Psychological Aspects of Human Dynamics in Underground Evacuation: Field Experiments

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Abstract.
The relevance of individual and social human factors in evacuation generally has been accepted, but only few studies aim at determining their specific influence on evacuation behavior. Data come from accident analysis, laboratory experiments, and field studies. A series of studies including passenger counts, passenger interviews and field experiments is reported. Data show that many passengers would need help in an evacuation, that passengers lack knowledge about evacuation signs and behavior, and that they expect their own behavior to be non-compliant with some evacuation orders. Field experiments show instances of helping participants with simulated impairments, and of altruistic as well as egoistic behavior. Results concerning group behavior include staying together and even building "human lumps".

Keywords: field experiments, human factors, passenger evacuation, social behavior, subway station, underground transportation

1 Introduction

Underground transportation systems are a part of everyday life in cities around the world. In the rare event of a major fire or a terrorist attack, the health and lives of passengers depend on fast and safe evacuations.
The research project OrGaMIR^{PLUS}, funded by the German Ministry of Education and Research, deals with human factors in evacuations from underground transportation systems. By specifically addressing human factors such as human social behavior, OrGaMIR^{PLUS} aims to further improve evacuation guidance in subway systems, e.g. escape routes, and evacuation simulation models. In this paper, we describe results from passenger counts, passenger interviews and results of evacuation field experiments in progress.

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2 Human Factors in evacuation research

As branch of science and technology, human factors are concerned with human characteristics and technical components to improve human well-being and overall system performance, e.g. safety in underground transportation systems. Human factors focus on human-artifact interactions in a systematic approach (e.g. Sanders & McCormick, 1993; Karwowski, 2012).
When considering human factors in evacuation, pedestrian dynamics are relevant behavioral human factors, e.g. keeping distance between pedestrians (Forell, 2004) or orientation behavior (Carlson, Hölscher, Shipley & Conroy-Dalton, 2010). For evacuations as exceptional and dangerous situations, further behavioral and physical human factors should be taken into account, such as decision making, motivation, attitudes and emotions as well as group related characteristics, e.g. social behavior and leadership, but also physical characteristics like size or impairment. The relevance of human factors in evacuation generally has been accepted, but only few studies aim at determining their specific influence on evacuation behavior. Studies rely on different types of data and analysis, as the following examples illustrate.

Analysis of real accidents

The behavior of humans in evacuation, especially from fires, has long been in the focus of research. Researchers often have addressed behavior that may seem irrational or not understandable, like "freezing" or sudden panic (e.g. Schneider & Kirchberger, 2007). But when the situation and perspective of the persons is taken into account, it turns out that human behavior in evacuation is usually neither irrational nor egoistic (Sime, 1985; Fahy & Proulx, 2009). Most researchers today agree that "irrational behavior" is seldom found in real events (Tubbs & Meacham, 2007; Schreckenberg, 2008; Quarantelli, 2008; Cocking, 2009, contrary to the popular belief that mass panic is the normal thing to happen). Not only rational, also pro-social behavior in evacuation is often found: Dynes (2006) reports altruistic behavior in several evacuation scenarios, so does Drury, Cocking & Reicher (2009). Fridolf (2010) summarizes accidents analysis and field research on fire evacuation in underground transportation systems. According to Fridolf, factors explaining the unwillingness to evacuate a subway train or subway station seem to be information processing (e.g. when dealing with incoherent or unclear information or ambiguous cues from the source of danger) and social influence. After more than 20 years of research a lot is known about human behavior in real events. But collection and analysis of individual data from real events is difficult and seldom tried (e.g. Drury Cocking & Reicher, 2009, researched behavior in subway trains after the London bombings of 2005.) In closing, results concerning human behavior in evacuation do not easily yield clear input factors for design of escape routes or evacuation simulation models.

Laboratory experiments

While simulation models have started to embrace a broad access to human factors, empirical data from laboratory experiments still seem to concentrate on external aspects that influence evacuation behavior. These aspects include the relevance of the number of individuals, consequences of escape route dimensions and obstacles for the evacuation time (e.g. Schreckenberg, 2010; Schadschneider, Klingsch, Klüpfel, Kretz, Rogsch & Seyfried, 2009). Individual human factors, e.g. motivation and behavior, are being considered as relevant for the improvement of simulations, yet only few studies investigate these phenomena empirically. Usually, laboratory settings are used for experiments, designed to observe single aspects of individual or group behavior like walking speed, route choice and lane formation, or avoidance behavior (e.g. overview in Fridolf, 2010) Human factors in evacuation from underground tunnel systems have only recently been addressed in laboratory experiments. Frantzich & Nilsson (2004) intended to assess realistic wayfinding behavior of passengers, using a 37 m tunnel filled with irritant smoke. Other evacuation experiments are done to investigate more general characteristics of pedestrian movement such as: evolving patterns and paths of movements in crowds (e.g. Helbing, Molnár, Farkas & Bolay, 2001) and underlying social forces (e.g. Moussaïd, Helbing & Theraulaz, 2011; Helbing, Farkas, & Vicsek, 2000). Typical laboratory settings for these experiments are hallways. Sometimes 3D virtual reproductions of an environment are created, e.g. of public buildings to investigate spacial cognition and orientation behavior (Conroy-Dalton, 2005), or even of a subway station to detect social human factors like cooperating or competing behavior in evacuation (Drury, Cocking, Reicher, Burton, Schofield, Hardwick, Graham and Langston, 2009). A recent example for a subway-related laboratory study is from the METRO project in Sweden (Nilsson, 2010): In the laboratory-setting of a prepared and smoke filled road tunnel (vs. a real subway tunnel), passengers´ way finding behavior in smoke - resulting from a “burning” subway train - was the human factor investigated, inspected in order to calibrate existing computer simulations.

With settings designed for specific experiments, laboratory experiments offer little room for an explorative approach. Also, they have only limited ecological validity with respect to the complexity of reality, e.g. of underground transportation systems.

Field experiments

As laboratory experimental settings lack ecological validity, field studies have been conducted to assess pedestrian dynamics and evacuation behavior in actual circumstances. Of course, also field studies do not represent real evacuation situations, so results are limited to behavior without fear. Predtetschenski and Milinski (1971) considered non-psychological characteristics of passengers in underground transportation systems, such as carrying baggage or wearing different types of clothing. A study by Oswald, Lebeda, Schneider and Kirchberger (2005) deals with passenger behavior in evacuation from a train taking place at the surface.

Only few empirical studies have collected data from underground transportation systems (e.g. Kang, Han & Kim, J., 2010, for the choice between escalators and stairs in underground transportation systems). Within the current GETAWAY project, a research group around Ed Galea from the University of Greenwich investigates wayfinding-behavior in over-ground and underground terminals. Frantzich (2000, after Fridolf, 2010, p.39) found discussions among participants and habit to be decisive for the choice of path. In the field studies by Norén & Winér (2003) and Nilsson (2009) analyzing evacuation from street tunnels, participants preferred the closest exit.

Usually, participants in field studies are given questionnaires concerning their experiences and knowledge. Results from field studies on evacuation behavior are limited as participants are never in real danger. So the results are not easily transferable to evacuation in actual dangerous situations. Yet, field studies can get closer to real-life phenomena with respect to human behavior than experiments in a laboratory can.

In the following, we describe a series of studies in a German underground transportation system that were conducted to identify human factors relevant for underground evacuation. A first study with passenger counts aimed at getting to know characteristics of those that could have to evacuate from a specific subway station. In the second study, passengers in the same subway station were interviewed concentrating on their knowledge and attitudes. The third study focusing on evacuation behavior included a series of field experiments in several subway stations.

3 Study 1: Passenger Counts - Who and how many are they?

3.1 Objectives

Study 1 in an underground subway station included counts of passengers in order to determine the average number of passengers in a subway station per hour and to identify their composition. Furthermore, the actual occurrences of specific physical aspects of the passengers in a subway infrastructure were to be identified.
Physical characteristics are important aspect of human factors that are likely to be relevant for evacuation. Therefore we wanted to determine the percentage of passengers with impairments in walking and seeing. We were also interested in the way out that passengers and especially passengers with impairments use in order to leave the station. A last interest was in the number of passengers in company, e.g. groups or families.

3.2 Design and participants

The specific subway station was chosen because it has relevance for commuters in the subway system and it is moderately complex with two platform levels of crossing subway lines (see figure 1). Three times, for the duration of one hour, the total number of passengers was counted. Passenger counts were conducted in the morning (10:15-11:15 a.m.) on one day, and at noon (02:30-03:30 p.m.) and in the evening (05:00-06:00 p.m.) of another day during one week in summer, in order to compare for possible “rush-hour” effects. Passengers were counted at all entrances and exits, stairs, the escalators and lifts inside the subway station. At the central staircases, the passengers moving up and down were counted by separate persons while every other counting position was taken by only one person. Counts included the total numbers of passengers and the number of passengers with impairments, with bulky luggage, and of passengers traveling in company.

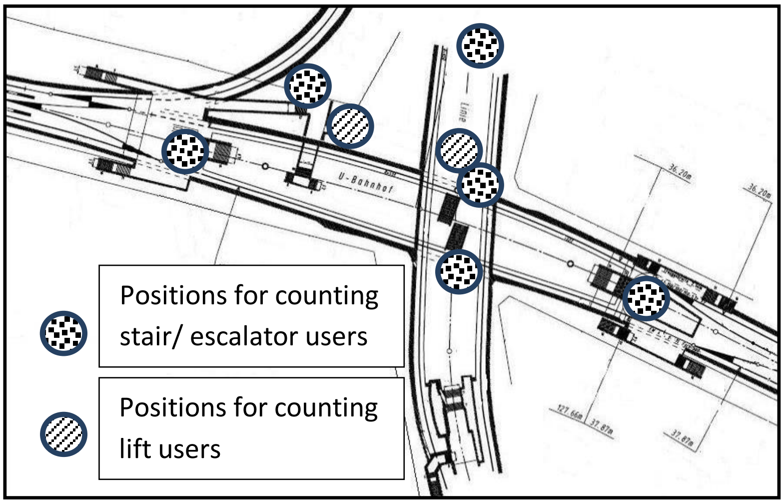

Fig. 1. Simplified model of two-level subway station, indicating all exits observed

3.3 Results

Overall counts at a single subway station summed up for an average of 8.400 passengers per hour at a regular two-level subway station. Roughly 4% of them had either an observable seeing or walking impairment and 7% were carrying luggage or were clearly detectable to be in company. A further finding was that a high number of persons using one of the lifts on either platform level (lower level/ upper level) was impaired in walking (22%) or seeing (9%), carried heavy luggage (26%) or were in company (40%). For the lift users several attributes could hold true for the same passenger, and percentages are relative frequencies compared to the overall number of lift users.

The stairs and escalators in the middle of the subway station were most frequently used. Almost one third of the passengers chose this way to enter or exit either level of the subway station. This is relevant, because passengers will likely choose an exit they already know from previous use (Tubbs & Meacham, 2007). The number of passengers counted at noon (9,245) and in the evening (9,814) were almost equal, compared to the number of passengers in the morning (6,063) which was considerably lower. The number of passengers moving into and coming out of the subway station was near balance for each counting interval.

3.4 Discussion

The one-hour counts only allow for first impressions about the average numbers of passengers. Yet, although the number of passengers in the morning hour was roughly one third less than at other counting intervals, there are always many passengers present in the subway station. The largest proportion of passengers was using the exits in the middle of the subway station. Thus, passenger will likely not use all available exits evenly, unless instructed to do so during evacuation.

Our study has limitations regarding the counts of passengers with impairments. It is not easy to determine impairments and passengers travelling in company. The actual numbers of passenger with these attributes might therefore be even higher. This study underlines the importance of the special needs of passengers with impairments in evacuation. While lifts are usually turned off in case of fire, they are highly frequented by impaired passengers that will have to walk alternative escape routes.

4 Study 2: Passenger Interviews - What do they know and think?

4.1 Objectives

The aim of study 2 was to determine passengers´ knowledge about evacuation, safety pictograms and the infrastructure subway station. Interviews also included questions about passengers' attitudes and estimations of their own behavior in the case of an evacuation from subway stations.

4.2 Design and participants

213 passengers took part in the structured interviews within a subway station. Passengers were selected by coincidence from the number of passengers waiting for a subway; only German-speaking persons took part (female: 122, male: 88, missing value: 3). Interviewees were of different ages. They were asked to answer 14 questions. Additionally, 39 passengers (female: 25, male: 15) commented on seven pictograms relevant for evacuation.
The pictograms presented included the one for the escape route leading towards the emergency exits (see figure 2, pictogram 1). A second pictogram (figure 2, pictogram 2) indicates the meeting point after evacuation, were e.g. passengers are being taken care of. Both of these pictograms were chosen from a norm (BGV A8 DIN 4844-2), defining the standard use of pictograms for escape routes in Germany. A third pictogram presented indicates the location of a fire extinguisher (figure 2, pictogram 3).

Pictogram 1 Pictogram 2 Pictogram 3

Fig. 2. Three selected pictograms from the questionnaire in study 2

4.3 Results

Pictograms

Three results for the pictograms (n=39) are to be highlighted here. Only three participants did not recognize the pictogram for the escape route leading towards the emergency exits. This indicates that participants would at least recognize the escape route pictograms if looking for a way out. Furthermore recognition of escape route pictograms could be interpreted as a necessary precondition for fast escape from the infrastructure.
On the other hand, 12 participants did not know the pictogram for the meeting point. The pictogram for fire extinguisher was not recognized by 11 participants. Since the meeting point is usually a safe area where users of an infrastructure are to gather after an evacuation in order to do a “role call” or

a medical check-up, not finding or recognizing a meeting point would make it difficult for first responders to ensure individual well-being after an incident. The pictogram for the fire-extinguisher is still in use in the respective public transportation system although a novel and self-explaining pictogram exists. Passengers used to the novel fire extinguisher pictogram could get confused and as a result might not find the fire-extinguisher.

Interviews

Some relevant results from the interviews can be stated for the context of emergencies. The participants that were asked: "Would you stay with your partner/ child, even if you could only move on if you separated from one another?" 62% answered that they would not leave without their partner or child (see figure 3a). For the question: "In case of a fire at the (intermediate level of a subway station), would you wait for rescue at the platform level if told to do so?" 52% of the interviewees replied that they would not wait for rescue at platform level (see figure 3b). More than three quarters (77%) of the participants that were asked: "Would you leave your luggage behind, if this would enable you to move on faster?" stated that they would leave their luggage behind (see figure 3c). In consequence, left behind luggage would block the way out for others. Each of these aspects would lead to a less homogenous and predictable escape of passengers from the infrastructure.

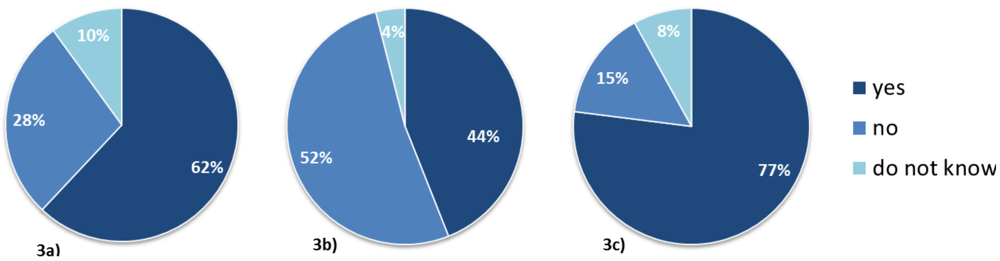

Fig. 3. Passengers' attitudes towards their own evacuation behavior. Explanation in the text.

5 A series of field experiments: How do they act?

5.1 Objectives

Based on results from studies 1 and 2 regarding passengers' knowledge and attitudes and on human factors found in the literature, a series of four field experiments were carried out. Observable evacuation behavior was of interest, especially the influence of social groups. Some preliminary results are presented here.

5.2 Design and participants

For each trial, participant groups varied between 25 and 90 participants. Most participants were students (of geography or psychology). The age ranged from 19 to 62. All of the participants were native or fluent German speakers, vision and hearing was normal. The trials took place in three underground subway stations in Germany and one in Great Britain (participants were German students). Each participant received a safety-vest with clearly visible numbers. Pre-existing groups (e.g. fellow students) received safety vests in specific colors. Because of numbers and colors, safety vests facilitated observations and the collection of data from individual participants. Furthermore, different colors of vests were to highlight group membership for participants inside and outside these groups.
In two equal sized groups impairments were simulated by vision-impairing goggles and by bandaging a knee of some participants. Even a person sitting in a wheelchair voluntarily participated in one group. Our goal was to receive additional insights from these participants and to artificially disrupt the flow of evacuation-movement in order to assess help-seeking requests and supporting social behavior of the groups.

In the beginning of the field experiments, participants were confronted with a potentially life-threatening scenario. They were asked to imagine effects of a volatile toxic agent detected within the subway station. Before each trial, they were instructed to leave the subway station into a safe area. Trials started with a spoken announcement including the order to leave the subway station.

Within each trial, participants were asked to walk "as fast as possible" along defined distances in the subway station on either the platform, the track-bed, escalators (either turned on or turned off), and stairs (upwards and downwards). In two subway stations, an additional "tunnel trial" was carried out: Starting from the tracks, participants were asked to go through the tunnel of the subway station and use the emergency exit within the tunnel.

Structured interviews were conducted after each trial. Participants were asked to comment on their own behavior, the group, and how they experienced infrastructural specificities. At the end of each trial, participants answered questionnaires. Questions aimed at their knowledge about underground transportation systems, escape routes, emergency behavior, and at decision making while finding a safe area. Furthermore, participants were asked to assess their integration into the group assigned by color of the safety vests. Social human factors were analyzed on video recordings from different perspectives and standardized observer protocols.

5.3 First Results

Analysis of field experiments is still in progress. But first results reveal, as expected, the importance of different human factors: infrastructural elements, group size and individual characteristics (physical impairments, preliminary experience with similar situations or infrastructure) influenced the speed of evacuation, speeding it up or slowing it down. Other findings include an influence of social human factors. In the following, a few results from the video analysis are presented, focusing on social behavior and group phenomena. Explanatory notes are added in the light of interviews and questionnaire analysis.

Helping persons with impairments

The participants moved inside a subway station which offers in general limited space. If participants did not keep up with the pace of the participant group they slow down the overall evacuation and are endangered to be run over by other participants. Especially at bottlenecks or "obstacles" like turned-off escalators, participants tended to offer help to others (not necessary altruistically) to move faster or to avoid falling.

Helping participants with impairments or slower participants to move safely and faster was observed almost in all trials. Helping behavior was always found when the participant with impairment asked actively for help. While help was needed for the stairs, the escalator and the tracks, participants hardly asked for help on the platform.

Fig. 4. Person in wheelchair being assisted on his escape

The seemingly smaller person in figure 6 (vest nr 9, yellow), is actually sitting in a wheelchair. At the bottom of the stairs this participant had originally asked a participant of his own group to assist him on the turned-on escalator. That participant pushed the wheelchair while members of other groups joined in to assist spontaneously. Some of them are holding the wheelchair; others are giving room for this participant.

Passengers with impairments have special needs. If these are not met by the infrastructure (e.g. no lift available in fires), they rely on social strategies. This was confirmed by video analysis and also stated in the questionnaires by the participant with simulated impairments.

Push and Shove? Egoistic and altruistic behavior

The passenger counts (see study 1) and the answers in the passenger interviews showed that passengers often travel in company, e.g., groups of friends, families, school classes. The intention to help others on their escape depended on the membership in a group and on the individual sense of integration into that group. The level of perceived integration ("group cohesion", see below) is higher in small groups; the level of perceived integration in the group corresponds with altruistic behavior within the group. Helping behavior and groups of people sticking together may not only lead to smoother evacuation but may have contrary effects by creating „human lumps", as the following episodes illustrate.

Fig. 5. Pushing away group members trying to get onto the escalator

In figure 7, a major part of members of a large group (wearing orange safety vests) is trying to move up an escalator in order to leave the platform. One participant (contours are highlighted) at the bottom of the escalator is being pushed aside by other participants trying to get past. The participant is forced to bend backwards moving her left leg back in order not to fall over. The participant's left arm is holding onto the banister while she is trying to get the right arm in front. The participant would hardly have been strong enough to reenter the stream of participants moving up the escalator. Another participant later slowed down and pulled her back onto the escalator. Helping behavior did not depend on group size and was observed in and across all groups, e.g. in the wheelchair example (see fig.4).

Group cohesion and staying together

In the tunnel trials, participants separated into smaller groups, staying together in pairs or quadruples. Within these groups, participants mostly relied on guidance of other participants who were familiar with the infrastructural specificities from former trials. When information about the escape route came from a member of another group it was inconsistently assessed as trustworthy or it was ignored. Then, small groups even moved past the nearest emergency exit and continued following the tracks into the tunnel, leading into the direction of the next subway station. However, in the tunnel trials spontaneous "human lumps" were found as a result of individual factors or social adhesion of groups. Individual factors included waiting for others to support their movement, to give them information, or originated from the waiting participants´ search for information and advice to the right choice of exit.

With respect to the participants wearing vests of the same color, a connection between helping behavior and asking for support was identified. Individually sensed integration in the group differ among participants groups according to their group sizes, with a tendency for a higher level of perceived social integration for smaller groups.

5.4 Discussion

Some of the limitations of the study concerning participants are that in order to meet ethic guidelines of the universities involved, all of the participants had to be informed about the general setting and aim of the field studies. Knowing they were going to evacuate, participants were ready to start leaving. At the same time they were hardly affected emotionally by the scenario announced to them. Yet, a moderate level of stress was experienced, as questionnaires showed.

Furthermore, with an average age of 27 years, the participants were physically in good shape; they also were able to resign from the experiments at any time, and some did do so when tired.

Although we have to rely on individual cases for the analysis of social phenomena at the moment, the (individual) social human factors phenomena presented could be found in several episodes of the trials. With respect to the single phenomena e.g. effects of group membership on staying together and on egoistic or altruistic behavior, the representativeness for evacuation from subway infrastructures is still to be determined.

6 Conclusion

The first findings from our passenger counts, passenger interviews and field experiments emphasize the importance of passengers´ characteristics and the need to understand more distinctly human (social) behavior in emergency situations and their respective influence on the speed and form of the evacuation movement. These aspects need to be included in models of passenger behavior in evacuations. Results are relevant for underground evacuation because passengers can be slowed down not only by architectural bottlenecks but also by individual and social human factors. In further field experiments phenomena will be investigated with larger numbers of passengers, for possible cultural variation and different types of infrastructures.

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