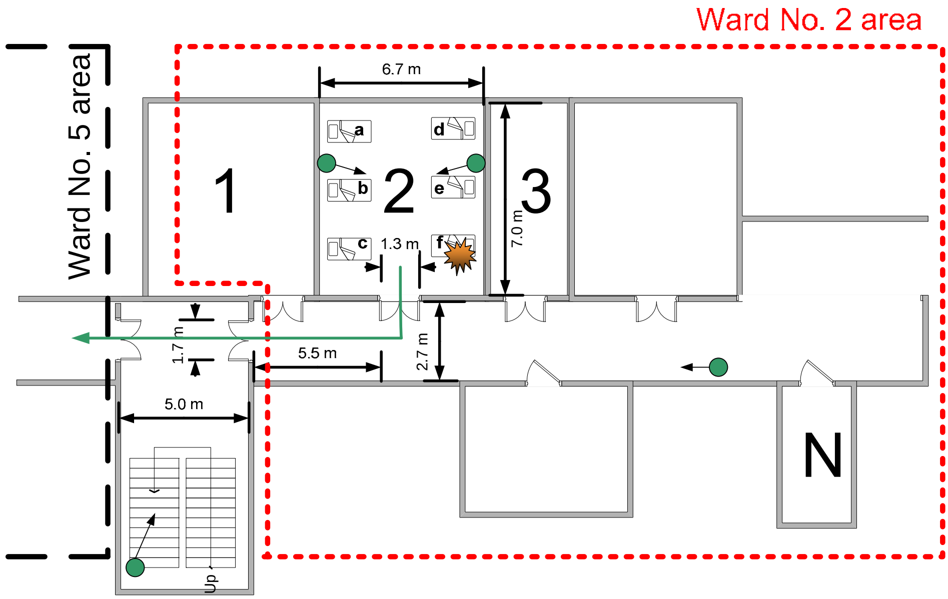


Figure 41. Illustration of the evacuation drill in the hospital ward. The arrow from room no. 2 shows the evacuation route to Ward No. 5. The fire is located in the bed with the letter ‘f’.

Results

Table 6 presents the events during the evacuation drill. Most of these events are based on the video camera recordings.

Table 6. Events during the evacuation drill in a hospital ward.

Time (min:s)	
-00:22	the cold smoke generator is pointed at the smoke detector
-00:10	the LED light of the detector comes on
00:00	the alarm bell sounds on the stairs
00:07	the alarm bell sounds inside Ward No. 2
00:07	the people inside room no. 2 cannot hear the alarm bell sound
00:14	the nurses react to the alarm bell sound (00:07 inside Ward No. 2)
00:33	the nurses find the fire after searching the other rooms
00:38	the nurse starts to extinguish the fire on bed ‘f’ with a blanket
00:52	the nurse starts to move the patient ‘e’ (see Figure 41)
01:00	the nurse goes to call to emergency number
01:10	twelve nurses arrive from Ward No. 5 to help with the evacuation; one stays by the stairs
01:18	patient ‘e’ out of room no. 2
01:19	the nurse starts to move patient ‘d’
01:26	patient ‘e’ is by the staircase and goes to Ward No. 5
01:28	patient ‘d’ out of room no. 2
01:34	the nurse starts to move patient ‘b’
01:36	the nurse starts to move patient ‘c’
01:38	patient ‘d’ is by the staircase and goes to Ward No. 5
01:43	patient ‘b’ out of room no. 2
01:43	the nurse starts to move patient ‘a’
01:51	patient ‘b’ is by the staircase and goes to Ward No. 5
01:53	patient ‘c’ out of room no. 2
01:57	patient ‘c’ is by the staircase and goes to Ward No. 5
01:58	patient ‘a’ out of room no. 2
01:59	the nurse starts to move patient ‘f’ (patient ‘f’ was a dummy)
02:05	patient ‘f’ out of room no. 2
02:06	patient ‘a’ is by the staircase and goes to Ward No. 5
02:06	checking the toilets in room no. 2
02:16	patient ‘f’ is by the staircase and goes to Ward No. 5
02:20	all the patients are out of room no. 2 and the door is closed

Figure 42 shows the time during which the patients are out of room no. 2 and at the same time the number of nurses inside the room. It shows that as the number of nurses increases the evacuation progresses faster. The other nurses from Ward No. 5 came to help after 1 min 10 s, as seen from Table 6.

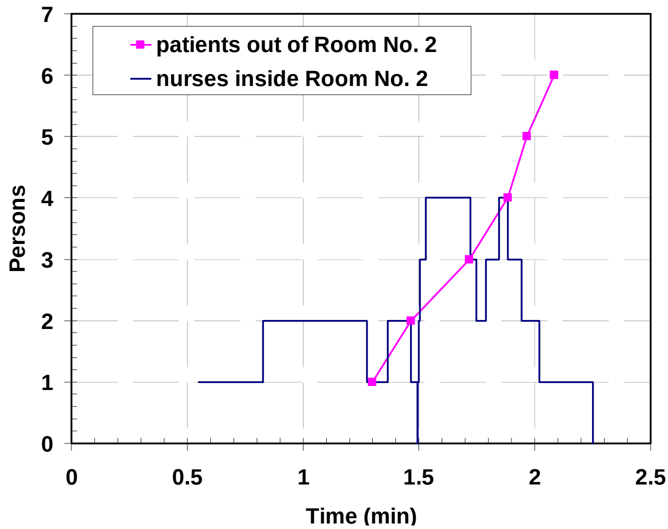


Figure 42. Results of the hospital ward evacuation drill. The figure shows the number of nurses inside room no. 2 evacuating patients.

Observations

The whole evacuation was carried out very fast. After 2 min, all the patients were evacuated from their rooms. Many nurses came to help from the other wards and the evacuation actions accelerated. Having beds moved by several nurses was an important action that prevented the beds from forming a plug in the corridor.

A8. Case H: A factory

Background

The evacuation drill held in the factory (Case H) was a combination of a rescue and evacuation drill. The simulated situation was an explosion in a warehouse inside the building. For the safety organisation and staff, the drill was the first to be held for a long time. The drill was partially unannounced and the safety staff were the only ones who knew the exact day and time. The number of staff, including safety staff, was about 80. The alarm was planned to activate through fire buttons and fire bells. No PA system was installed in the factory. The factory also had a text messaging system that was going to be used for the drill. The first message concerning the situation was planned to be sent to the first aid group and the safety organisation members, and the second to the staff.

Building description

Figure 43 shows the floor plan of the factory. The factory and the warehouse premises were on the first floor, to which doors 1 and 3 led. The office workers on the second floor used door 2. The camera installations inside the building were on the first and second floors next to long corridors. The cameras were installed unobserved. Two cameras were outside, monitoring doors 1 to 3.

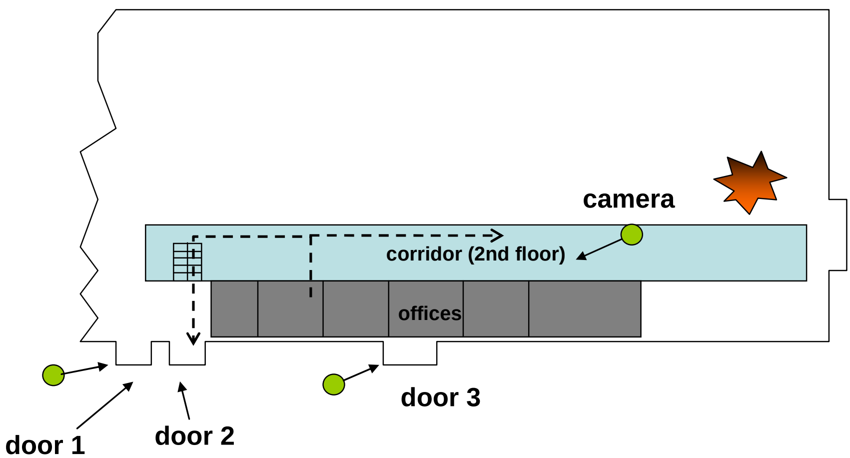


Figure 43. Part of the floor plan of the factory (Case H). The dotted line represents the possible exit routes for the second floor office workers.

Results

The number of evacuated people is shown in Figure 44. All the office workers who were in their offices at the time the simulated explosion occurred were evacuated through door 2. The rest were evacuated through doors 1 and 3. The video on the second floor showed that no one was evacuated in the direction of the fire. As the number of evacuees was lower than 80, some had to evacuate using the door located on the other side of the building. Interestingly, the fire buttons did not work, so the alarm had to be raised by text messaging and verbal commands.

The first aid group members were the first to receive the text messages about the explosion and they began to act and guide the others. The camera installed on the second floor showed that some people noticed the smoke before any text messages were sent. This happened about 1.5 min before the first text message. Table 7 presents the events monitored from the second floor corridor.

Table 7. List of events that occurred in the second floor corridor of the factory (Case H).

Time (min:s)	**Event(s)**
-2:00…-1:30	A woman walked along the second floor corridor in the direction of the fire.
-1:30…-1:00	The same woman noticed the smoke, turned back and started to shout ‘fire in the building, leave immediately’. Another woman who was walking along the same corridor asked, ‘Is there really a fire in the building?’ After convincing her, they both walked out. The workers did not come out of their offices (offices **A**, **B** and **C**) at the time.
-0:45…0:00	A man walked along the corridor, opened the office doors and gave orders to exit. Approximately ten offices were checked and three were occupied (offices **A**, **B** and **C**).
-0:30	The workers in office **A** got direct instructions to leave.
-0:15	The worker in office **B** got direct instructions to leave.
-0:14	Two women from office **A** came out into the corridor and started to evacuate.
-0:04	The worker in office **C** was given direct instructions to leave.
0:00	*(The time when the first text message was sent to the first aid group)*
+0:07	A woman from office **C** came out into corridor and began to evacuate.
+0:17…+1:15	About ten people came from the direction of the fire and walked through the corridor to evacuate. Some of the people went to their offices to get dressed or collecting something before going out. (These people knew that the evacuation was a drill.)
+0:25	A man from office **B** came out into corridor and started to evacuate.
+2:45…	No one else walked through the corridor.

As shown in Table 7, the pre-movement times for the workers from offices A, B and C were 16 s, 40 s and 11 s, respectively. It is not known if the workers in offices A, B and C heard the first fire alarm announcement given by the woman at time interval -2:00…-1:30 (see Table 7).

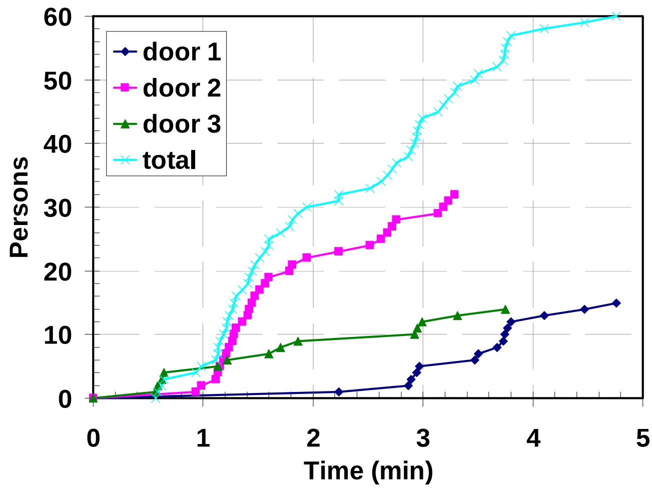


Figure 44. Number of persons as a function of evacuation time. Time zero represents the time when the first text message was send to the first aid group members.

Some other observations were made when people evacuated via their offices to pick up their jackets or for some other reason. Figure 45 shows the results of the pre-movement times for three office workers. After they noticed the fire alarm (from either a text message or a verbal announcement), they started to walk towards their offices and stayed there for a while before they started to evacuate.

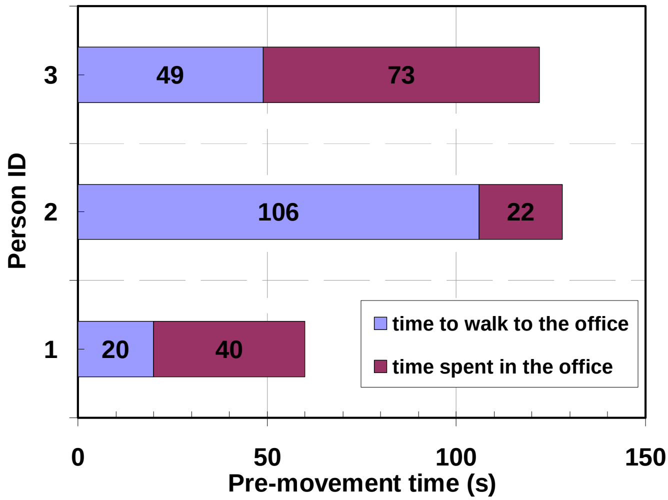


Figure 45. Pre-movement times of three office workers. The time zero represents the time when the first text message was send to the first aid group members.

Observations

The most interesting event was when the fire buttons for the fire bells were pressed but did not activate. Despite this, people evacuated quite well from the building. The text messaging at the first phase applied only to the small first aid group. The verbal announcements seemed to spread through the building quickly, however, and the whole evacuation process lasted about 5 min. The cameras installed outside showed that most of the workers received the second text message (meant for the staff, including the fire alarm note) after they had evacuated (five minutes after the first message). This would obviously have been too late for them if the situation had been real and no other signals of fire had been present.

A9. Case I: Three office buildings

Background

Normal evacuation drills were held in three office buildings (marked here as a, b and c) on the same day. The office buildings belonged to the same company, and the safety staff decided to hold all the drills on the same day. The workers were briefed about the drill and had familiarised themselves with the evacuation routes beforehand. The fire bells and voice alarm systems were used in all the drills. The staff knew the exact time and day of the forthcoming drills. Each of the office buildings had its own safety staff organisation that participated in the drills.

Building description

Each of the office buildings had a few hundred workers, and the number of floors varied from three to seven. The monitoring places were mainly outside, near the main doors and the meeting places. One of the evacuation drills was performed so that the main door of the office building was blocked and the workers had to use the other available routes (exits).

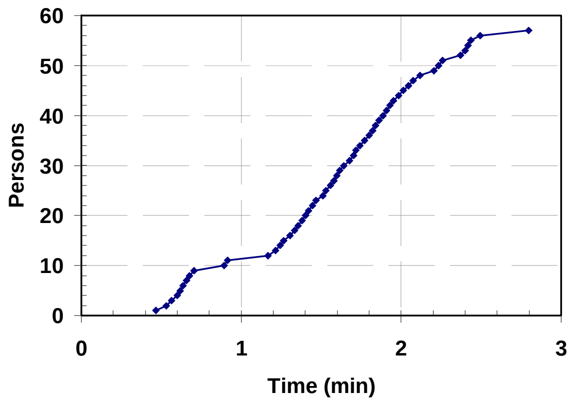
Results

Figure 46 shows the number of persons vs. the evacuation time results for the three office buildings. Figure 46b also shows the persons coming in after the evacuation drill through the same opening as they went out. The maximum specific flows through the doorways were 0.82 pers.$\cdot s^{-1} \cdot m^{-1}$ (Figure 46a), 0.78 pers.$\cdot s^{-1} \cdot m^{-1}$ (Figure 46b) and 1.35 pers.$\cdot s^{-1} \cdot m^{-1}$ (Figure 46c). The specific flow from Figure 46b is calculated from the flow in the data.

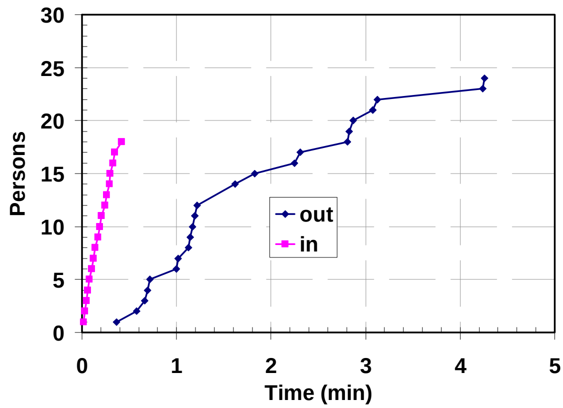
The camera installed inside the corridor of office b (Figure 46b data) showed that within one minute of the alarm, most of the staff members were in the corridor considering which way they should go. Three workers decided to choose one route and the others (about ten people) followed them. The corridor was empty of people in 1.5 min.

Four women came out of their offices and entered the corridor after the fire alarm. The observed pre-movement times were as follows: 19 s, 22 s, 23 s and 28 s.

a)



b)



c)

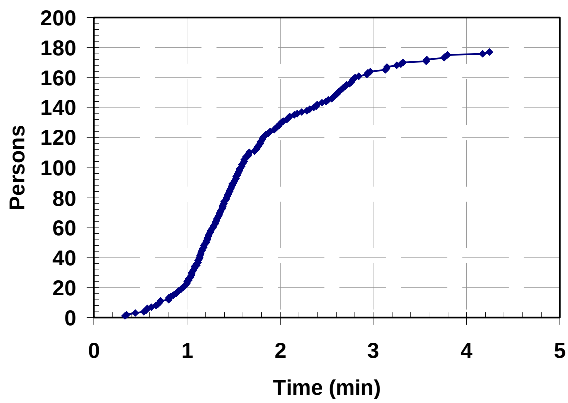


Figure 46. Total evacuation times of the three office buildings. The number of persons walking in b) is counted after the evacuation drill.

Observations

As it was well known beforehand that the evacuation drill would be carried out, the evacuation times were quite short. This was especially clear from the first reactions of the people and the way they had probably prepared themselves and waited for the fire alarm.

The people's actions in the meeting place were uncontrolled, as the safety organisation did not take the lead. This was particularly obvious from the congestion of people in the wrong places in front of the main entrance of the buildings and it probably blocked emergency routes.

In office b, the cyclic alarming between the alarm bell and the voice guidance began with an alarm bell phase that lasted 90 s and continued with a 30 s voice guidance phase. After this, short alarm bell (40 s) and voice guidance (20 s) phases were heard until the end of the alarm continued with the alarm bell. The first 90 s, in particular, seemed too long for the evacuees to be without any information about the situation. The voice guidance would have been more useful if the duration of the alarm bell phase had been shorter.

A10. Case J: A primary school

Background

The evacuation drill was held in Mynämäki in November 2008 at a local comprehensive school with 650 pupils. The drill was targeted at the younger pupils attending primary school classes 1 to 6, with a total of 290 pupils. The number of pupils attending the drill was somewhat lower, however, as the drill was held early in the morning and the school day started later for some of the pupils. Some pupils also attended a gym class that did not take place at the school's premises.

The drill was monitored with video cameras. One camera was on the second and one on the first floor monitoring parts of the classroom corridors. One camera was placed outside the school building so that two of the primary school's entrance (exit) doors could be monitored.

Building description

The primary school has five floors. The ground floor has the main entrance and hallway, kitchen and canteen, and a connecting passage between the different parts of the building. The first floor has classrooms and the staff room. The second floor has classrooms. There are also classrooms situated a couple of steps down from the ground floor, and further down the stairs there are mainly technical premises.

Results

The pupils were informed of the evacuation drill while they were seated in their classrooms. The school's central radio, which was audible throughout the building, was used to inform the pupils that an evacuation drill would take place and that there was no real emergency. At the end of the message, the pupils were instructed to leave the classrooms and exit the building.

The following two charts (Figure 47) show the number of persons exiting through the two school entrance doors that were monitored by one of the video cameras.

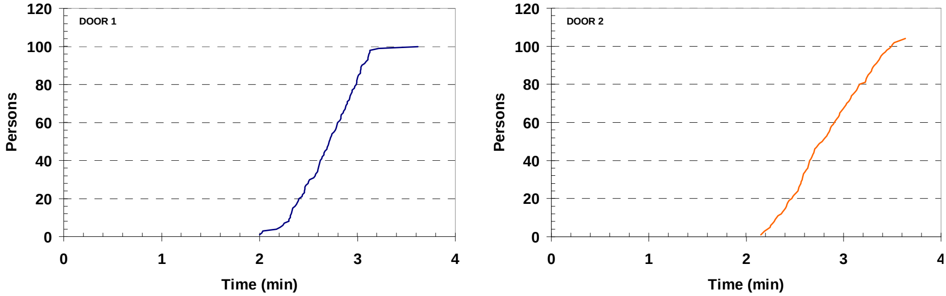


Figure 47. Number of persons per time exiting through the monitored doors.

One hundred people exited door 1 in 97 seconds and 104 people exited door 2 in 89 seconds.

In the passage on the first floor, the exit times from one of the classroom was also monitored. After the pupils had exited the classrooms, they collected their outdoor clothing, put on their shoes and then started to move through the passage and stairs to the school entrance doors where they exited the building. The preparation time of six pupils, from exiting the classroom to having put their shoes on and being ready to start exiting the building, was also measured; this is shown in Figure 48.

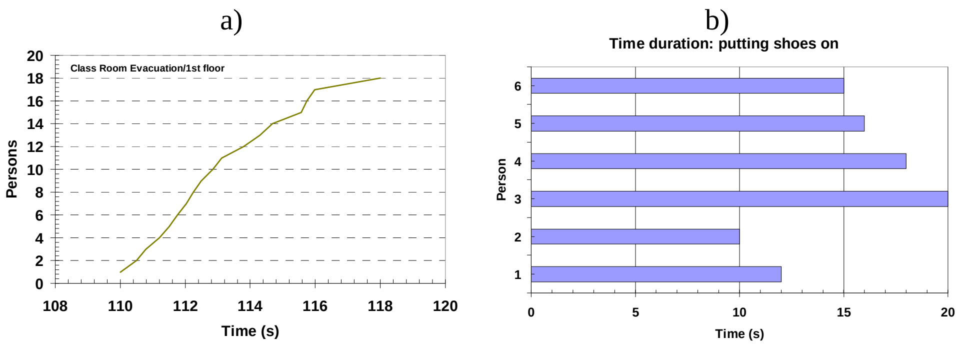


Figure 48. The number of persons exiting a classroom and the preparation times of six pupils.

Observations

The evacuation announcement given through the central radio lasted for 2 minutes. The announcement stated that the situation was a drill and that the parties were on the scene to observe and assist with the drill. At the end, the teacher instructed staff and pupils to exit the building. The teachers in the classrooms and corridors assisted the pupils, and some were given the instruction to grab their jackets, while most of the pupils were just advised to put their shoes on. The evacuation itself was very quick, as the children either walked very fast or ran.

A11. Case N: A church

Background

The evacuation drill was held in April 2009 in a church located in western Finland. The evacuees knew that the drill was going to start during the ceremony. The local fire brigade started the event by producing smoke from the altar using a cold smoke generator. The request to leave the building was given by the priest who interrupted the ceremony after seeing the smoke spread and hearing the alarm signal in the church. The number of evacuees was about 200.

Building description

Quite a good surveillance camera system was installed in the church just a few weeks before the drill. As well as the surveillance camera material, recordings from four digital cameras were used as the evacuation drill was analysed. The floor plan of the church is presented in Figure 49. The number of persons going out through doors A and B was calculated from the videos. The view of door C was blocked due to white cold smoke, so the number of people using that door could not be calculated exactly.

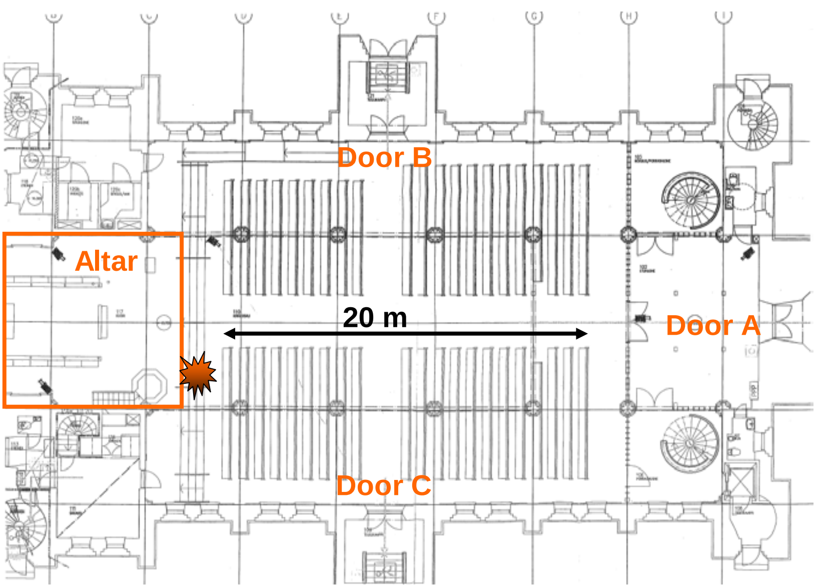


Figure 49. Floor plan of the church.

Results

Usage of doors

The rate of evacuated people was counted from the videos using the Evaccounter described in Section 2.2.

About 80 people were evacuated through door A (double door in Figure 51a) within 2 min 5 s, as seen in Figure 51b. Almost 60 people were evacuated through door B (double door in Figure 51c) within 4 min, as seen in Figure 51d. The estimation of the number of people using door C was about 70–80 within 2 min of the fire alarm.

Four of the evacuees went out through door B in wheelchairs. Three of the wheelchairs were manual and one was electrically powered. The evacuees on the manual wheelchairs each had two helpers and the evacuee on the electrically powered wheelchair had four helpers to assist them out of the church on a ramp. The ramp was hinged and was opened about 1 min 17 s from the time of the alarm.

Figure 50 shows the usage of different doors relative to the initial position of the people. As shown, door C was the door that was used most, probably because the priest gave instructions to go to the meeting place located in the direction of door C.

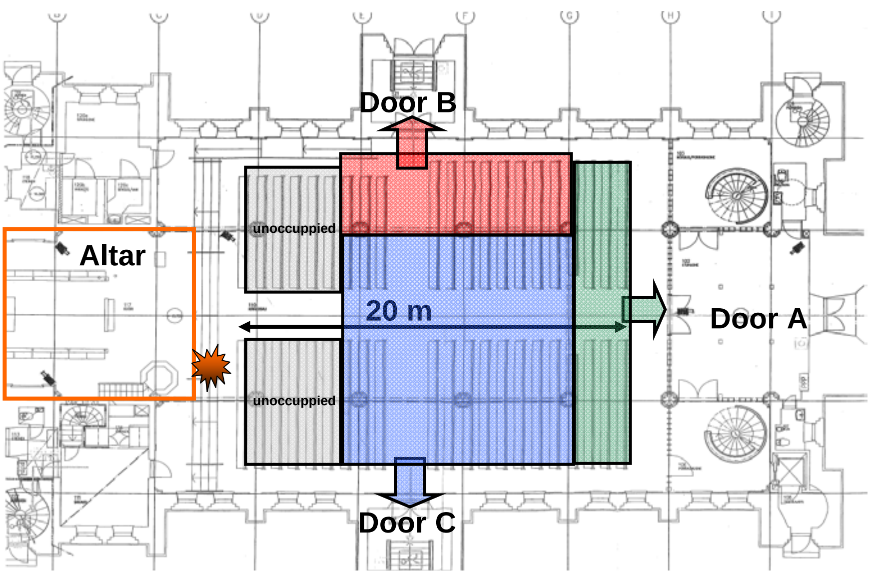


Figure 50. Doors in the evacuation drill in relation to the initial position of the people.

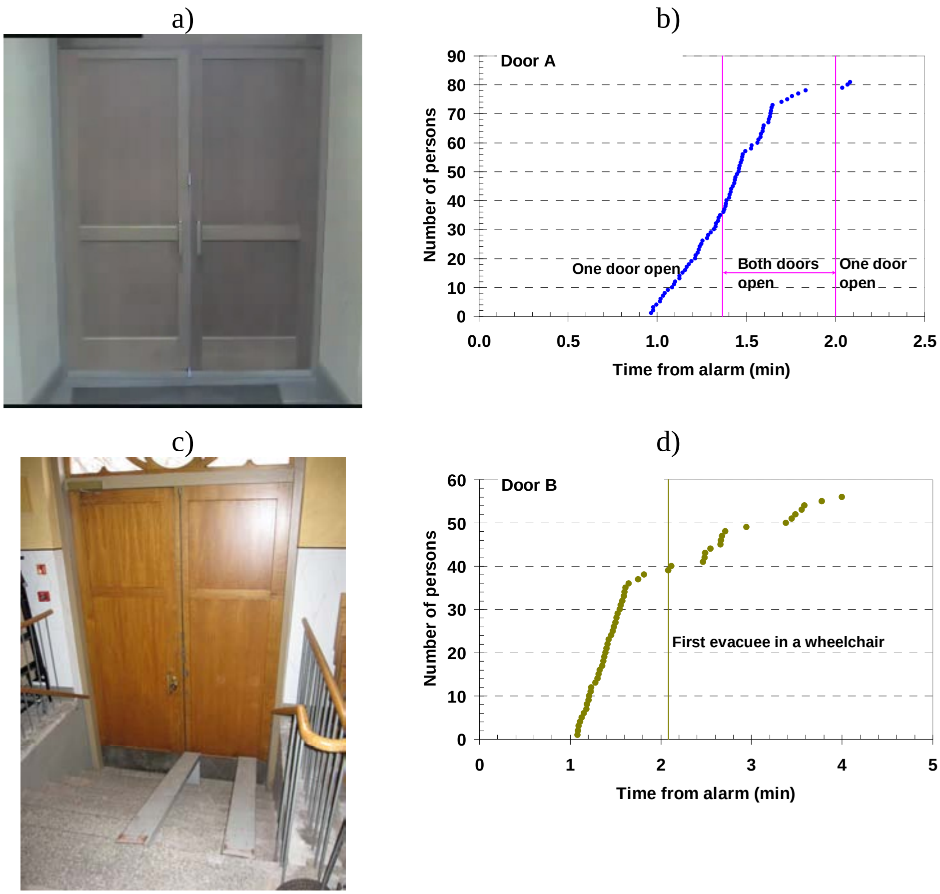


Figure 51. a) Photograph of double-leaf door A, b) number of people who went out of door A as a function of time, c) photograph of double-leaf door B; the hinged ramp for the wheelchairs is in front of the door on the right, and d) number of persons who went out using door B as a function of time.

The human flows

Figure 52a shows that the value of the crowd flow rate through door A was about 3.7 persons/s at its highest, while the maximum flow rate out of door B (Figure 52b) was about 2.0 persons/s. The specific flow rate through door A (Figure 52c) was about 2.8 persons·s^{-1}·m^{-1} at its highest and about 1.1 persons·s^{-1}·m^{-1} through door B (Figure 52d). The cumulative distribution functions are plotted in Figures 52e and 52f. The lower and upper quartiles and the median value of the specific flow rate [persons·s^{-1}·m^{-1}] are tabulated in Table 8.

Table 8. The lower (25%) and upper (75%) quartiles and the median of the specific flow rate [persons·s^{-1}·m^{-1}].

	Lower quartile (25%)	Median (50%)	Upper quartile (75%)
Door A	1.9	2.2	2.4
Door B (all evacuees)	0.4	0.6	0.7
Door B (walking evacuees)	0.6	0.7	0.9

The cumulative distribution function of specific flow rate presented in Figure 52e shows that for door A, the lower quartile (25%) of the specific flow rate is 1.9 persons·s^{-1}·m^{-1}, the median (50%) 2.2 persons·s^{-1}·m^{-1} and the upper quartile (75%) 2.4 persons·s^{-1}·m^{-1}.

Figure 52f shows two cumulative distribution functions of specific flow rates out of door B. One distribution function consists of all the evacuees (walkers and wheelchairs) and the other only of walkers who evacuated before the first evacuee in a wheelchair.

For the data set consisting of all the evacuees in the lower quartile (25%), the specific flow rate was 0.4 persons·s^{-1}·m^{-1}, the median (50%) 0.6 persons·s^{-1}·m^{-1} and the upper quartile (75%) 0.7 persons·s^{-1}·m^{-1}. For evacuees who walked out of door B, the lower quartile (25%) of the specific flow rate was 0.6 persons·s^{-1}·m^{-1}, the median (50%) 0.7 persons·s^{-1}·m^{-1} and the upper quartile (75%) 0.9 persons·s^{-1}·m^{-1}.

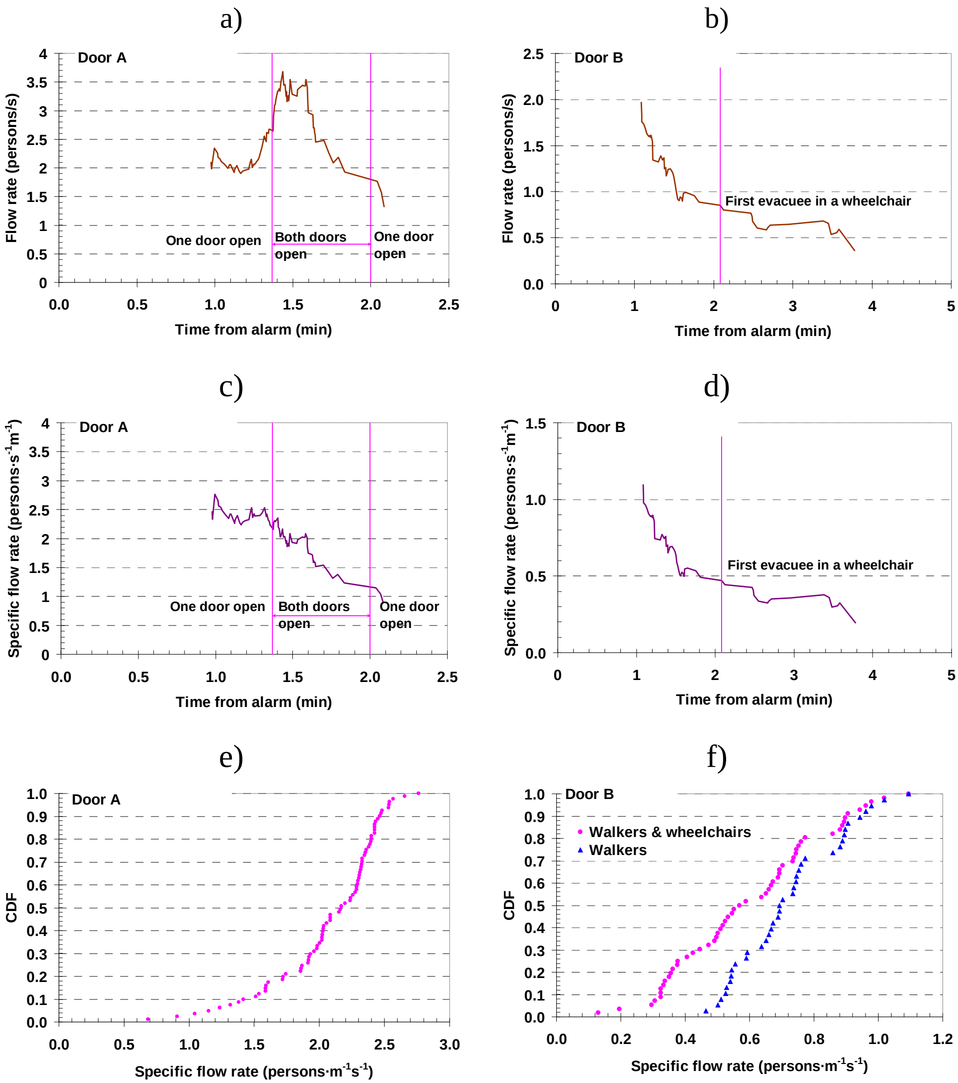


Figure 52. The crowd flow rate through a) door A and b) door B. The specific flow rate through c) door A and d) door B. The cumulative distribution function of the specific flow rate e) door A, f) door B.

Evacuees in wheelchairs

As shown in Figure 53, the first of the four evacuees in wheelchairs came out through door B at about 2 min 5 s and the last one at about 3 min 23 s after the alarm. The first three evacuees were on manual wheelchairs and the fourth had an electrically powered wheelchair. All the wheelchair evacuees were assisted out on a hinged ramp that was opened at about 1 min 17 s after the alarm. The evacuees on manual wheelchair each had two helpers and the evacuee on the electrically powered wheelchair had four helpers.

Figure 54a presents the time it took for each of the wheelchairs to move down along the ramp. The length of the ramp was about 3.5 m and the inclination about 15°. The inclined speed of each wheelchair moving down the ramp is presented in Figure 54b.

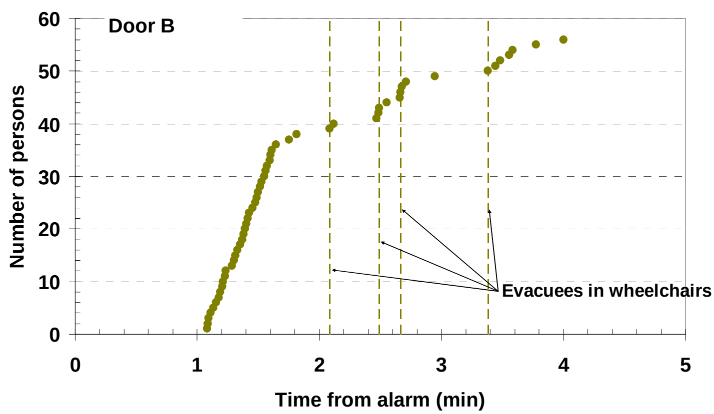


Figure 53. Number of persons who went out of door B as a function of time. The four vertical lines represent the evacuation times of the evacuees in wheelchairs.

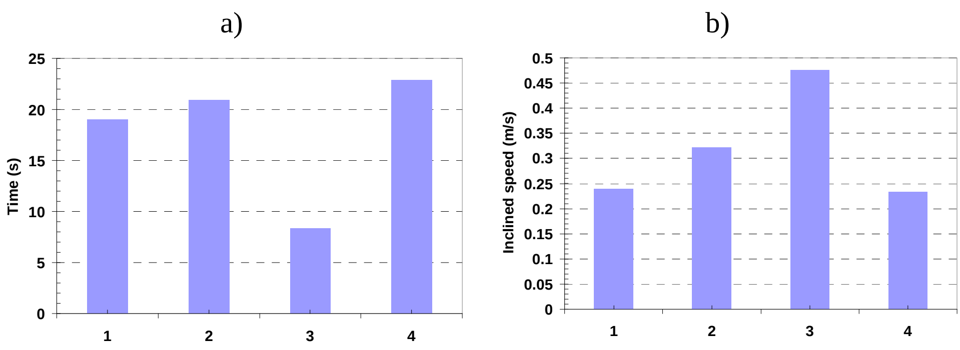


Figure 54. a) The time it took each wheelchair to move down the ramp. b) The speed of each wheelchair down the incline. No. 4 represents the electrically powered wheelchair.

When the evacuation request given by the priest started, the people were sitting on the benches. The evacuation request lasted 67 s (blue arrow in Figure 55). After 40 s, the first evacuees stood up and started to move towards the exits. The cumulative distribution of the reaction times of the evacuees is shown in Figure 55.

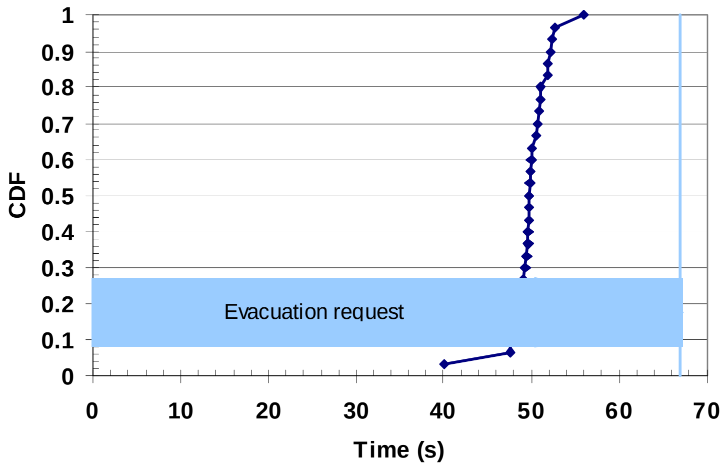


Figure 55. Cumulative distribution of the reaction time of the evacuees.

Observations

The evacuation request given by the priest was very long and thorough. The priest gave very good instructions to the evacuees but as the speech was so long, the people did not have the patience to hear it out and started to move towards the exits.

Observations of the wheelchairs showed that the electrical wheelchair was too wide to fit the ramp properly. The width and weight of the powered wheelchair were the reasons for the wheelchair needing the assistance of four men.

A12. Case O: A factory

Background

This case differed from the others by the nature of the evacuation drill. The building was a large factory and the simulated thread was an irritating plume outside the factory. Due to the plume, the evacuation had to be carried out inside the building and no evacuation to the outside was allowed.

The alarm was raised using cell phones and the short message service (text messages) because of the risk of evacuating outside when using the normal fire alarm bells. Two alarm messages were sent during the drill. The first (received at 9:57 am) was sent to all employees and it contained the following information: ‘Danger! An ammonia leak. Move inside immediately and wait for further instructions.’ The second message (received at 10:05 am) contained the request to evacuate inside to the meeting place, which was a large hall across the factory. There is normally some time delay between these two messages because of the time it takes the safety organisation to estimate the situation until sending the second message to everyone. Some technical delay also occurred when sending multiple messages through the text messaging systems.

The zero time in this analysis is assumed to be the time when the first people received the first text message.

Building description

The evacuation drill focused on employees in the office building; see Figure 56. One of the monitoring points was on the second floor of the office building where the first text messages were heard. Other monitoring points were located inside the evacuation route and in the meeting place.

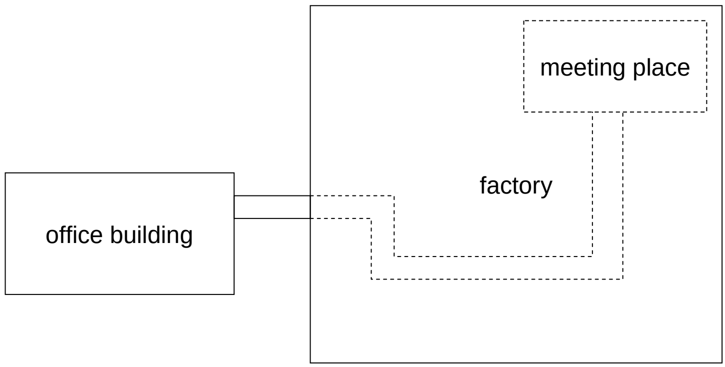


Figure 56. A schematic illustration of the factory and the evacuation route from the office building to the meeting place.

Results

Figure 57 shows the number of people evacuating to the meeting place after the first text message is received. As shown, the total evacuation time calculated from the first received text message is about 18 min. The time is shorter if the delay between the first and the second messages is reduced. This was between 5 and 8 min. Even then, the total evacuation time was quite long compared with the other cases. This was mostly because of the long travel distance inside the large factory.

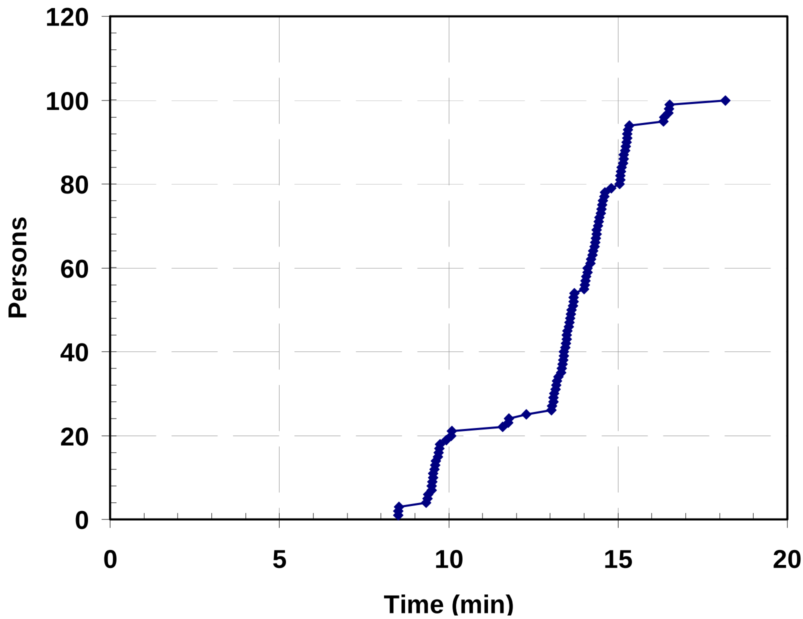


Figure 57. Number of evacuated people at the meeting place after the first received text message.

One interesting point during the evacuation was that the evacuation route went through a short flight of stairs in the factory area. This allowed people's walking speeds on smooth and upwardly inclined floor to be observed. The geometry of the stairs is shown in Figure 59. The horizontal walking speed values were monitored before the stairs in a long corridor. The persons were categorised into three groups:

- group A included people who walked alone in the corridor and on the stairs
- group B included people who walked in a group in the corridor and side by side with others on the stairs
- group C included people who walked in a group in the corridor and alone on the stairs.

The distribution of horizontal and inclined walking speeds is represented in Figure 58. The log-normal fit to both curves is also presented. Figure 58c shows that the horizontal and inclined walking speed data do not correlate strongly.

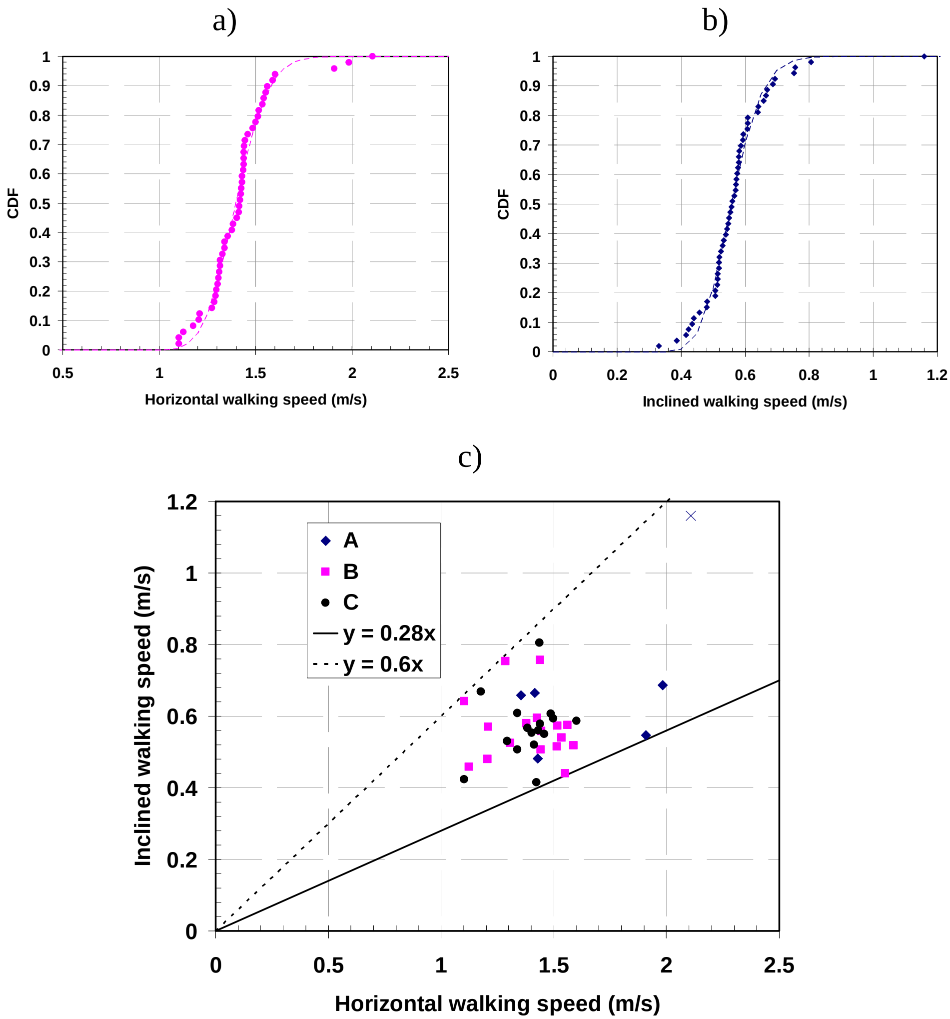


Figure 58. The distributions of a) horizontal, b) inclined walking speeds (the speed is measured along the sloped stairs), and the correlation c) between the horizontal and inclined speed during the evacuation drill of a factory. The log-normal fit parameters are a) $\mu = 0.33$, $\sigma = 0.10$ and b) $\mu = -0.59$, $\sigma = 0.14$. The symbol x represents one person walking in the corridor.

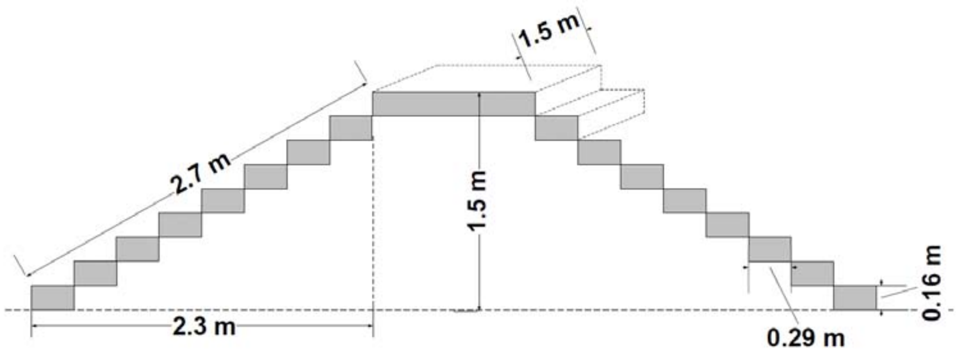


Figure 59. The geometry of the stairs on the evacuation route. The angle of the stairs is 28.8° (measured from the stair-step dimensions).

Observations

As the simulated danger was an ammonia plume, most of the employees would have been safe long before they entered the meeting place. As normal, e.g., in an office building, the total evacuation time is counted until the last person is out of the building and the last person enters the meeting point area.

The horizontal and inclined walking speeds did not correlate because the stairs had quite a short inclined distance and the individual’s own target speed may not have been seen clearly in the upward direction.

A variance of at least 2 min was noted for the employees on the second floor to receive the first text message. The variance for the second message is not known, but the time when the second message was received after the first one, varied between 5 and 8 min. Some of the employees decided to evacuate in the time between the first and second messages. On the second floor, the decision to evacuate was collective. Some of the employees probably knew the meeting place beforehand because the first message did not include information about it. One member of the safety organisation did not receive either message until he or she called and asked for the messages to be sent.

A13. Case Q: A special school

Background

The evacuation drill was held in October 2009 in a school that provides special education in a normal school setting. The school's students have extensive learning and understanding problems, autistic symptoms and mental retardation. Some of the students use wheelchairs. The teaching at the school ranges from pre-school teaching (2 years) to year 10. The schoolchildren usually number about 100 and the teachers and school assistants about 50, which is quite many.

The school staff and a few of the students knew the exact time of the planned drill. The local fire brigade started the event by producing smoke with a cold smoke generator. The request to leave the building was given by the headmistress through a PA system. The number of evacuees was about 100.

Building description

The floor plan of the school is presented in Figure 60. The grey smoke plume in Figure 60 represents the placing of the cold smoke generator and the green boxes represent the places of the seven cameras that were used to monitor the drill. The main exits are marked in Figure 60 with the symbols A and B.

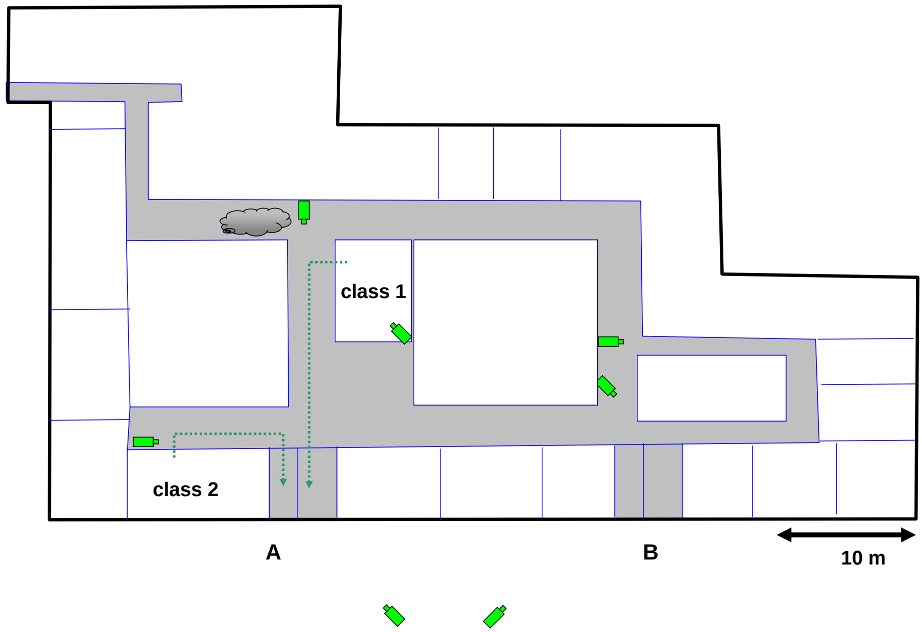


Figure 60. Floor plan of the school.

Results

The rate of evacuated people was counted from the videos using the Evaccounter described in Section 2.2.

After the evacuation request, 112 persons were evacuated through doors A and B within 3 min 4 s. The number of persons as a function of time is presented in Figure 61.

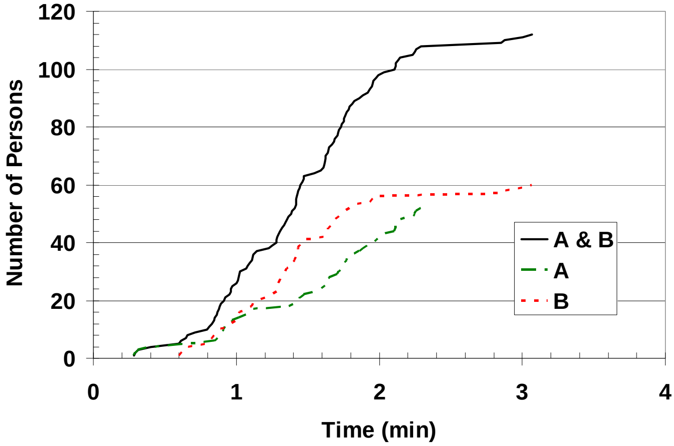


Figure 61. Number of persons evacuated through doors A and B as a function of time.

Figure 62a shows that the value of the crowd flow rate through door A (right) was at its highest at about 1.1 persons/s, while the maximum flow rate out of door B (right) (Figure 62b) was about 1.5 persons/s.

The width of the doors was 1 m, so the specific flow rates (persons$\cdot s^{-1} \cdot m^{-1}$) in Figures 62c and 62d are similar to the crowd flow rates presented in Figures 62a and 62b.

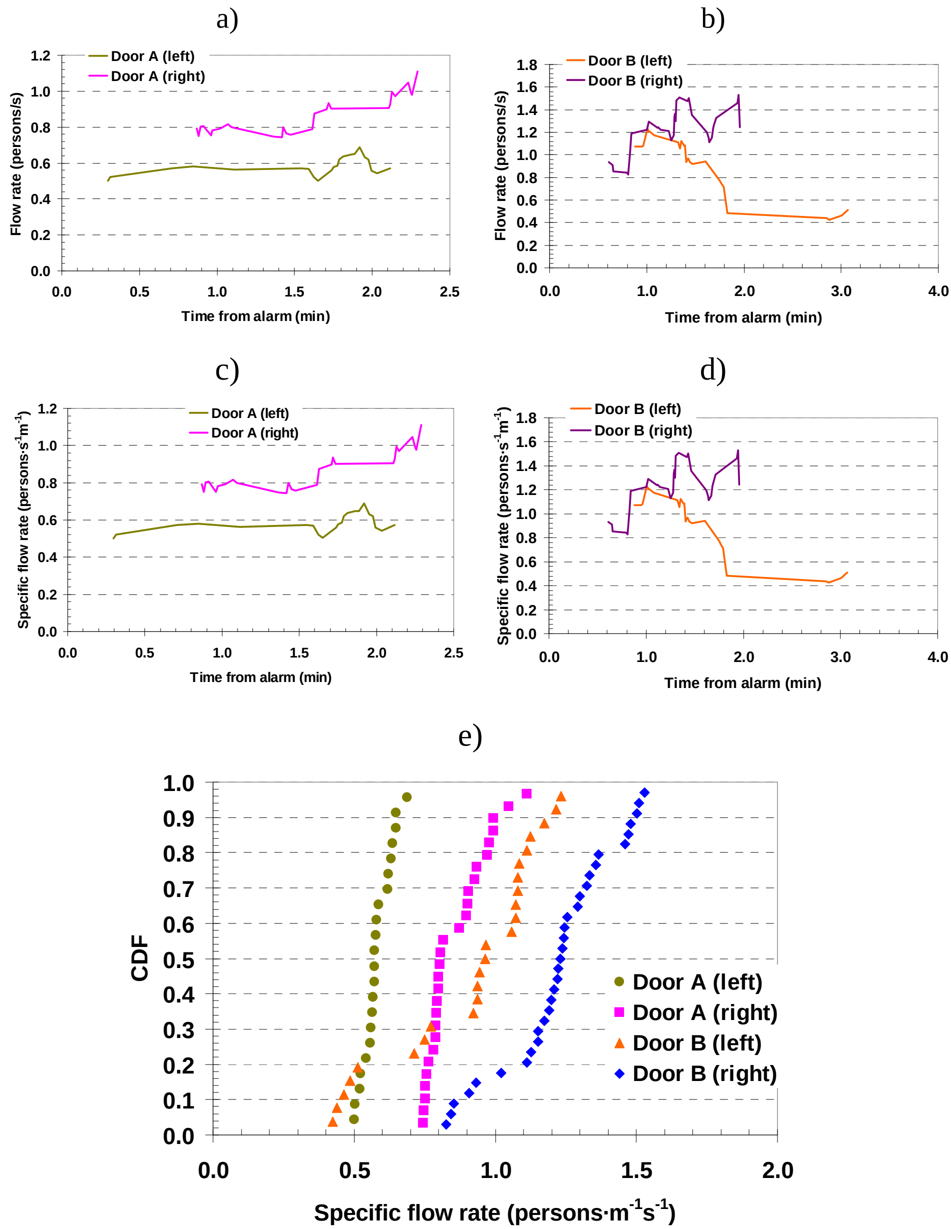


Figure 62. Crowd flow rate through a) door A and b) door B. The specific flow rate through c) door A and d) door B. e) The cumulative distribution function of the specific flow rate.

The cumulative distribution function is plotted in Figure 62e. The lower and upper quartiles and the median value of the specific flow rate [persons·s^{-1}·m^{-1}] are tabulated in Table 9.

Table 9. The lower (25%) and upper (75%) quartiles and the median of the specific flow rate [persons·s^{-1}·m^{-1}]

	Lower quartile (25%)	**Median (50%)**	**Upper quartile (75%)**
Door A (left)	0.55	0.57	0.62
Door A (right)	0.78	0.81	0.93
Door B (left)	0.73	0.96	1.09
Door B (right)	1.14	1.23	1.35

The music class at the school was also monitored by one video camera. The video showed the first reactions of the pupils quite well after perceiving the fire alarm announcement. Figure 63 shows both the pre-movement time and the movement time out of the music class (class 1). In this particular case, the pre-movement time represents the time when a pupil rises and starts to move towards the doorway of the classroom. As shown, at the time of 50 s from the evacuation alarm announcement the music class is empty of pupils. Some of the pupils were also out of the classroom while the last ones were still sitting on their chairs (see Figure 63). The evacuation of another classroom was performed within 53 s (the teacher was the first to enter the corridor in 43 s); see Figure 63 (class 2). There were six teachers in the music class and two in Class 2.

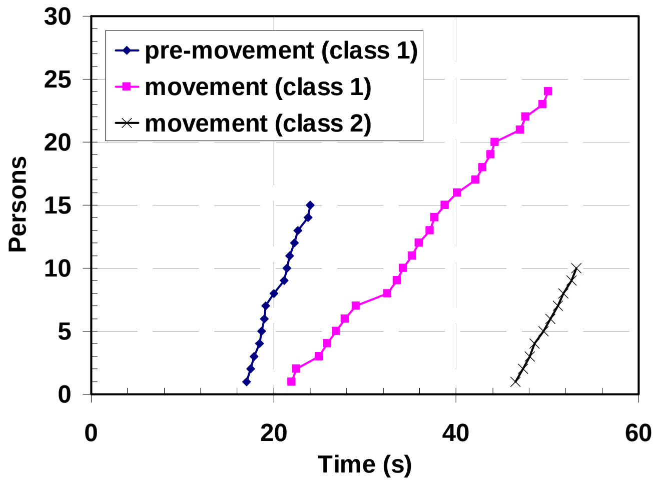


Figure 63. Number of persons as a function of pre-movement and movement times.

Observations

It was observed from the video material that some preliminary preparations were made with the youngest schoolchildren, e.g., putting outerwear on before the evacuation announcement was given. This should be taken into account when evaluating the whole evacuation time. As the students need guidance and assistance in their daily activities, the same routine was seen during the evacuation. The teachers especially looked after the small children and walked with them out of the school building.

The evacuation was planned so that the teachers would pick up the pupils' outerwear from the cloakrooms in the corridors. The videos show that the teachers spent about 15 s to 40 s trying to search for certain outerwear whereas the pupils spent only 2 s to 5 s because they knew the position of their own outerwear better.

The evacuation from the music class showed that the first pupils stood up immediately after they heard the key words '…evacuate the building…' at the time of 13 s from the beginning of the announcement. This activated the so-called chain reaction that the other pupils followed. The evacuation therefore started while the announcement was still on and the pupils did not wait for the announcement to finish first. It is not clear whether all the people in, for example, the music class heard the whole 30 s announcement and the last part when the headmistress addressed where the smoke was located in the building.

A14. Case R: Bus terminal

Background

This was a real emergency situation that took place in November 2009. One of the buses entering an underground bus terminal in downtown Helsinki had probably already developed a short circuit in its engine compartment when it unloaded passengers at the arrivals platform. At the time the bus moved to one of the departing platforms to pick up new passengers, visible smoke emerged from the rear of the bus.

The attempt to extinguish the fire manually before the arrival of the fire department was successful in suppressing the fire so it was not able to spread. The bus terminal and all the spaces in the building complex (bus terminal, waiting area, shopping centre and restaurant area) were evacuated. No one was injured during the outbreak of the fire, the extinguishment or the evacuation. Nor did the building suffer any damage from the fire or its consequences.

Building description

The building complex has three underground levels (two bus terminals and a parking facility on the lowest level). The fire broke out on the first underground level. This floor also has shops, restaurants and other facilities. From the ground level up, there are five shopping area floors and apartments arranged on nine floors above ground.

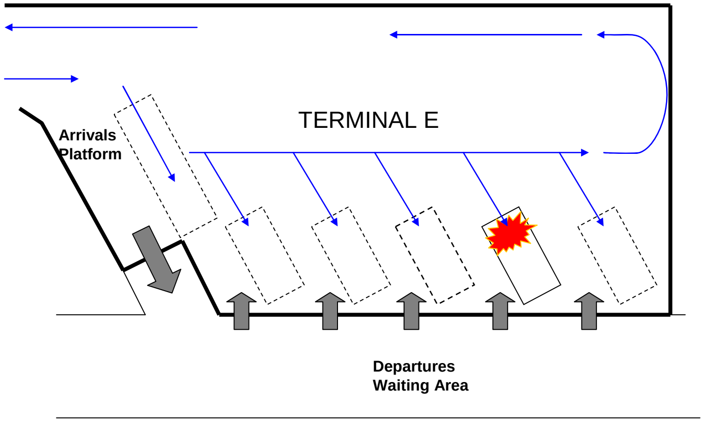


Figure 64. Bus terminal and waiting area layout in Terminal E.

The local traffic bus terminal (Terminal E) and waiting area arrangement are shown in Figure 64. The waiting area is separated from the bus terminal area by a glass fire partition and fire doors at each entrance opening.

Results

There is an extensive network of surveillance cameras throughout the building complex. The observations are based on these recordings, security reports and meetings with the building administration and security staff.

The following time curve (Figure 65) shows the number of people in the waiting area from the time of the bus arriving at its departure platform and catching fire (at 18:29). The numbers are estimated by observing inflows and outflows at the exits/entrances serving the waiting area.

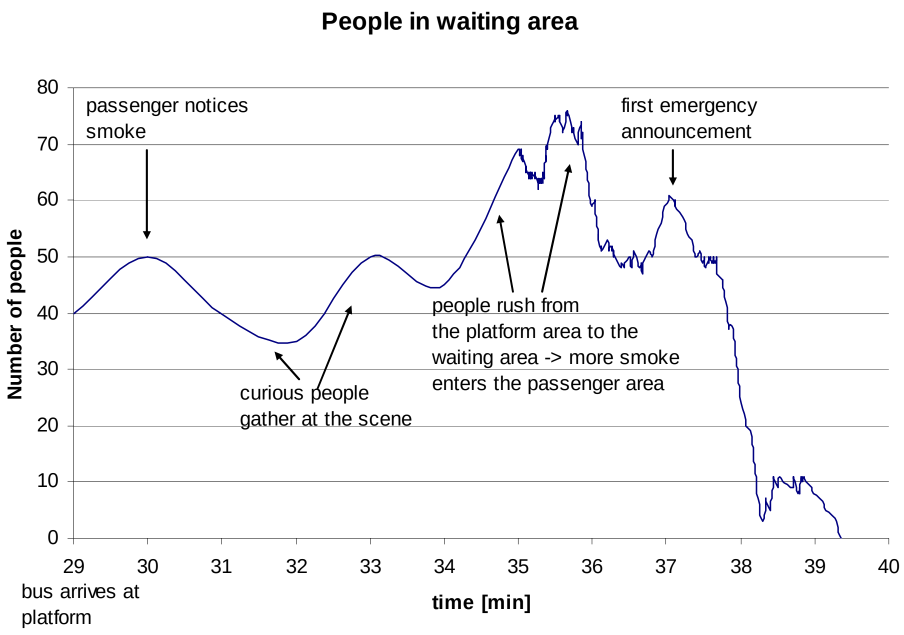


Figure 65. Number of people in the waiting area. Time is given as minutes of the full hour, e.g., starting at 18:29.

The following table describes observed actions per time in the departures waiting area and Terminal E, in direct vicinity of the origin of the fire.

Table 10. Actions in Terminal E.

Time	Action
18:29	The bus moves to the departure platform, the door between the waiting area and the platform is opened and the passengers start entering the bus (10 persons).
18:30	One passenger notices smoke emerging from the rear of the bus while entering and notifies the driver. The passengers return to the waiting area. Security is informed (in person and by a phone call) of a bus on fire in Terminal E. Surveillance cameras also locate the fire.
18:32	The bus drivers and security staff start manual extinguishing. The staff, bus drivers and passengers use the doors between the terminal and the waiting area causing smoke to spread to the waiting area side.
18:33	The smoke was visible in the waiting area. People enter and leave the area as normal. Some people take notice of the smoke and interested viewers watch through the glass partition.
18:34	
18:35	Normal movement through the waiting area and adjacent shops and restaurants. A group of people exit from a bus (two platforms away from the burning bus) back to the waiting area because of the excess smoke.
18:36	Normal movement plus approximately 30 people rushing in from the arrivals platform door, entering the waiting area. More smoke enters the waiting area because of this. The building control room makes an emergency call.
18:37	Fire alarm caused by the smoke. People are informed by an automatic announcement that there is a fire alarm, that the cause is being examined and that they are to stay calm. People start to exit the waiting area, but others are still entering the area.
18:38	People move away. Some enter.
18:39	Single events with people passing through. The security staff try to stop more people from entering the area.
18:41	An evacuation order and announcement are made. The system tries to shut the bus entrance ramps but fails, and buses continue entering carrying passengers.
18:46	The first units of the fire department arrive on the scene. The remains of the fire are put out. The police take charge of preventing people entering the scene and blocking the bus entrances so that no more buses enter the terminal.

Observations

Smoke was visible from and in the waiting area early on. This had little effect and made some people curious. The burning bus was behind a glass wall/doors and almost no flames were visible, which may have given a false sense of security.

The first alarm announcement came quite late and informed people to stay calm and wait for further information. The fire alarm system was activated late because the initial fire was not big and the smoke cooled and did not rise to the ceiling. The first alarm was raised by the smoke entering through doors used by people and activating the smoke sensors. The temperature sensors did not react.

People reacted to the first announcement by starting to exit the waiting area. The problem was that people entered the building, as the number of security staff at the scene had no way of blocking all the entrances before the police arrived.

The greatest risk was that the alarm system did not block the bus entrance ramp. This only happened after the second phase of the fire alarm when the evacuation announcement was made. The blocking attempt failed, however, as a bus was passing underneath on the two attempts to lower the boom, causing the boom to rise. The police had to stop the buses and, with the help of the fire department, they evacuated the buses from the terminal area.

This led to a situation in which buses and passengers entered the terminal long after the outbreak of the fire. If the fire had spread and grown in size, the situation could have been fatal.

A15. Case S: A stadium

Background

The second normal situation was monitored in an ice hockey stadium. The stadium was not as big as the Case T stadium. Approximately 3 000 people watched the ice hockey game. The people movement started immediately after the game ended. The focus was on monitoring the doorways, especially the main door.

Building description

The seats of the stadium are on two floors. The normal routes out of the stadium go through the first floor and the main door; see Figure 66. There are also smaller exits on both sides of the stadium building. The cameras were installed near the main door A and near one of the side exits B. The schematic presentation of the main door is shown in Figure 67. Three of the doorways were not used during the moving phase. The staff opened the inner doors (shown in Figure 67) beforehand and the outer doors had to be opened manually by the moving people. Doorway B was near the stairs, where the aim was to collect data on the descending people.

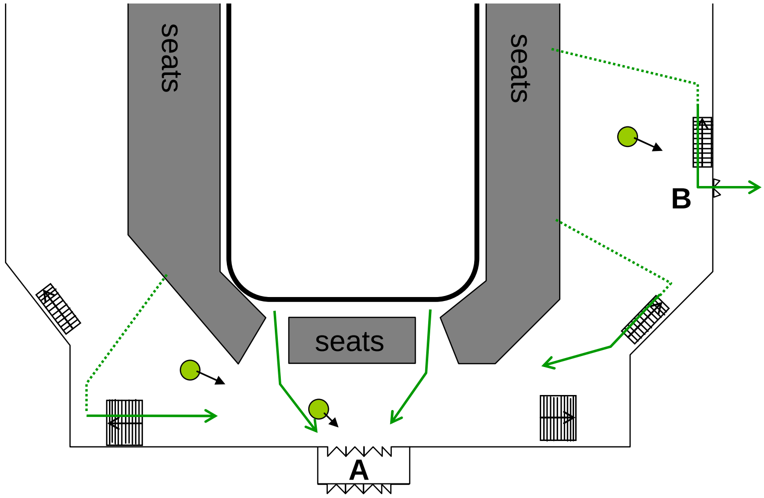


Figure 66. A floor plan of the stadium's (Case S) first floor and monitored doorways A and B. The camera positions are shown with circle symbols.

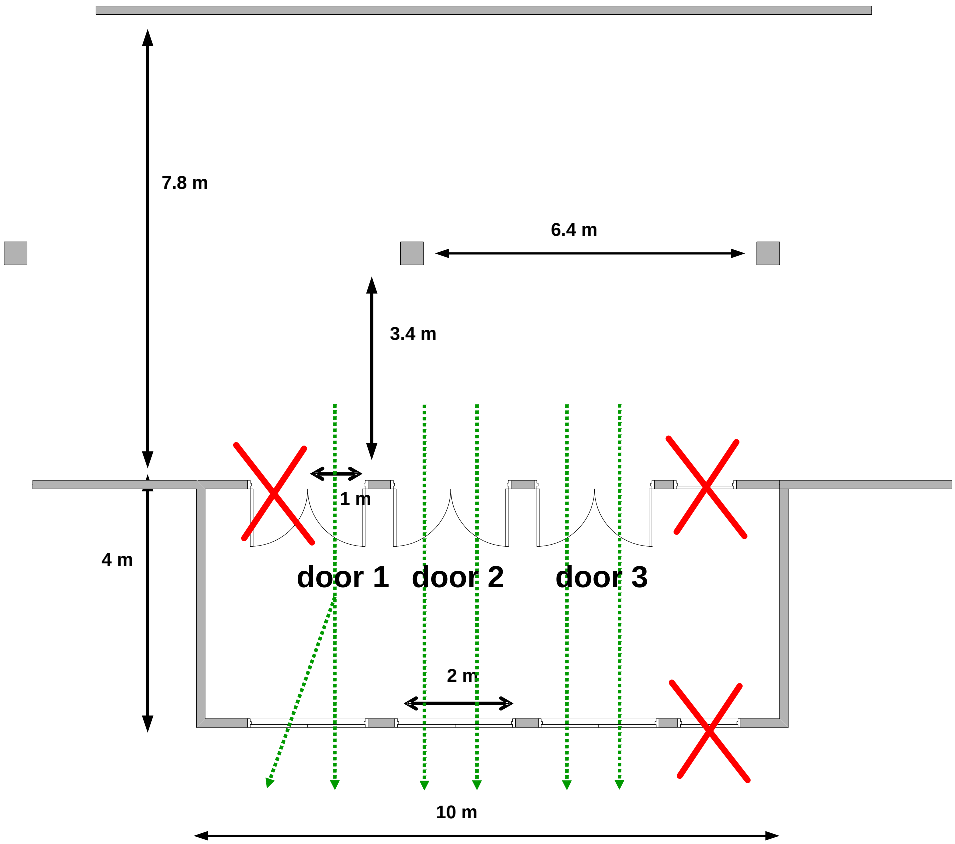


Figure 67. An illustration of the main door area of the stadium (Case S). Three doorways were not used during the movement phase after the ice hockey game. The staff opened the inner doors beforehand, but the outer doors had to be opened manually by the moving people.

Results

The total number of people walking through monitoring points A and B is presented in Figure 68. Approximately 800 people walked out of the stadium building in 6 min through the monitored doorways A and B.

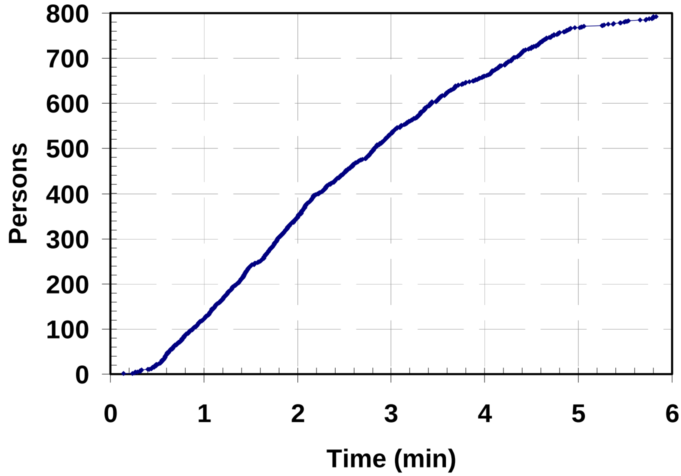


Figure 68. The total number of people walking through doorways A and B after the ice hockey game.

The number of people using the main door is shown in Figure 69. As shown, doors 1 and 3 were used most and door 2 in the middle of the door geometry had the fewest users. The video material showed that the crowd moving towards the main door preferred the outermost doors 1 and 3, probably because the moving direction of the people was not in line with doors 1 to 3. Even though door 1 was narrower than door 2, the people used door 1 more.

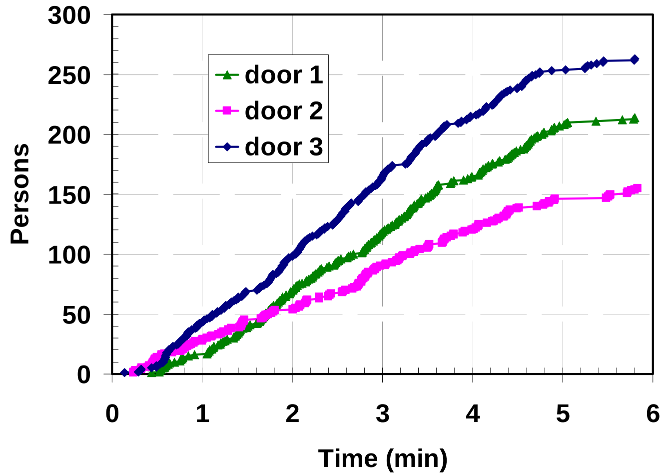


Figure 69. Number of persons walking through doorways 1 to 3 of the main door A.

The number of people coming from the stairs near doorway B is shown in Figure 70. The crowd density on the stairs is also presented in Figure 70. The moving direction of the people was downward. The dimensions of the stair step were 0.31 m (length), 0.16 m (height) and 1.9 m (width). There were 24 steps in all, but the monitoring and calculations were performed over ten steps (thus the inclined distance was about 3.5 m). The angle of the stairs was about 27.3° (calculated using the stair step dimensions).

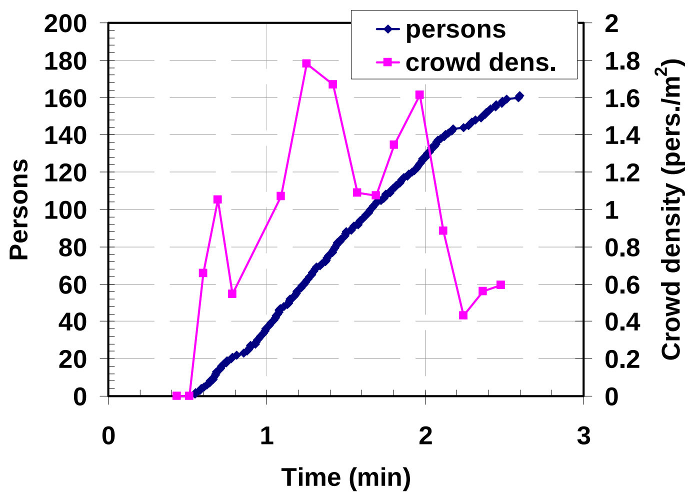
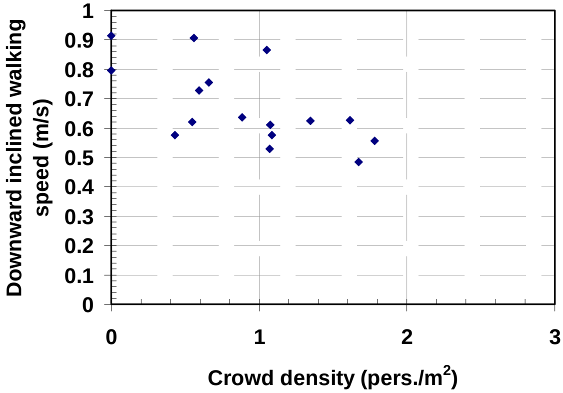


Figure 70. Number of persons walking along the stairs near doorway B. The crowd density on the stairs is also presented.

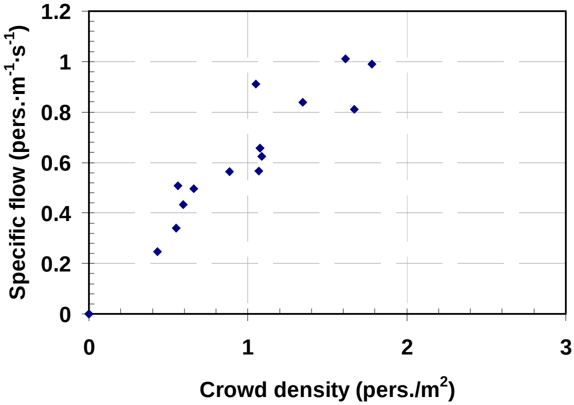
The results of further investigations into the downward moving people on the stairs are shown in Figure 71. As shown, the maximum downward moving speeds (the sloped speed along the inclined surface) were about 0.9 m/s (Figure 71a) and the moving speed decreased with increasing crowd density. The factors for the linear equation are $y = -0.16x + 0.83$ (Figure 71c).

The crowd density did not reach its maximum point (Figure 71b) on the stairs and the specific flow kept growing. If the situation had been a little more congested, the specific flow would have decreased. The factors for the fit curve are $y = -0.17 x^2 + 0.84x$.

a)



b)



c)

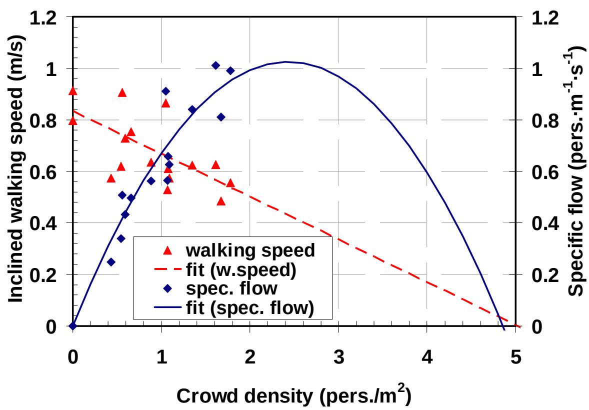


Figure 71. a) Downward inclined walking speed and b) specific flow on the stairs as a function of the crowd density. c) Fit curves and predictions of the data from figures a and b.

Observations

The same phenomenon as with the door leaf usage was also seen in this case. The other door leaf of door 1 was not locked and could have been opened manually, but no one did so, and all the people came through the one already open door leaf. Another interesting event was that the people seemed to choose the door in the middle (door 2) when the front of the main door area was clear. These events were usually when the people were not walking in line and the visible range of doors was better than in congested situations.

It is notable that the capacity of the stairs can produce higher crowd densities than the crowd densities observed on a smooth surface (see the results of Case T). This is probably due to the geometry of the steps and the forced step lengths taken by the humans. Thus, the congested movement along the stairs is more controlled than it is on a smooth surface.

A16. Case T: A stadium

Background

Two normal exit situations were monitored in an ice stadium in Case T. The first was after a concert and the second was after an ice hockey match. There were more than 10 000 people at both of the events. The motivation to monitor these events related to a possible congestion occurrence. All the people came in through the main entrance before the concert and hockey game began. This was the place where the tickets were checked. It was assumed that most people would also exit through the same route.

Building description

Figure 72 shows a simplified illustration of the area of the stadium's main entrance. The area was monitored by four video cameras shown in Figure 72. The walking speed and flow rate observations were monitored using cameras I and II, respectively. Two cameras monitored the crowd movement near the main entrance. Camera position III was on the second floor and camera IV was located near the main entrance. As seen from Figure 72, the cloakrooms narrowed the corridor near the main entrance in the case of the concert. The temporarily built cloakrooms were not used during the ice hockey game, so the corridor was wider at that point. Near the main door, a stall was built for selling merchandise during the concert. The stall was not built for the ice hockey game.

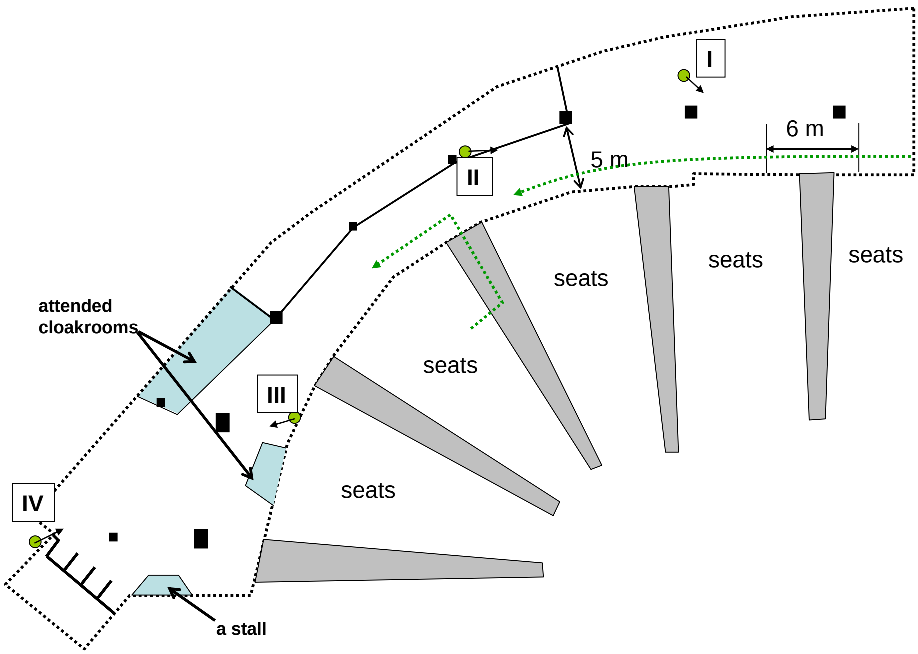


Figure 72. Part of the floor plan near the stadium entrance. The numbering I, II, III, and IV shows the camera locations. The green dashed lines represent some of the possible exit routes. The grey areas represent the stairs. The stall and the cloakrooms were not used during the ice hockey game.

The door selection behaviour was monitored from camera position III (see Figure 72). The main door consists of four double-leaf outer and inner doors for which the handrails inside separate the flows near the doorway; see Figure 73.

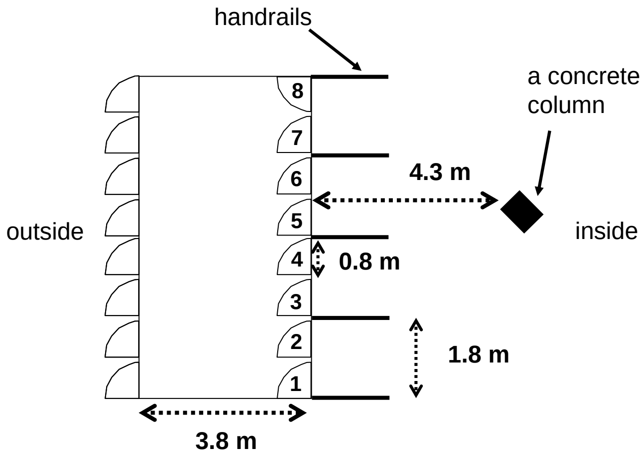


Figure 73. A drawing of the stadium (Case T) main door area.

Results

Exit after the concert

As the situation was normal, careful attention had to be paid to examining the total exit times. This is because, for example, no exit doors were used and people walked through an attended cloakroom to pick up their outerwear. All the people exited the stadium in 27–30 min. After that, there were people who stayed inside to finish their meals and those who just talked to each other. The exit time of 27–30 min includes those who had decided just to walk out after the concert. Figure 74 shows the number of people walking through monitoring point II (see Figure 72). The reference point (time = 0 min) is the time the concert ends. As shown, about 1 000 people pass the monitoring point within 5 min. The dense crowd flow continued up to 22 min at monitoring point II. The maximum human flow along the 5-m wide corridor was 4.3 pers./s in the range of 400 to 600 persons passing monitoring point II; see Figure 72. Figure 72 also shows the approximate human flow rate changes after the 3 min point due to the growing crowd density.

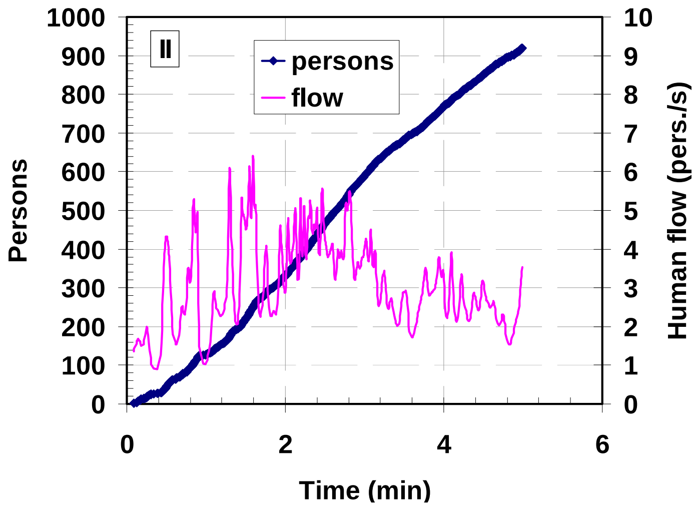


Figure 74. Number of people passing monitoring point II in the first 5 min after the concert.

As a result of the dense crowd flow, some estimation could be made about the correlation of walking speed and crowd density along the corridor. Figure 75 shows the relation to be quite linear. The factors for the linear equation are $y = -0.67x + 1.65$.

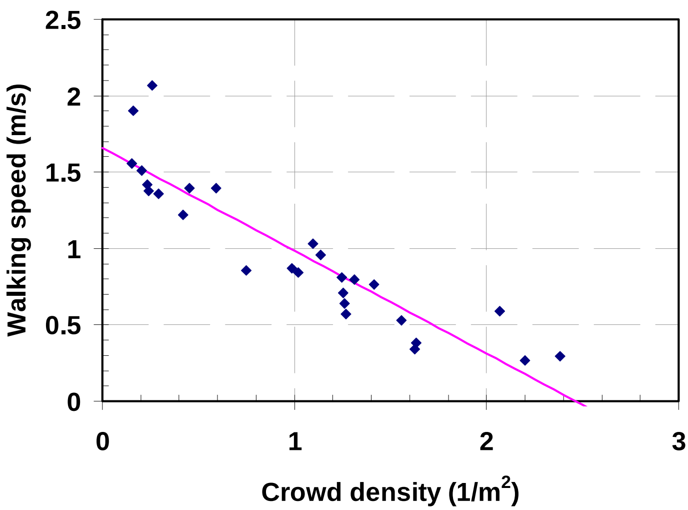


Figure 75. A linear relationship between walking speed and crowd density.

Figure 76 shows the specific flow rate as a function of crowd density. As shown, the specific flow rate is at its maximum at the point of about 1 pers.·m^{-1}·s^{-1}. After this, the crowd density grows and the specific flow rate starts to decrease. The factors for the fit curve are $y = -0.40\,x^2 + 1.18x$.

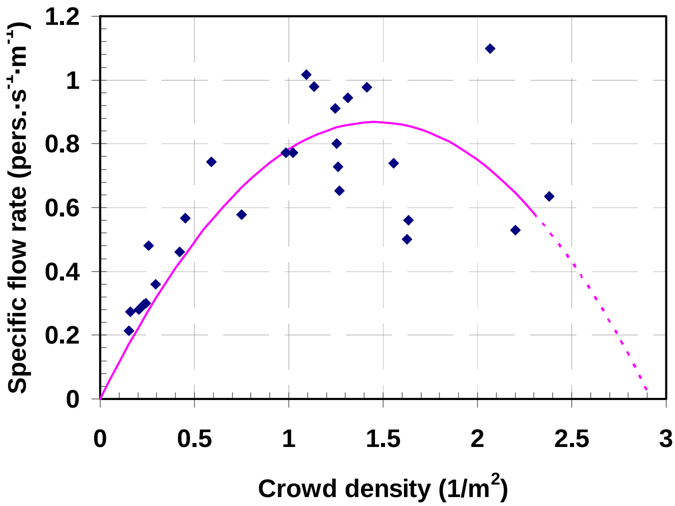


Figure 76. Relationship between the specific flow rate and the crowd density.

The selection of the main door was monitored using video camera position III (see Figures 72 and 73). The motivation was to see how effectively people use all the available door capacity. Figure 77 shows the time and persons curves and the door mode (0 = closed, 1 = opened by the staff, and 2 = opened by the people) of doors 1 to 8. The rectangular blue curves represent the door mode. The data were collected in the first 5 min after the concert ended.

As seen in Figure 77, the people did not use all the available capacity of the door openings. Three door leaves remained unused in the first 5 min after the concert ended. Further investigation into the video material shows that this kind of behaviour is seen throughout the exit event: there were always two or three unused door leaves.

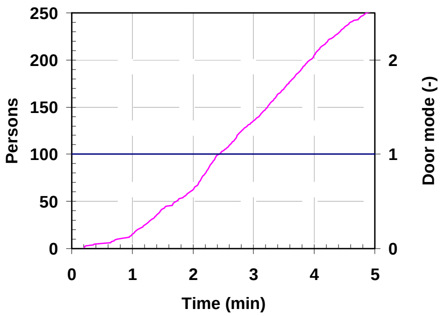
The probable reason for this behaviour at the early stage can be explained by the staff having opened doors 3 and 7 beforehand. This caused a majority of the people to go in line through these pre-opened doors. For example, the usage of doors 3 and 4 in the 5 min period was approximately 1/13 of that of door 4, which had to be opened by the moving people. The doors are situated side by side (see Figure 73). Only one 20 s period was monitored when door 4 was used. The same behaviour was seen with doors 7 and 8: every ninth person used door 8, which had to be pushed open, whereas the staff mostly opened door 7. Door 5 was used late, about 3 min after the concert ended, and door 6, next to door 5, was not used at all. These are good demonstrations of people’s door selection behaviour: First, the people follow each other and second the easy and already open door draws people to walk through it.

The reason for the poor usage of doors 1 and 2 can be partly explained by the congestion that formed in the time range 3–4.5 min in front of doors 1 and 2. The congestion formed when some people stopped and started to buy merchandise from the stall (see Figure 72).

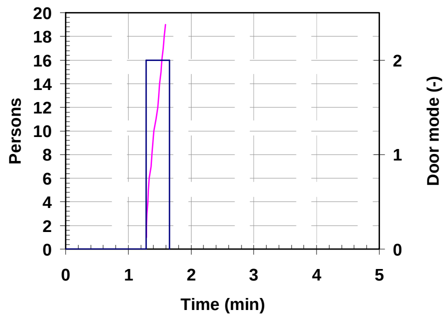
door 1:
(no one used door 1 within the first 5 min)

door 2:
(no one used door 2 within the first 5 min)

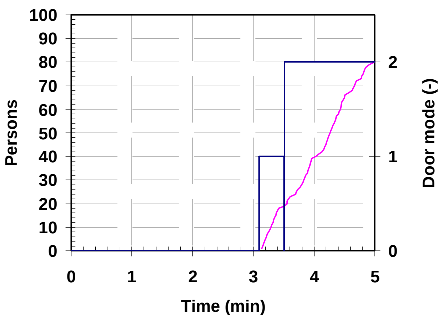
door 3:



door 4:

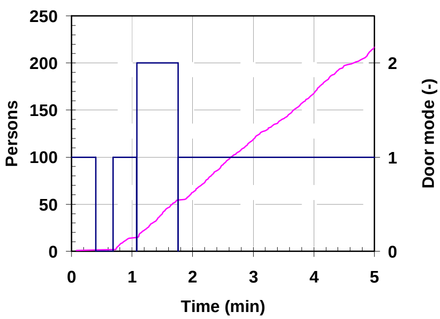


door 5:



door 6:
(no one used door 6 within the first 5 min)

door 7:



door 8:

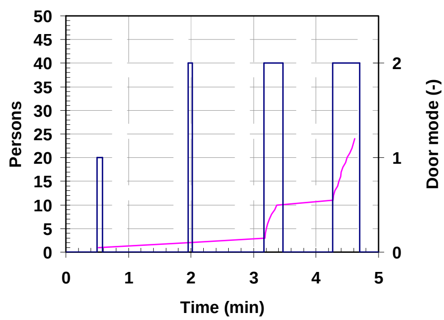


Figure 77. Use of the main door in the first 5 min after the concert ended. The rectangular curves (blue line) represent the door mode (0 = closed, 1 = opened by the staff and 2 = opened by the moving people).

Exit after the ice hockey game

The ice hockey game was the second monitored event in the same stadium (Case T). The situation was normal, as in the concert, and most of the people were expected to exit through the main door. Some differences between the concert and the ice hockey game were observed however: the stall and the attended cloakrooms were not in the corridor. The stall seats were also not available, as in the concert, and this decreased the number of people that would have used the corridor by approximately 2 000. Figure 78 shows the number of people walking through monitoring point II. The monitored time interval was 10 min after the ice hockey game ended.

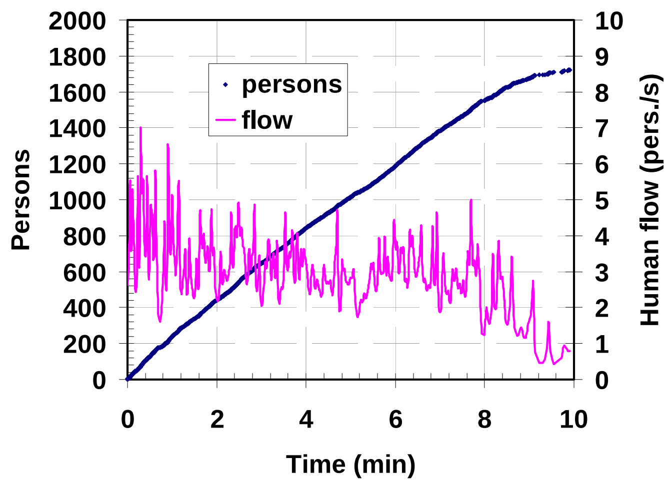


Figure 78. Number of persons walking through monitoring point II after the ice hockey game.

As shown in Figure 78, the human flow remains steady in the monitored time interval. The flow starts to decrease at the time of 9 min after the end of the game when most of the people had passed monitoring point II. The cumulative number of the people seems quite similar when comparing the data against the crowd movement after the concert: about 1 000 persons in 5 min in both cases.

The crowd density in the corridor was almost equal to the crowd density observed after the concert (Figure 80). In general, the relations between walking speed vs. crowd density and the specific flow rate vs. crowd density were similar to those in the case of the concert (Figures 80 and 79). The parameters of the fit curves are presented in captions below.

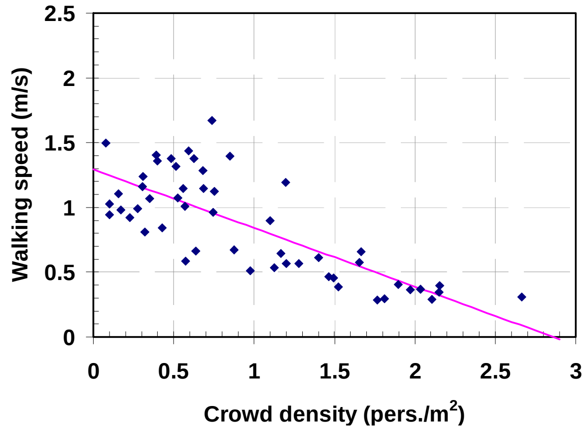


Figure 79. Walking speed as a function of crowd density in the corridor after the ice hockey game. The factors for the linear equation are y = -0.45x + 1.29 (solid line).

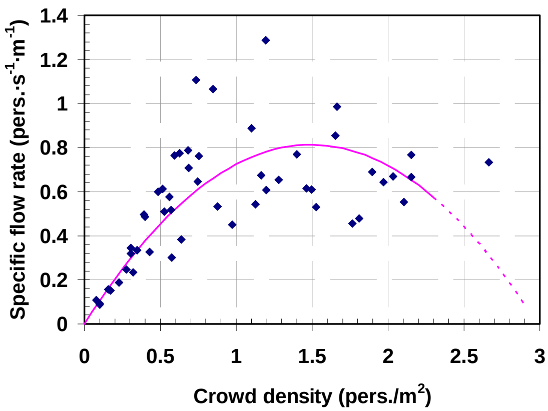


Figure 80. Specific flow rate as a function of crowd density in the corridor after the ice hockey game. The factors for the fit curve (solid line) are $y = -0.36\ x^2 + 1.08x$.

Compared with the usage of the main door after the ice hockey game and concert, it was noticeable that people used all the available doors within 5 min of the ice hockey game (Figure 81). The staff opened only two doors at first, so the people opened most of the doors themselves. From the results observed from doors 3 and 4, the human flow through both door leaves was very efficient, unlike in the case after the concert.

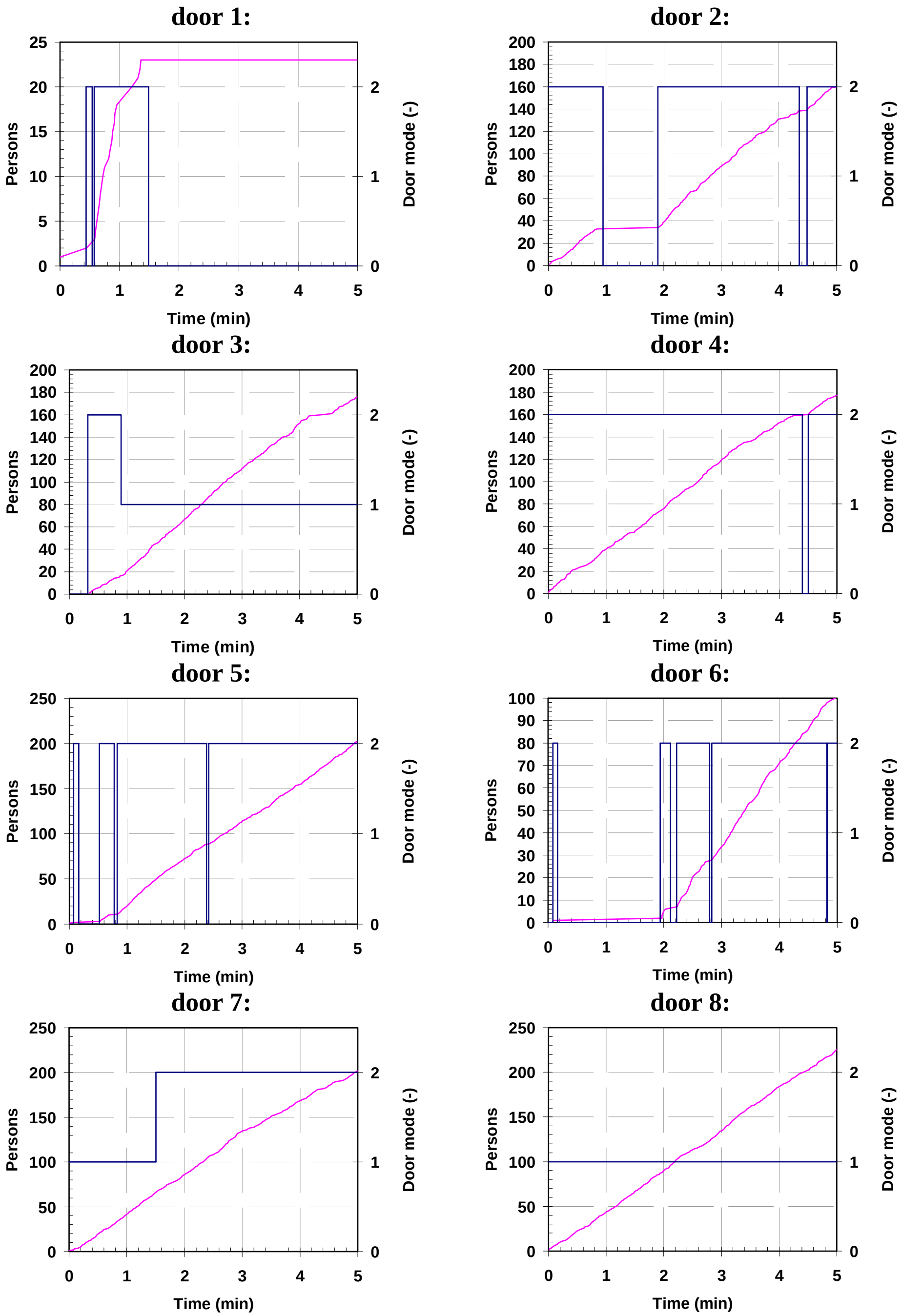


Figure 81. Use of the main door within the first 5 min of the end of the ice hockey game. The rectangular curves (blue line) represent the door mode (0 = closed, 1 = opened by staff and 2 = opened by the moving people).

Observations

It was difficult to count the people from the video material because of the huge number. The video screen had to be divided into three segments. The people in each segment were counted and, finally, the results were summarised.

From the videos, it could be seen that the congestion observed after the concert at monitoring point II was due to the two cloakrooms about 30 m further ahead, near the main door. The geometry of the cloakrooms and the people themselves narrowed the corridor so that congestion formed. The front of the main door remained quite clear, so the congestion observed at point II was not because of the main door geometry or the door selection behaviour of the moving people.

The biggest difference between the concert and the ice hockey game cases was observed in the door selection routines. The people who visited the ice hockey stadium often to watch the games seemed to know how to get out quickly after the game. The people at the concert may have been unfamiliar with the stadium geometry and followed each other nicely when walking out. It was worth noting that all the extra geometries such as the cloakrooms and the stalls near the main door area affected the line formation in the case after the concert. The people after the concert were also in no hurry to walk out and they seemed to form small groups in the area of the main door. This also affected the line formation and poor usage of the available doors.

A17. Case U: A cinema

Background

An evacuation drill was held in April 2010 in a cinema located in the city centre of Helsinki. The participants were primary school pupils from years 4 to 6 with accompanying teachers. Approximately 200 pupils and teachers took part in the drill.

Before the drill took place, a short briefing was held explaining the course of the drill, and the pupils familiarised themselves with the exit routes during a walk-though exercise.

The pupils were divided into two cinema halls that were situated on different floor levels of the cinema building. Hall B was one floor below hall A. The exit route of hall B coincided with the exit route of hall A after the first initial staircase ascended one floor level.

The method of alerting the pupils at the start of the evacuation was different in the two cinema halls. As common practice, the fire alarm bell was audible in the entire building and thus inside both halls. In one of the halls (hall A), the staff also gave additional verbal instructions to aid the evacuation, whereas in the other hall (hall B) an evacuation instruction video was shown on the screen at the time of evacuation, but the staff gave no additional verbal instructions. Thus, in hall A, the pupils had to react to the fire alarm bell and the instructions given by the cinema staff. In hall B, the staff used the evacuation video but gave no verbal instructions or commands inside the hall (the staff met the exiting pupils at the exit door and then entered to verify that everyone had left the hall).

The pupils knew about the fire alarm bell and the two different alerting methods, but they did not know which one would be implemented in which hall. The distribution of the pupils into two different halls was also only decided a little before the start of the drill.

Building description

The cinema consists of several cinema halls on different floor levels. The building also has restaurants and other facilities that share some of the same routes for entering/exiting and evacuation.

The halls that were used for the evacuation drill are situated two (hall A) and three (hall B) floors below ground level. They share the same exit route from level -2 (the level on which hall A is situated). Figure 82 shows the layout of the halls and the exit route to level -1 through the staircase.

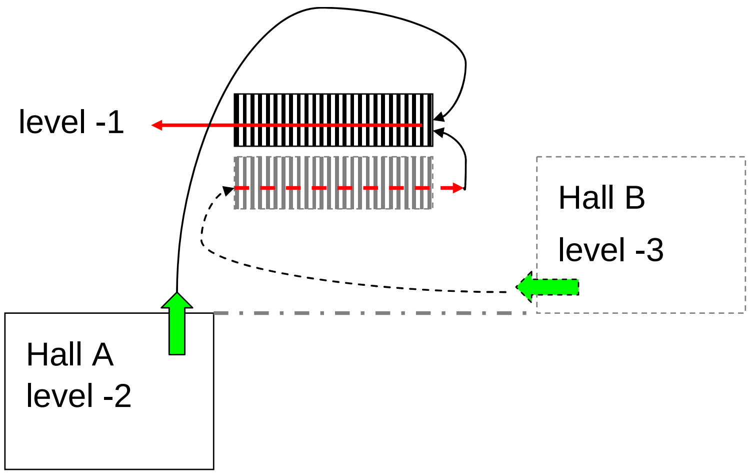


Figure 82. Cinema hall layout.

From level -1, the ascent to the ground level leads to a main passage that leads out to two opposite sides of the building.

Results

Table 11 lists the observed course of action during the evacuation drill.

Table11. Observations during the evacuation drill.

Time	**Hall A**	**Hall B**
0:00		Evacuation video starts
0:03		First pupils stand up
0:13		First person exits the hall
0:23	Fire alarm bell	Fire alarm bell
0:55	Staff informs people to evacuate	
1:00	First pupils stand up	
1:03	First person exits the hall	
1:18		Last person exits the hall
1:34	Last person exits the hall	

The number of evacuated persons (exiting halls A and B) as a function of time is shown in Figure 83.

The reference time started at the moment the evacuation video started in hall B. There was a 23-second delay before the fire alarm bell rang (audible throughout the building). The people in hall A did not start to evacuate, despite the fire bell, before they had been given instruction to do so by a member of staff. Figure 83 also shows a relative evacuation curve for hall A, where the relative zero point of time is taken as the moment when the evacuation order was given by the staff.

It seems that the people in hall A ‘waited’ for the evacuation video or staff to arrive and did not start to exit even though the alarm bell rang. The pre-drill briefing may have been a contributor to this behaviour. The fact that the people did not start to evacuate at the sound of the bell and that the unplanned delay between the start of the evacuation video and the fire alarm bell accounts for the big time difference in the start times of evacuation between the two halls.

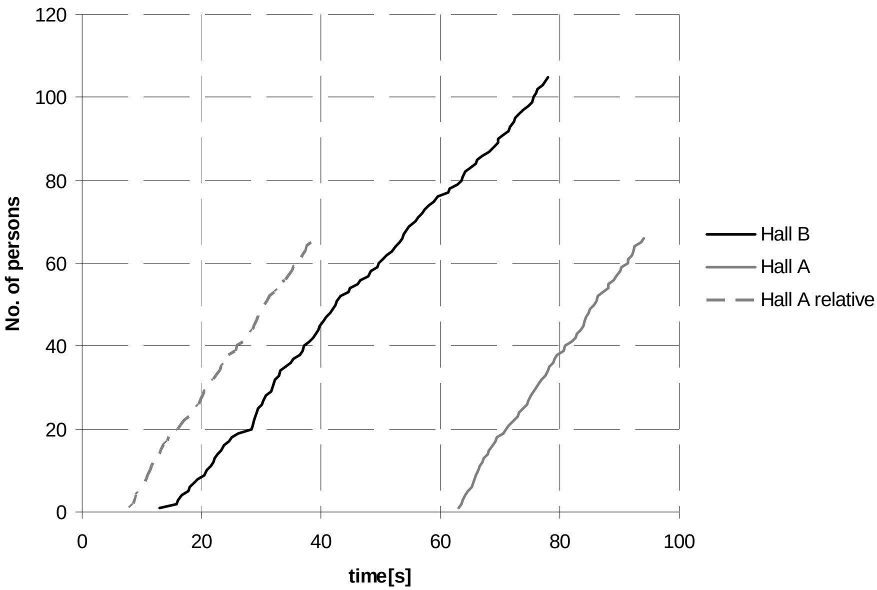


Figure 83. Number of evacuated persons per reference time.

The average walking speeds of people exiting hall A were determined by timing people exiting the door opening and timing the same people passing a point visible in the video recording about 7 m away from the door. The observed walking speeds varied with a mean of 1.5 m/s and standard deviation of 0.2 m/s; see Figure 84.

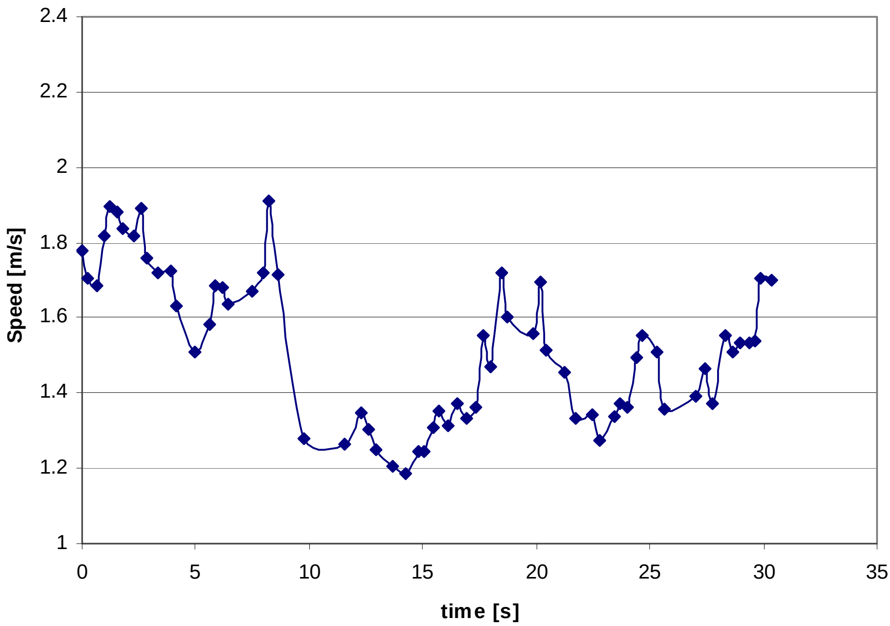


Figure 84. Average walking speeds of people exiting hall A.

The staircase between floor levels -2 and -1 was monitored because the lower end of this staircase was the point at which the people flows from halls A and B met to share the same passage to level -1.

The number of people entering the staircase at its lower end and exiting it at its upper end was monitored, as was the number of people ascending the stairs at each moment (Figure 85).

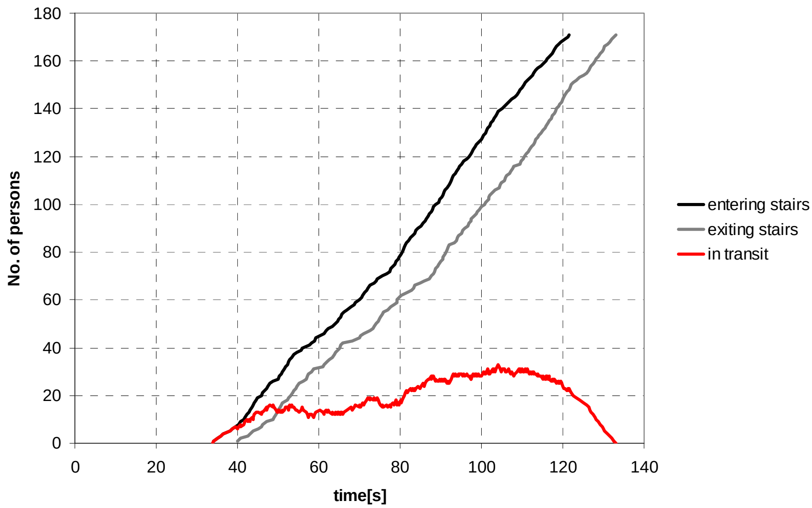


Figure 85. Number of people entering and exiting the staircase (the difference in these curves is the red curve showing the number of persons occupying the staircase).

The average speed of people ascending the stairs and the relative density of people occupying the staircase simultaneously are shown in Figure 86. The inclined (24°) walking distance was 7.7 m including a short 1.2-m-long smooth (0°) surface.

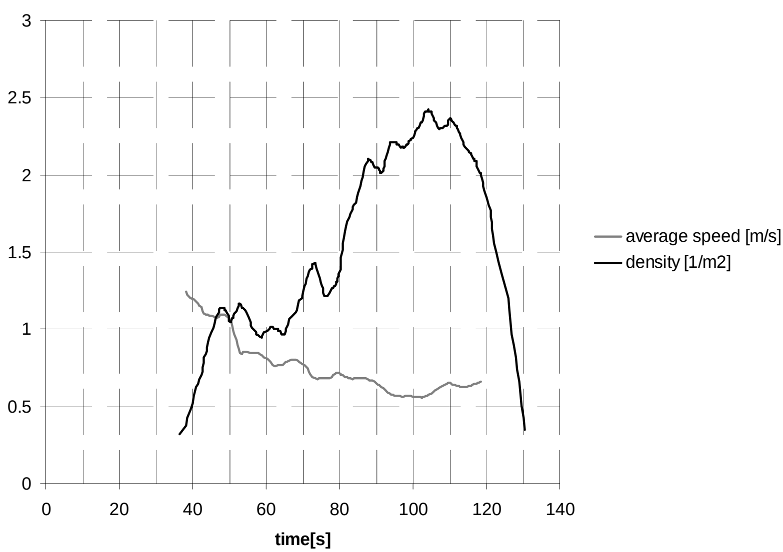


Figure 86. Average speed and relative density of the group of people occupying the staircase.

The relative time to evacuate the halls was 66 persons in 39 seconds (hall A after the evacuation order given by the staff) and 105 persons in 78 seconds (hall B from the start of the evacuation video). The time taken from the start of the evacuation video in hall B to the first person to exit to the -1 floor was 40 seconds, and the last person reached the floor -1 after 134 seconds (same reference time).

As explained above, there was a 57-second difference in reaction times (from the moment the first people stood up and started to exit the hall) between halls A and B. This can be seen in the staircase loading curves at around 60 seconds, when the people from hall A started to reach the lower end of the staircase and the passage was fed by people exiting from both halls.

Observations

Except for the teachers, practically all the participants in the drill were elementary school pupils aged 9–13 years. Despite the small number, the role of the teachers (adults) looking after and instructing the children had a non-negligible impact on the overall behaviour of the group and subgroups of pupils.

Variation was evident in the behaviour of the children during the evacuation in the doorways, on the floor levels and stairs. They typically tended to form and move in groups of two to four. The children who seemed to move by themselves usually ‘moved along’ observantly. The tendency to slow down or speed up significantly and ‘race’, without the limitation of crowding or onset of panic, was manifested more as a subgroup than the behaviour at an individual level. In the absence of the feel of real danger, the children were influenced by and they largely obeyed the instructions and guidelines given by the adults present.

A18. Case V: Door selection test

Background

The door selection test consisted of a series of tests held on two separate occasions in spring 2010. The tests were carried out in a university building. There was a lecture hall with two adjacent doors leading to the passage. University students participated in the test. At the beginning of each test, the students stood at the end of the passage, and after being given an audible start signal, they started to move towards the lecture hall doors and then entered the lecture hall by using either door.

The test series was divided into three categories of tests. In the first category of tests, the students were instructed to walk to the doors and enter as they would normally at the beginning of a lecture (tests 1–4). In the second category of tests, the students were instructed to try to enter the lecture hall as fast as possible, prioritising their own interest, that is, minimise their personal moving and entrance times (tests 5–10). In the third category, the tests were carried out in the same manner, but instead of personal interest, the students were advised to consider the interest of the whole group and try to minimise the time it would take for the entire group to reach the inside of the lecture hall (tests 11–16).

Building description

The place of the tests was a university building and consisted of a lecture hall and the adjacent passage (Figure 87). Two doors separated by 5 m were used to enter the room and the door leaves were removed. The door openings were 0.9 m wide but were narrowed down to 0.7 m by attached stanchions. The passage width was 2.8 m, and distance to the door opening centres was 9.6 m and 14.6, respectively. The doors are marked as door 1 and door 2, referring to the nearest and the furthest door.

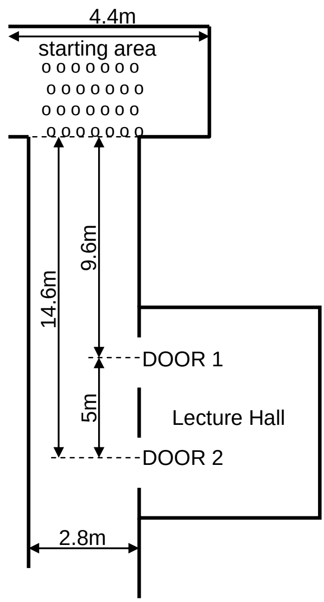


Figure 87. Passage and lecture hall layout. The door openings were 0.7 m wide.

Results

The ideal strategy to enter the room using two doors is to maintain even loading at both doors so that an equal flow can be maintained. In the case of a relatively small group of people, more people will use the first door. The difference between the numbers of people using each door in this case was proportional to the distance between the doors and the time it took to move that distance. This assumes that queuing at the first door does not significantly restrict people moving towards the further door.

As the doors were consecutive on the left wall of the passage, people arriving at the first door could see the situation more easily at the next door when making a door selection decision. If they were already at the further door, moving back to the first door would most probably mean walking against the flow and made this decision more unlikely. A queue formation at the further door or a large group movement towards it would most probably balance the situation by people preferring to stay at the first door.

Figure 88 shows the proportional results of the door selection tests as number of people and relative percentages of door usage. The lower figure shows the respective distribution of time at which the last person at that door had entered the room.

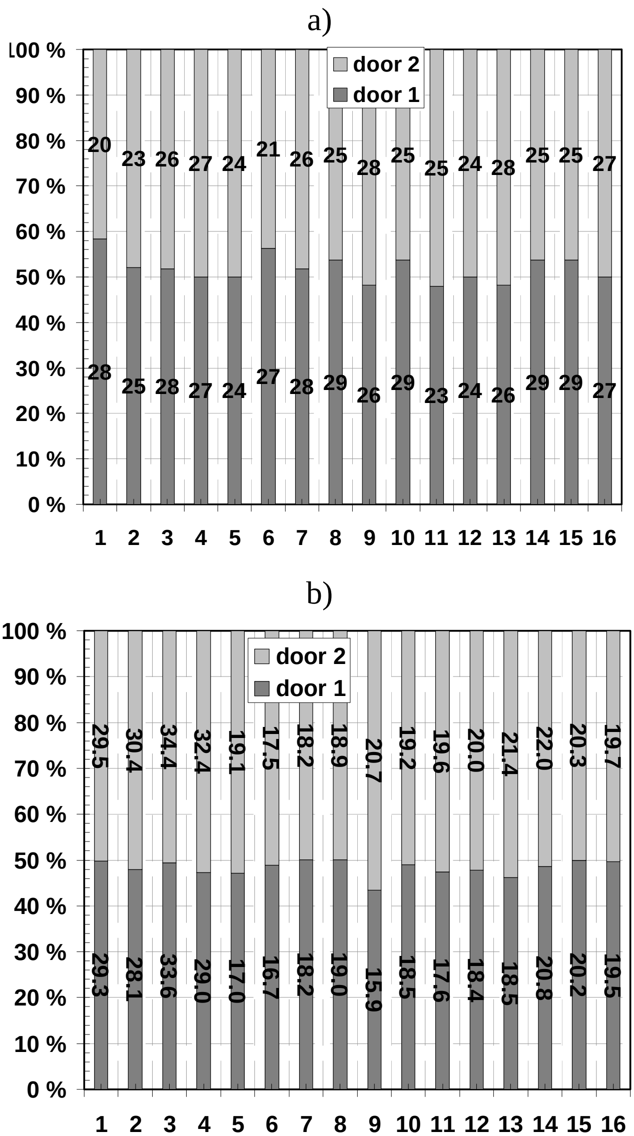


Figure 88. Distribution of a) people and b) entry times in the tests. The first category included tests 1–4, the second 5–10 and the third 11–16, respectively.

The results show, as assumed, that the number of people entering through door 1 was usually slightly higher. The entrance times at door 2 were also usually slightly higher. One reason for this is that it was very unlikely to observe movement back from door 2 to door 1 even when the passage started to clear. When the number of people still in the passage and in the queues was low, the decision to stay in the queue at door 2 was preferred to the decision to take the time to move back to the first door and queue an expectedly shorter time (with added uncertainty). When there were more people in the passage, it was more difficult at door 2 to estimate the situation at door 1. Deciding to go back was also difficult against the main flow.

The process of people arriving at door 2 was also more uneven, partly because people at door 1 were still making a decision at door 1 on whether to move along or stay. The situation at door 1 was more stable. This can also be seen in the specific flows for each door in the test, in which the flow was usually higher through door 1; see Figure 89, which shows the entry times and specific flows for each door.

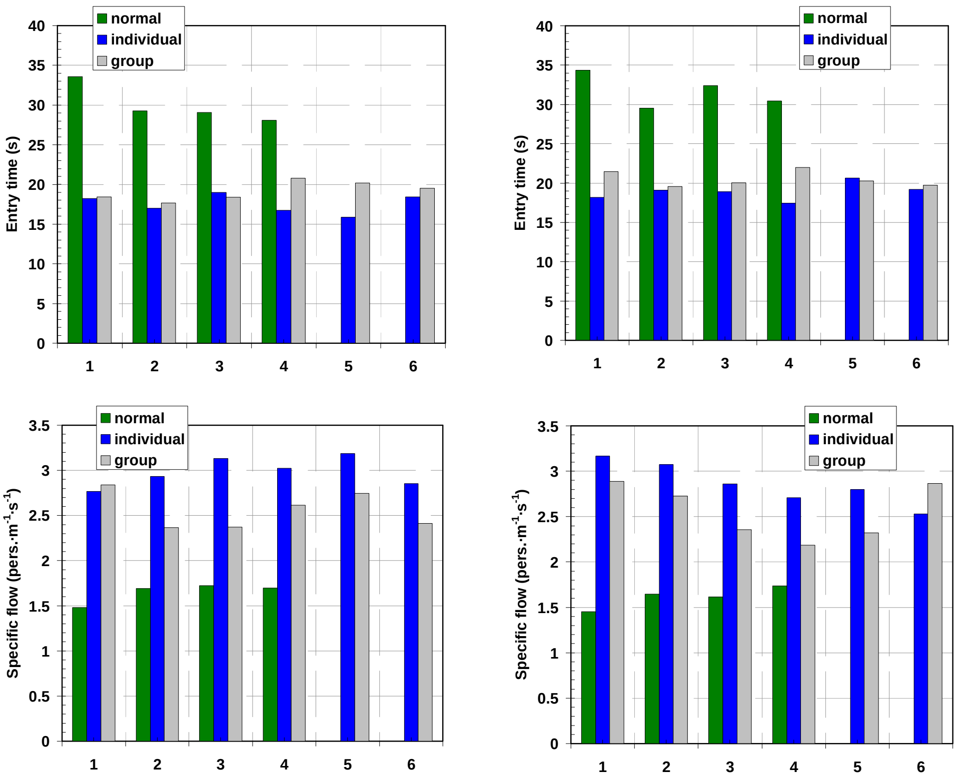


Figure 89. Entry times (upper) and specific flows (lower) through door 1 (left column) and door 2 (right column) in the different tests. Four tests for normal and six tests for the individual and group categories, respectively.

Figure 90 shows the total entry time for the four normal, six individual and six group tests. This measure is the time when the last person entered the room using either door 1 or door 2. This time was mostly determined by the entry time at door 2, that is, the last persons usually entered through door 2.

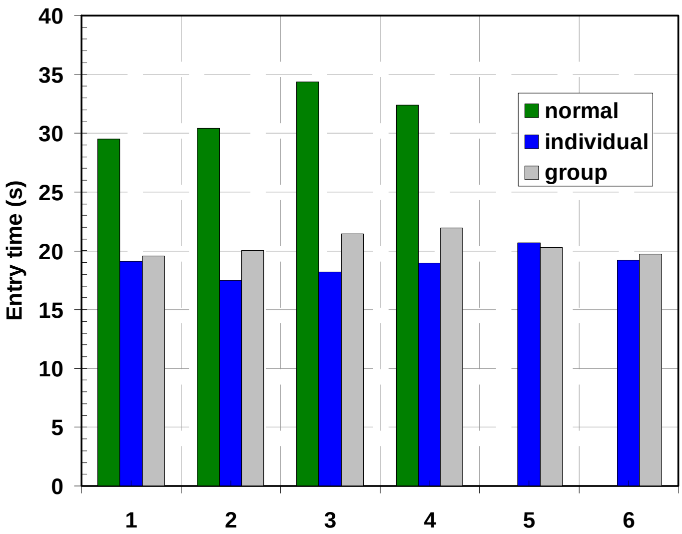


Figure 90. Total entry time for each test.

The fastest entry times occurred when the number of persons using door 1 was slightly higher than the respective number for door 2. In these cases, the entry time at door 2 was longer.

Equal or greater usage of door 2 in relation to door 1 or a longer entry time for door 1 predicted a longer total entry time.

The time differences in the tests were comparably small, and the greatest variation could be observed between different test categories, with the individual interest test having on average lower total entry times than the group interest tests, with the normal test being the slowest.

The number of participants on the two different test occasions differed in that the first set of tests had 48 students and the second 54. This is believed to have a significant, though relatively small, effect on the entrance times.

The fastest entry times were observed in the tests in which people prioritised their individual interest. Tests in which the group's interest prevailed tended to lead to more polite behaviour and slower entry times. In addition, the unlikely behaviour of people returning back from door 2 to door 1 took place in these tests. The decision to return to the first door seemed to be preferred if the situation in the passage was such that the number of people at the other door was smaller and there was enough time to join the other queue before it had disappeared. The group behaviour was thus more polite and the decision-making more versatile. People were nonetheless reluctant to make decisions diverging from the overall group behaviour if, in all likelihood, that would have significantly delayed their individual entry. That is to say, the performance of the individual would start to define/affect group performance, for example, by making a decision that would presumably make the individual the last person to enter and thus define the entrance time of the whole group.

Observations

The group attending the door selection tests consisted of relatively young university students. The group was homogenous in terms of their level of fitness and ability to move in the context of these tests.

The decision-making was narrower but efficient when people prioritised their own interests. When prioritising the group's interest, the people seemed more willing to re-evaluate their decisions and reduce their own state while trying to enter the room, but only to a point. It is also harder to evaluate which individual means and decisions are effective at group level. Training and how well the people in the group know each other or act and communicate together certainly have significant influence. The test simulated a typical situation in which no prior training, strategy or communication existed before.

The high, observed specific flows were certainly related to the composition of the group. When entering the narrow door opening, some people entered sideways to minimise their need for space. The group movement and behaviour can be described as dynamic.

The tests were arranged on two different occasions. On the second test occasion, the people were given a number before each test. This number determined the person's place on the starting grid at the end of the passage. These numbers were also used to observe which door each person used to enter and his or her relative entering order. One of the objectives here was to examine how the starting position (in front, at the back, in the centre, on the left or right side of the group, etc.) influenced the door selection.

As a general observation, people on the right (relative to the direction of movement) on the starting grid chose door 2. People on the left of the grid or in the centre of the front rows chose the first door: door 1. In the back row, there was a tendency to use door 2. Other positions did not lead to a particular preference of door. This is partly explained by the narrow passage in which people in front of the group and on the left side of the group obstructed door 1 on arrival. It was natural for the right side to move towards door 2. The crowd was not large enough to block the right side of the passage permanently.

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Author(s)
Tuomo Rinne, Kati Tillander & Peter Grönberg

Title
Data collection and analysis of evacuation situations

Abstract
This study covers data from 18 evacuation situations in different building types ranging from a single hospital ward to a stadium. Twelve of the cases were ordinary evacuation drills, four were real fire alarms and the remaining two were normal but congested situations. The data were collected in Finland, starting in autumn 2007 and finishing in autumn 2010. The data gathered are designed for the buildings' safety and security staff, the fire authorities, the fire safety engineers and the model developers.

The results obtained from the evacuation situations are represented using quantitative and general approaches to link similar data together. The original data from the single evacuation cases are also represented individually.

Several distributions were formed to quantify different time intervals of the whole evacuation process. The distributions were pre-movement times, total evacuation times, and walking speeds on smooth and inclined surfaces. The congested situations were investigated using correlations between the walking speeds and crowd densities.

In the general part, the alarm systems, the pre-evacuation actions and the differences between the real fire alarms and the drills were monitored to reach conclusions about the reactions of the people and the safety staff. The behavioural aspects of humans were also analysed. The evacuation phase was investigated in terms of the exit routes and the people's door selection routines.

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