Human Factors in Pedestrian Simulation: Field Studies in Underground Stations

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Abstract – For the purpose of emergency evacuation design, reliable data on the occupants of an infrastructure are necessary. Also, the occupants' wayfinding and the route choice strategies of evacuees should be considered as these factors account for part of the evacuation time. In this paper, two field studies are reported: First, passenger flows and occupancies were counted on all three levels of a complex underground station in Germany, including all exits and transitions to the platform levels, e.g. stairs and elevators. Data will be used as initial and boundary conditions for future full-scale simulations using the pedestrian simulation framework JuPedSim. Additionally, passengers with special physical needs were counted, e.g. persons using wheelchairs, travelling with children, or having other mobility restrictions. Methodological aspects of pedestrian counts are discussed. The second study reports a field experiment on wayfinding, focussing on perception and route choice strategies. Results show the significance of signage for employed wayfinding strategies depending on participants' knowledge and physical state. These results will be used for further progress in the modelling of wayfinding.

Keywords: occupancy measurements, wayfinding, exit choice, signage, population characteristics, field studies, human factors

1. Introduction and Motivation

For the purpose of emergency evacuation design, reliable data on the occupants of an infrastructure are necessary: The required number and dimensions of emergency exits are usually based on the number of users and the type of the infrastructure, e.g. [1, 2]. Yet, occupant numbers are not always available. For example, German local transportation services often do not have accurate knowledge about occupant numbers or different subgroups of occupants in their underground stations, e.g. people with physical disabilities. In German underground stations, no turnstiles are used at the entries to the stations, and most local transportation services do not perform regular passenger counts in trains or stations. In stations with shops, in addition to passengers, shoppers add to the occupant numbers, so even counts at turnstiles would yield inaccurate numbers. Therefore, for determining occupancy, it is necessary to count occupants reliably and determine pedestrian flows over time. For occupants who may not be able to evacuate without assistance, there are even less numbers available. [3] showed for public buildings that about 12 % of the mobile population of Northern Ireland are disabled and that all kinds of public buildings (including stations) are frequented by a significant number of physically disabled persons.

Within the context of a research project on underground fire safety, the authors conducted a pedestrian count study in one underground station. In addition to counts, physical characteristics relevant for evacuation were identified, e.g. usage of a walking stick. Some of the findings are reported in this paper. This data will be used as initial and boundary conditions for future full-scale simulations of a specific underground station using the pedestrian simulation tool JuPedSim [4].

However, even if the characteristics and numbers of occupants of a facility are known, we still need to understand why and how people will select exits in an emergency. Wayfinding and preferences for route choice need to be examined by different methods, taking psychological aspects such as knowledge and strategies into account. But although the relevance of individual and social human factors in pedestrian and evacuation modelling generally has been accepted, only few studies aim at determining their specific influence on pedestrian behaviour [5]. Therefore, the second study presented here aims at route choice and basic strategies of wayfinding. Methods included video recordings, interviews and questionnaires. Data was collected in the same underground station as in Study 1. Results will also be integrated in the setup of simulation ensembles. The results allow to model inhomogeneous cognitive characteristics which can be as decisive as physical characteristics like walking speed or space requirements for the evacuation progress. Cognitive inhomogeneity can be represented by providing simulated pedestrians (agents) with different spatial knowledge degrees and preferences [6].

Although both studies were conducted in an underground station, the methods and results can be applied to other infrastructures as well.

2. Study 1: Analysis of Population Characteristics
2.1 Design of the study

A first goal of Study 1 was to determine absolute numbers of occupants inside the station throughout a defined period of time. For that purpose, a dual approach of data collection was chosen consisting of manual countings (using tally counters) and video recordings. The counting period was one hour (5 to 6 p.m.) on a regular week-day in January 2016.
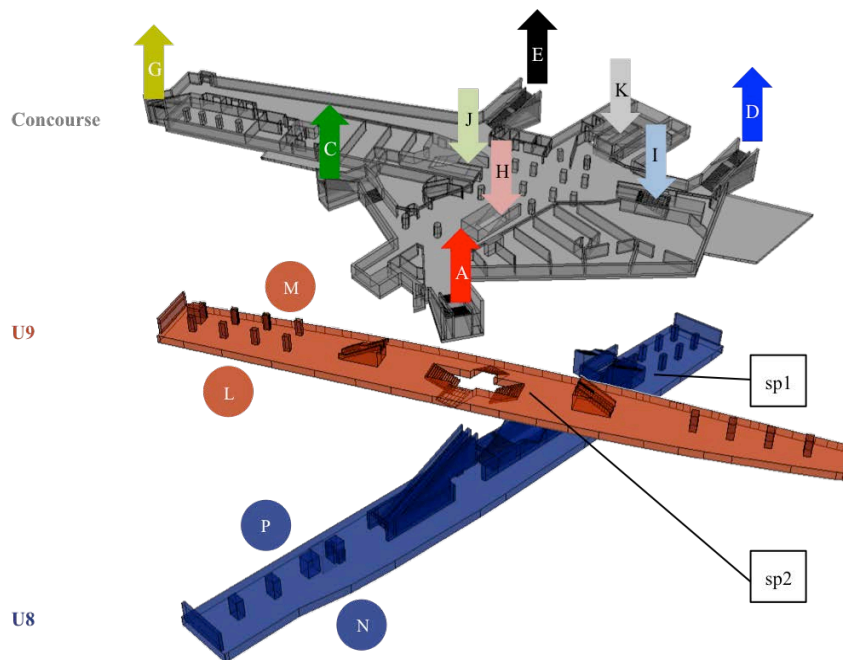

Figure 1: Overview on counting positions throughout the station. Positions A to K cover the staircases of the concourse level. Positions L to P observed the four tracks on the platform levels. Positions B and F (lifts) are not included. sp1 and sp2 refer to the starting points for Study 2 in this paper.

A second emphasis of study was on the lifts users. In case of fire lifts will be turned off. Thus, it is necessary to know about the characteristics of lift users because they might need assistance for evacuation. The analysis of video data and manual counts aimed at total numbers of lift users and their physical characteristics, e.g. walking disabilities.

Since the platform levels are pretty well observable, countings here were done by two persons per platform. One person was responsible for each track at the positions L to P as shown in Fig.1. In intervals of 5 to 7 minutes, always shortly before the arrival of a train, the manual counts started and video recordings were made at the same time.

The concourse level, in contrast, provides a wide spatial extent with limited observability. Hence, video material was recorded at the two lifts (B and F, not included in Fig. 1) and the staircases A to G, which connect the concourse level to the street level. For the stairs connecting the concourse level to the platform levels (H to K), no video recordings were made. At the positions A to K, two persons counted each one direction of passenger movement: entering or leaving the concourse level. Afterwards, the video recordings were analysed to confirm the reliability of manual counts.

Additionally, at the beginning and the end of the counting period, the number of persons in the concourse level including the shops was counted by two observers.

The countings on the platform levels were conducted simultaneously with those in the concourse level. In order to gather insights about the statistical distributions of occupant numbers, a second counting on the platform levels was conducted the following morning, during a peak hour.

2.2 Methodological and privacy aspects of passenger counts

If counts are only done manually, the counting persons have to keep a constantly high level of attention. Comparing the results of manually recorded countings and countings using video data, we found deviations of the results ranging up to 25 %, even for those few persons entering or leaving the lifts. In order to keep this error rate low, only one counting task should be assigned to one person at the same time [see also 7]. Ideally, every counting task is given to two persons. Tasks have to be specific, e.g. "only count persons walking into direction A"; "only count persons using a wheelchair". A combination of tasks increases the task complexity so that manually recorded countings (in real-time) are not reliable. If the number of counting persons cannot be increased or if there are more complex counting tasks, video recordings are the method of choice. Here, we present the reliable numbers from afterward countings using video-recording.

The usual video perspective from above (counting heads) is insufficient to code characteristics like body shape and visible disabilities. In this study, the recording visual angle was from the side and slightly above.

When using video recordings, privacy has to be taken into account according to local regulations (e.g. by using blurring). For this study, information about video recording was given to passengers by posters at each entrance, indicating that every person could object to being recorded. Permission to record inside the station was granted beforehand by the transportation service and shop owners in the concourse.

2.3 Results
Occupant numbers

All data was converted to time series representing both upstairs and downstairs flows at all staircases. Given the initial number of occupants and the time series, the flow data was used to conduct a balance calculation over the period of one hour (Fig. 2). The consolidation of the platform and concourse recordings allows for a rough estimate of the total occupant number present in the station.
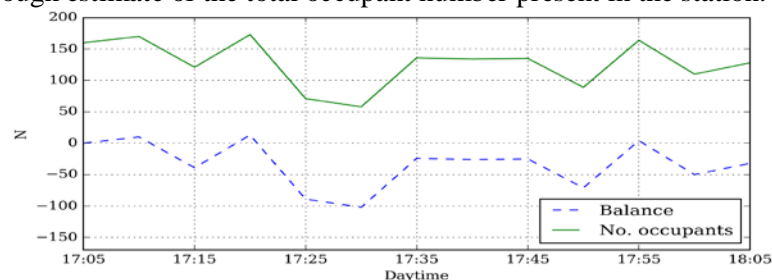

Figure 2: Balance of occupant numbers inside the concourse level showing the balance calculated from the video material and the predicted occupant numbers over a period of one hour.

The balance calculation reveals an alternating pattern ranging from approximately +10 to -100 occupants. The resulting occupant numbers alternate between approx. 60 and 170. The numbers may correlate with peaks caused by the train traffic and the resulting passenger flows towards the platform levels and out of the station. The intervals are uneven and are usually slightly ahead of the train schedule (passengers moving towards the platforms) or behind of the train schedule (passengers coming into the concourse level).

The histogram plots presented in Fig. 3 summarise selected statistical distributions results. Data analysis revealed interesting differences between the two services (U8, U9) operating at the station. In terms of the absolute numbers, platform U9 handles almost the double occupant load than platform U8. These differences also apply for the variability over the day. U9 provides remarkable differences in the occupant load over the day, the morning hours being the busiest ones. The variability throughout the day appears to be less distinctive on U8 and the major load was recorded in the evening hours. These results can be accounted to different courses of the services, U9 passing major regions of the central district of Berlin.

Given the data collected simultaneously during the early evening hours, a rough estimate of the occupants present in the station can be conducted as follows. The balance calculation in the concourse level revealed maximum occupant numbers of approximately 170 persons. During these times, an average of 240 occupants was counted on both tracks of U8. The departure track of U9 was occupied at most by 160 persons. The summation of these numbers yields an approximate number of 550 to 600 occupants being in the station. However, this number does not consider passengers inside the operating trains.
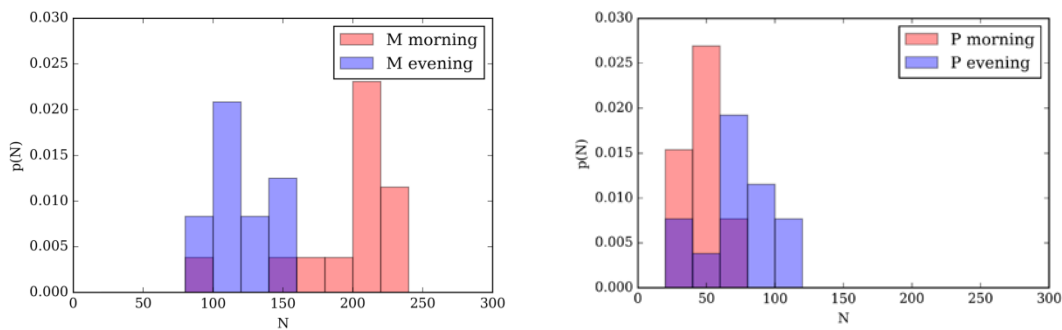

Figure 3: Distribution plots illustrating the number of occupants waiting on the tracks during both evening and morning times. Measurement position M corresponds to platform U9 track 1 and P to platform U8 track 1.

Exit choice

The video recordings utilised for the balance calculation presented above allow for another interesting analysis: the exit choice of occupants. For that purpose, we analysed the generated passenger flow item series with regards to exit choice distributions. Here, we only consider the exit choice of occupants leaving or entering the concourse level to/ from the surface (Fig. 4).

Again, these numbers reveal some interesting results. The data is by far more variable for occupants leaving the concourse level. In case of leaving the concourse level, mainly the exits C, D, and G are preferred. The exits C and D are also frequently used when entering the station. However, for entering the station, exit G is less frequented whereas exit A is more often used. The reason could be that exits C, D, and G lead to connecting tramway and bus services.

However, there are limitations when interpreting the data. The total number of leaving occupants was higher than the number of persons who entered the station. Since the counts were made during the evening peak hour, it is not clear if the pattern of exit choices persist during the morning peak hour. Unfortunately, it was not possible to extend the counts to an entire day.
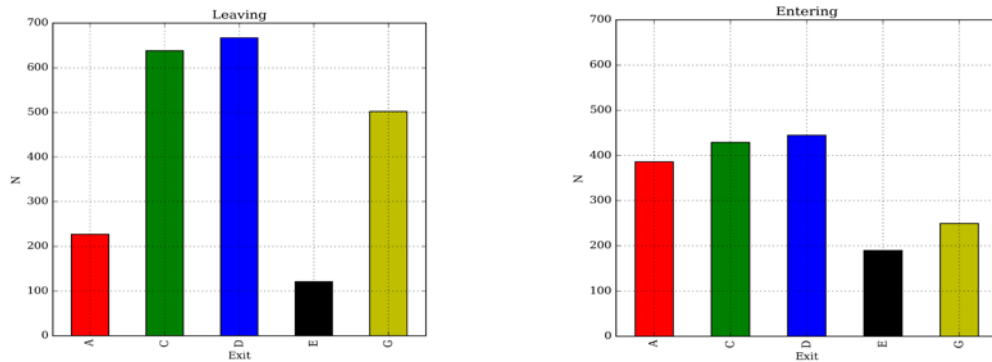
Figure 4: Bar plots illustrating the exit choice for occupants either leaving the concourse level (left) or entering the concourse level (right).

Occupancy composition - categories for persons with special characteristics

For both lifts in the station 237 lift users were counted in total. During video analysis of the recordings at the two lifts, categories were defined for passengers with special characteristics. The focus was on occupants who would need assistance during an evacuation if the lift is taken out of service, either due to a disability or due to other circumstances (e.g. small children). The following characteristics hindering a self-rescue in evacuations could be clearly identified in the videos and were most frequently counted:

– Persons sitting in a wheelchair (5)
– Babies in a pram or carried in a baby sling (17). Carrying a baby may slow down the carrier.
– Small children, either sitting in a pushchair or walking on the hand of an adult (24). These children are heavier than babies and the carrying would definitely slow down the adult. This holds true especially for three cases where there were more small children than accompanying adults.

Some relevant occupant characteristics for evacuation have not yet been coded, e.g. visual impairment. Since no person observed used a white walking stick and armlets or even heavy glasses, visual impairment could not reliably be identified in the videos or during countings. Further analysis is in progress.

3. Study 2: Wayfinding strategies in an underground station

The second study aimed at identifying preferences for wayfinding and route choice strategies, e.g. searching for landmarks, use of signage, and preference for direction. These are of particular relevance for evacuation and simulation as they may account for part of the evacuation time, e.g. [8].

3.1 Method
Participants

Study 2 was conducted with 32 volunteers. Informed consent was obtained by all participants. 31 participants were Germans from several cities. Their age ranged from 20 to 31 years (average: 24.8; standard deviation: 2.74). 15 participants stated to be male, 15 female, and 1 other. 25 participants were (master or bachelor) students from several specialities, e.g. geography (19) or social sciences (2); 6 participants were postgraduates, e.g. working as a musician, or architect. One participant did not answer this question. 30 participants were right-handed, two left-handed. Two participants stated that they had a (temporary) mobility impairment, hindering fast movement (one of them was using crutches).

Performing a wayfinding task was expected to be easy for participants with local knowledge due to the accordance of the cognitive map and the given building [9]. Therefore, participants were asked initially how well they knew the particular underground station. On a range from 1 (not at all) to 10 (very well) participants answered with a median of 3 (average: 3.63; standard deviation 2.7). Despite this low level of local knowledge, 29 participants stated to have at least some generalised knowledge about underground traffic and stations.

Wayfinding Tasks

The tasks in Study 2 consisted of finding a safe exit to the street level from two different starting points on each of the underground levels (either platform U8 or U9; cf. Fig. 1 and 5). The criterion for the starting points was not to indicate which way to go. For this purpose, starting point 1 [sp1] was located on the lowest level of the station at the end of the platform (U8). Participants started facing a wall (the rear side of a staircase) 2 m in front of them. They were positioned in the centre of the platform with track beds on both sides (each 3-4 m away) and with the end of the platform in their back (approx. 6m distance). Starting point 2 [sp2] was located on the second level of the station (U9), in the middle of the platform. Participants started facing a staircase leading downwards to the lowest platform level. Just like for sp1, participants were positioned in the centre of the platform with track beds on both sides, each 3-4 m away, and with the backside wall of another staircase behind them, in a distance of approximately 4 m.

The experimental design of Study 2 included 2 runs in two groups. Participants were divided into two groups (16 for group 1; 16/15 for group 2). For the first run, group 1 started from sp1 and group 2 from sp2 and for the second run vice versa (Table 1).

Participants were led to each starting point after they had been blindfolded, using either the direct route from the concourse level (to sp1) or a detour via the lowest platform (to sp2). At the starting points, the participants were equipped with a head-mounted action camera. They were then asked to follow the instruction of an announcement read out to them. This announcement imitated a loudspeaker announcement in case of a fire and demanded to leave the station right away but without running.

For the second run, participants were asked to comment on how they were orientating themselves and to explain their choices of a specific route ("thinking-aloud"). Participants' answers were recorded by the action camera. Data with and without thinking-aloud were obtained for both starting points either in the first or as second run, so that effects of thinking-aloud on orientation would be noticed (Table 1).

Table 1: Wayfinding tasks and type of instruction.

Starting point / Type of instruction	Starting point 1 (U8)	Starting point 2 (U9)
Find a safe exit to street level	Group 1 (n=16)	Group 2 (n=16)
Find a safe exit to street level and comment on action	Group 2 (n=15)	Group 1 (n=16)

Collected data

All participants answered a questionnaire on socio-demographic data before the two tasks.

Performance of the two tasks was recorded with a head-mounted action camera, showing the chosen route, spots where participants stopped for reorientation and thinking-aloud commentaries. The instructors followed the participants from their respective starting points and marked the participant´s route on a paper map of the station including stopping points.

When reaching an exit, the participant was stopped and interviewed by the instructor, using a standardized set of questions on wayfinding and route choice. Finally, participants were asked to fill in a questionnaire including aspects about their knowledge of the station, their strategies of wayfinding and perception, the assumed geometry of the station as well as their reasons for their route choices.

3.2 Results

A total number of 31 (32 in trial 1) persons completed both trials. Fig. 5 displays the individual trajectories for both trials in separate illustrations for each starting point, for sp2 at the top and sp1 at the bottom. Participants' walked paths are indicated by lines of various colours. Fig. 5 also contains first decision points and walked paths. Walked paths are only presented for the platform level of sp1 and sp2.
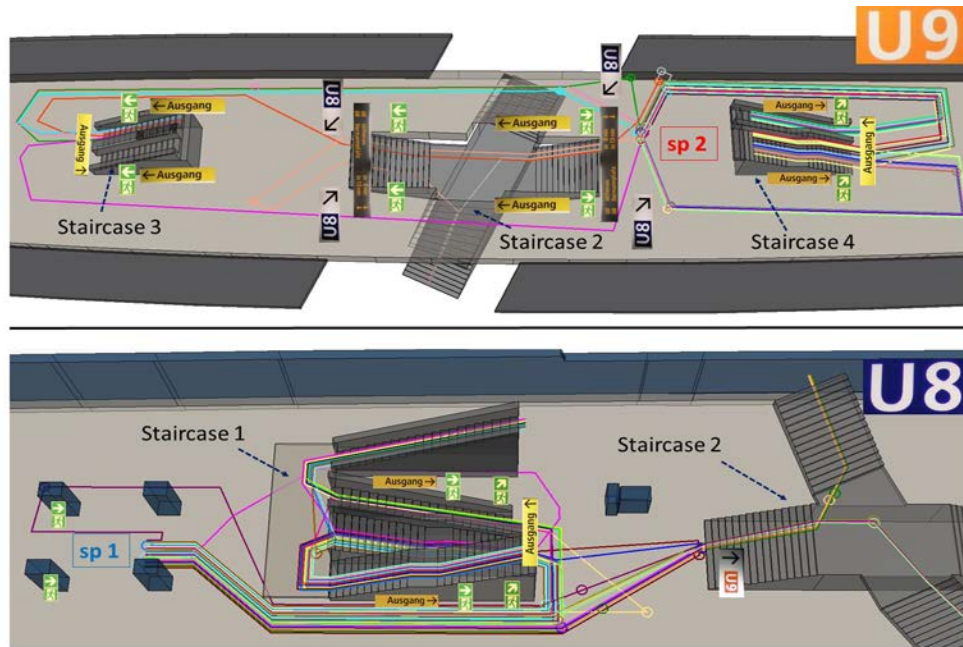
Figure 5: Platform U8 (bottom) with Starting point 1 (sp1) and platform U9 with Starting point 2 (sp2), including signs and trajectories for occupants´ route choice ("Ausgang" means "Exit").

Starting point 1

At sp1, participants started between the pillars on the platform of the U8 (cf. Fig. 5 bottom). Except for two of the participants, they all started searching for an exit by passing the staircase on its right side (in Fig. 5 near the bottom). At this point, there were no signs in sight which could influence the choice for one of the possible ways. This position was a first critical decision point with respect to wayfinding strategies. Here, participants faced three options: (A) proceed on the platform, (B) turn left and use Staircase 1 (leading to the concourse level) or (C) use Staircase 2 (leading to platform U9). 78% (25 of 32) of the participants chose option A. Possible explanations are that after being led to Starting point 1, the participants might have remembered the last final turn coming down from a staircase. Or they might have had the specific knowledge that Staircase 1 would directly bring them to the concourse level. In both cases the underlying strategy is "*Use the way that is known to you*". A second strategy, explicitly stated by the 2 participants with walking impairments, is "*Use the closest (comfortable) way compensating your impairment*". This strategy leads to Staircase 1 as well because there is an escalator next to the normal stair on the left side (the normal stair was used by 20 of the 25 participants choosing option A).

In the area between Staircases 1 and 2, some participants stopped (indicated in Fig. 5 by circles in participants' walked paths) and looked around (also commented) in order to investigate the surrounding and plan their next step. In the interviews, participants said they had looked for information in their surroundings that would give them orientation, e.g. signs or stairs. After having collected novel information in this way, two participants turned around at the bottom of Staircase 2 and used Staircase 1 instead. The strategy applied could be "*Follow the exit signs*".

Signs above the bottom of Staircase 1 indicate that an exit can be reached this way. Yet, when passing Staircase 1, participants couldn't see its bottom if they looked ahead. So, the sign couldn't influence their decision to choose Staircase 1. Participants seem to have taken the next available staircase, no matter where it lead. This strategy could be called "*Use the next possible way up that you can see*". Those 7 participants who choose Staircase 2 could have followed the same strategy, as signs above the bottom of staircase 2 indicate that it leads to platform U9; no exit is indicated. At the platform of staircase 2, 3 of 7 participants took the stair to their left, 4 used the stair to their right, and none walked down the stair on the other side back to the level they came from. These choices and also the fact that no participant chose option B (proceed on the platform) also emphasize the relevance of this "go-up" strategy.

Starting Point 2

At sp2 on platform U9, participants were faced with multiple alternatives. In consequence, before starting to walk most participants looked around trying to gather information about their surroundings. 28 of 31 participants (90%) decided to first remain on the platform U9 instead of using Staircase 2 right in front of them. The sign hanging from the ceiling above Staircase 2 (leading downwards) indicates that this way leads to platform U8. However, 3 participants (10 % out of 31) chose to go this way. 2 of them then used the stair at the opposite side of the intermediate landing, which brought them back up to platform U9. The third person turned left and followed another stair down to platform U8.

In addition to these 3, 8 more participants (in total 11 of 31) decided to walk into the direction they had been positioned at sp2 and passed Staircase 2 (7 of them on the right side/ upper side in Fig. 5, one on the left side/ lower side in Fig. 5). 71% (20 out of 28) of the participants who stayed on platform U9 proceeded in the opposite direction, to Staircase 4. 14 of them passed Staircase 4 at the left (upper side in Fig. 5); the remaining six participants passed staircase 4 at the right side (bottom side in Fig. 5).

Many participants stopped after having moved away from the centre of platform U9 and getting closer to the track beds on the sides. From here they had a better overview of the platform compared to their starting position. They collected new information to reassess the chosen route. This may be summarized in a strategy "*Find a position to gain an overview of alternatives before proceeding*".

All participants who stayed on the current level, platform U9, walked on until they reached the first staircase leading upstairs (Staircase 3 or 4). This was one of the possible strategies identified for sp1, "*Use the next possible way up that you can see*".

At Staircase 4, 50% of participants coming from the left side (in walking direction) of the platform stayed on their side and used the escalator. The other half chose the stairs instead of the escalator. A possible explanation could be a blockage of the escalator by other passengers. This would follow two strategies already implemented into pedestrian dynamics simulations, "*Avoid jamming and use the local shortest path*" and "*optimize travel time*".

The strategies formulated above were identified from the interviews and questionnaires and summarized here for both starting points. Some more findings relate to structural factors: There was a self-reported relevance of using signs for wayfinding stated by 27 out of 31 participants. Yet, a strategy for evacuation possibly familiar to most or all German participants, "*Follow the green exit-signs displaying a running man*" could not be applied easily: Inside the station these signs are located near the floor (so they will be visible in smoke), and participants rather looked for signs near the ceiling, where only yellow signs with black writing ("Ausgang") indicated exits.

Another possible strategy, "*Search for landmarks from whereon you know the way out*", was not applied. Participants answered explicitly that landmarks (e.g. known objects or scenes inside the station) did not exist for them.

4. Discussion and Outlook

The field studies presented in this paper show methods to reliable count pedestrians and to identify strategies of wayfinding route choice. Despite their usefulness, there are some limitations and lessons learned:

Results suggest an importance of countings, if no numbers are available by the transportation services. These numbers may not entirely correspond to accepted numbers for the calculation of evacuation scenarios and occupant loads, e.g. according to standards for underground stations defined in NFPA 130 [1]. Further clarity about occupants or passenger populations could be reached by having more sample counts, for different times of the day, throughout the week and the year.

Further analysis of the population, regarding sub-populations of passengers, will be needed. These should not be restricted to the lifts, but also include passengers using stairs and escalators for entering and exiting underground stations.

All methods used in these field studies require a high amount of observers or other staff. Also, the analysis of video data is not trivial and must be done by trained observers. In particular, special needs are in general not easy to identify (e.g. not all blind people use white canes). So, it wasn't possible to find selective categories for the classification of all special characteristics of pedestrians. Even apparently obvious categories as "small child" are not easy to code if no data apart from appearance and walking behaviour are available. Even if special needs are recognizable, they are not always clearly visible from a single camera perspective (e.g. due to persons blocking the view on others). Here, additional camera perspectives could be useful.

With regards to wayfinding, more analysis is needed on structural factors influencing wayfinding, e.g. presence and visibility of signs, staircases, and exits. Furthermore, generalised knowledge and knowledge about the specific spatial structure of the station, physical fitness (participant with walking impairment used escalators) were found to be relevant for wayfinding as well. These also need to be investigated in more detail. Another analysis still in progress is the influence of individual factors like handedness, gender, physical fitness, specific and generalised knowledge, and thinking-aloud on wayfinding and route choice. Additionally, data from another study on wayfinding in small groups will be included in further analysis.

Acknowledgements

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