

Safe Evacuation for All

A top 10 List of Requirements

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Abstract

Evacuations are an important aspect of emergency planning. Many persons with special needs could reach a safe area on their own or with assistance by other people around, if evacuation planning and guidance considered them. The so-called self-rescue is crucial for safe evacuation, as fire services and other first-responders need some time to arrive at the scene. In general, people should find the conditions to arrive at a safe area on their own.

In many buildings and infrastructures today, self-rescue is difficult for persons with special needs, e.g. wheelchair users. Sometimes it appears that designers and fire safety engineers only think of “average”, healthy and agile people in evacuations. But for safe and effective evacuations, different groups of people and their needs have to be considered.

The paper suggests a top 10 list of requirements for safe evacuation and improvement of self-rescue from a psychological point of view. Universal Design or Design for All in evacuation has become more relevant in recent times, since accessibility as a political goal has made it possible for persons with special needs to participate more easily in public life. Nonetheless, regulations focus on how people enter a building but not on how to evacuate safely. Preparing for safer evacuations requires knowledge about different occupant groups and their needs. Requirements for different phases of evacuations are discussed and their implications for simulation and modelling, e.g. the potential impact of physiological requirements. The need for a multi-method approach to gather and integrate data, factors to foster safe evacuations, just as practical and design requirements are included. When self-rescue is not possible, assisted evacuation will rely on good leadership fostering social motivation. Last but not least, implementing design for all will help everyone to evacuate safely.

Keywords: Universal Design, Design for All, evacuation, psychology, requirements, special needs

1. Motivation and objective

In case of fire or other incidents, evacuation has to take place as fast and as safe as possible. As fire services need some time to arrive at the scene, self-rescue of occupants is important for safe evacuation of buildings, transport systems and other infrastructures. This is documented in laws, fire codes, and other regulations (e.g. for Germany [1, 2]). If evacuation planning and guidance include persons with special needs, more people could reach a safe area on their own or assisted by other people around.

“Self-rescue should be possible for everyone!”. This is not only an ethic imperative but a practical necessity: As inclusion of persons with special needs encourages that more and more persons with mobility or perception impairments use public infrastructures such as transport systems. But often, efforts are made to let people enter an infrastructure, but not for evacuations on their own.

First responders or fire services are often not prepared to ensure timely rescue of large numbers of persons with special needs. Also, fire services have to contain and fight hazards. If self-rescue is possible for (nearly) everyone, fire services can use their resources for firefighting. But still, not all occupants will be able to evacuate on their own. Rescue or support by others are necessary in special cases, or particular evacuation measures such as safety areas will be required.

In assessing the requirements for self-rescue of persons with special needs, the authors found that there are only few empirical studies on the subject, e.g. [3]. However, single studies explicitly including people with certain special needs can be found for high-rise buildings [4, 5], work places for handicapped persons [6] or day care centers [7].

The paper suggests a top 10 list of requirements for safe evacuation and improvement of self-rescue including a psychological point of view. Furthermore, the top 10 requirements are discussed for their use in simulation and modelling, e.g. the potential impact of physiological requirements.

2. Background

This paper reports recent results from the authors' studies on evacuation from subway stations [8, 9] and from previous research projects reaching back to 2008 [e.g. reported in [10–13]]. A mixed-method design was used in order to gather as many aspects on safe evacuation as possible. Data comes from field studies, surveys, observations, interviews, passenger counts, walk-arounds/ field visits and experiments in the context of underground transportation, but is generalized for other infrastructures using findings from the literature. Participants included wheelchair users, elderly, families, and people with visual impairments [14] (see section 3.1 and 3.3).

Studies (see also [9, 11, 15]) aimed to describe requirements for the design of evacuation routes and evacuation guidance. This included identifying different groups of subway users with special needs, describing their route choice behavior, their strategies in evacuations as well as their knowledge, e.g. knowledge about fires, how they would behave in case of a fire, and what they need to be able to evacuate safely [16].

3. Top 10 Requirements for safe evacuations

3.1 A portfolio of qualitative and quantitative methods is needed for research on special needs

No single method suffices to get insights on the requirements of different groups. Instead, several qualitative and quantitative methods are necessary, as well as an integrated analysis design (triangulation) [17, 18].

For example, persons with visual impairments cannot fill in a questionnaire on their own. Also, the standardized form of a questionnaire can be experienced to disregard their special situation. So, the authors also choose interviews for acquiring self-reported data. Field studies, such as walk-arounds/ on-site visits with persons with visual impairments, wheelchair users and parents of young children in subway stations helped to discover specific requirements. As many persons cannot verbalize their evacuation strategies or route-choice behavior, observations in field experiments were used as an additional method. Data was first analyzed by explorative data analysis and then weighted for detailed and integrated data analysis.

For some research (or most research with humans), study designs and documentation needs to be reviewed by an ethic committee. That might lead to delays in the realization of a study. Consequently, persons incapable of giving informed consent should receive special protection and should not participate studies unless the benefits outweighs potential risks.

3.2 Four factors fostering safe evacuation

Events that lead to evacuations are usually not rooted in isolated causes, they are influenced by the setting. To determine safe and purpose-built evacuation measures, the following four factors should be included [12, 19]:

1. the type of hazard or the triggering event, e.g. a fire or a gas leak;
2. the environment or infrastructure, considering structural properties such as length and accessibility of escape routes, e.g. in a subway station or office building;
3. the reason and occasion why people are in a particular place or building poses different challenges in evacuations, considering an event hall used e.g. as a concert hall for a rock concert or as a convention center;
4. the persons involved (occupants), their competencies, mental and physical abilities, needs and their actual emotional state; e.g. their fitness and excitation.

These four factors interact with each other and make evacuation planning even more complex. But if these factors are systematically considered for each venue, evacuation measures can be identified for persons with special needs and become more effective.

3.3 Persons with different special needs have different requirements for safe evacuation

The authors use the term “special needs” because fast and safe evacuation is not only a challenge for persons with impairments. There are many different kinds of occupants who have conditions that affect their fitness and mobility, and therefore their abilities to evacuate. In order to specify evacuation measures, different groups need to be identified. Results of own research lead to the following differentiations:

- persons with permanent handicaps, e.g. persons using a wheelchair, people with auditory or visual impairments;
- persons with temporal reduced mobility or impairments of perception, such as leg injuries, eye injury, intoxication by alcohol or drugs;
- persons with physical conditions like obesity or heart diseases;
- persons with other conditions that may also impede or prolong self-rescue: pregnancy (especially in third trimester), accompanying small children, lack of local knowledge (tourists) or not understanding local languages;
- persons or groups that may need exceptional assistance for self-rescue and are usually accompanied, e.g. small children or persons with mental disabilities.

Some of the “special needs” do not count as impairment in everyday life (and might even not be easily observable), may also prolong or impede evacuation, for example the ability to climb stairs. Note that each differentiation also has to be determined in more detail and definitions are not always distinct. In most evacuation concepts wheelchair users are considered. But there is a great variation between the impairment and mobility of wheelchair users and consequential movement speed, required space and their need of assistance in evacuations [5, 20].

Research with persons with impairments can be “troublesome” for researchers: Recruitment of participants, valid differentiation of groups (some persons have several impairments) and getting informed consent might be difficult, especially for children or persons with mental disabilities.

3.4 Design for All is relevant for using and evacuation transport systems

Wheelchair users’ needs are different from those of persons with visual impairments. But the authors found that the different groups have some requirements in common. This is true for everyday life but should also be applicable for evacuation. For some years, the idea of Universal Design or Design for All [21] has spread. Even if designs (here: evacuation routes and guidance) cannot suit everybody perfectly, it should be possible to design measures that suit a broad range of people. This leads to the formulation of principles that can help all occupants to evacuate safely. Universal Design principles, e.g. intuitive design, accessibility, equitable use, give the theoretical frame for the design of alarming systems and evacuation routes and are already discussed in the contexts of evacuations [8, 22].

Design for All (or barrier-free design) in evacuation has become more relevant in recent times, since accessibility as a political goal has made it possible for persons with special needs to participate more easily in public life. But often, regulation focus on how people enter a building but not how to evacuate safely.

3.5 Build a shared understanding and bring together different perspectives

Planning that strictly adheres to regulations is a start. But when considering safe evacuation, it is necessary to test practical implications of evacuation routes and guidance. Ideally, measures should be tested together with persons with special needs

In research and practical planning, round-table workshops seem a good method to bring together different perspectives and develop a shared understanding: What is relevant for persons with special needs? Which of their requirements can be usefully implemented in simulation models? How to deal with

conflict between different groups, e.g. tactile guidance systems on the floor for blind people may be a problem for persons using walking aids - at the same time fire safety regulations often focus single needs without considering the side effects of actions for other impairments.

Involving persons with impairments in research studies is sometimes not easy. Researchers need to allow more time for participant acquisition than in studies with students. It can be helpful to make contact via organizations or support groups. Also, data collection often might not follow researchers' expectations: For example, in an interview on evacuation people may tell the researchers all the problems they have with the public transport system and demand improvements. But research with the persons concerned is worth the effort as they are the ones who know their needs best.

3.6 Reduce response time by appropriate alarms

Warnings and fire alarms are used to initiate evacuations. Responses to these alarms are always influenced by individual evaluation, recognition and motivation. However, studies on fire evacuation exercises or case studies [11, 23] show that people often only start to evacuate with hesitation and delays or even refuse to evacuate. To reduce response time or pre-movement time, five phases of perception and information processing that influence compliance behavior to an alarm need to be considered [12, 24]:

1. **Perceive**, e.g. hear or see an alarm: Even if an alarm is transmitted by a public address system, it cannot be assumed that all intended recipients will take notice, even if they have the physical ability. To avoid this, the audibility, legibility and visibility of an alarm should be tested in a particular environment (see 3.2). Also, installed technology such as speakers need to drown out surrounding sounds by soundscapes or speech transmission index [25]. It is also advisable to reach out for more recipients by addressing at least two senses, e.g. by combining visual and acoustic information (redundancy by multi-sensory-principle and multi-channel principle).
2. **Understand**: The perception of an alarm cannot be equated with the understanding of the alarm itself and the comprehension of the importance of this alarm. A fire alarm constitutes an acoustic warning signal which might transmit an ambiguous meaning. The warning signal may be received as urgent by the recipients due to its tonal properties, but the present hazard and intended actions might not be explicitly clear, especially if the recipients never heard the alarm before.
3. **Authenticate**: Responses to alarms are influenced by evaluation of factors such as credibility, urgency and severity of the alarm. In the context of fire alarms the so-called Cry Wolf-syndrome can be observed [26, 27]. Previous "false alarms", because alarms were presented in fire exercises, might decrease the credibility of an alarm and recipients might take alarms no longer seriously ("This is just an exercise..."). Lack of authentication may lead to ignoring the alarm, continuing current activities or even refusing to evacuate. As it is not advisable to neglect exercises, the problem of alarm recognition should be addressed in organizational guidelines and debriefings of exercises. The more credible the alarm the sooner people will start to evacuate. Independently of the infrastructure, live announcements have the strongest effect in reducing response time in evacuation [28].
4. **Consider as relevant**: Personal risk assessment and credibility of an alarm play crucial roles in evacuation warnings. Only if people consider themselves to be the intended recipients of an alarm ("That's an actual fire alarm, which is now important for me!"), they will respond appropriately, e.g. by leaving the building. If possible, specific information concerning the actual hazards and instructions help to increase the relevance of an alarm.
5. **Response**: If a person has successfully completed phases 1 to 4, the person has to decide how to react to the alarm. Studies show that people responses may include [11, 19]:
 - waiting for further instructions ("wait and see")
 - actively searching for further information in order to make a more informed decision
 - helping/ supporting others to evacuate
 - showing attempts to extinguish fire

- actually leaving the infrastructure

Beside features for the design of warnings and alarms, e.g. volume, choice of words, etc., additional features for different requirements should also be included in the design process, e.g. for visitors who do not speak the local language. Paying attention to these features may reduce response time significantly and, thus, should be considered in the application of evacuation time calculations.

3.7 Adequate design of infrastructures can speed up movement time

Movement speed of occupants with special needs are influenced by architectural elements. If their maximum moving speed is to be guaranteed, three elements need to be considered:

1. **Required space, movement areas and accessibility** are especially relevant for occupants with walking impairments. Their requirements exceed the spacial needs of unimpaired users, e.g. up to the factor 2.5 in width. In order to enable their free movement and changes of directions, doors widths and required space need to be considered, e.g. for wheelchair user or occupants using crutches.
2. **Stairs and ramps** have to fulfil special requirements especially for occupants with walking or seeing impairments, e.g. steps should not overlap or exceed 15 cm to 17 cm in height. Wheelchair users will need movement areas at the start and the end of a ramp. The incline of the ramp influences motion and should avoid steep ascending slopes, e.g. up to 6%.
3. **Elevators** may be the only means of reaching a safe area quickly, occupants in wheelchairs exclusively rely on elevators if they want to reach a different level inside an infrastructure on their own. Impaired occupants, e.g. in walking or seeing, may walk the staircase – furthermore slowing down their own movement and reducing the capacity of escape routes for others waiting to pass them. In contrast to the widespread warning: “do not use in case of fire”, elevators can be equipped with a smoke-protection housing and will still operate. But, as most infrastructures do not integrate such elevators yet, future planning and implementations have to give insights of the use of those elevators and their influence on evacuation time.

3.8 Design of evacuation routes and evacuation guidance

Evacuation routes have to be designed according to the requirements of all occupants of an infrastructure (and not only for the sake of regulations). For evacuation simulations it is sometimes assumed that all available (emergency) exits are evenly used. Interviews and case studies show that people tend to use routes which can be considered as the common path of travel [27] e.g. people use the same routes to enter and exit a building. Passenger counts from field studies support these findings [10]. These can lead to an unequal distribution of evacuees and an increase in evacuation time [11].

A more even use of all exists can be reached, if design and guidance features support evacuees based on knowledge on psychological needs, on their wayfinding behavior and route choice strategies [13, 15]. Among these strategies people displayed and reported, the following appear most relevant, often also found in combination [10]: “Use the next possible way up that you can see”, “Follow the green exit-signs displaying a running man”, “Use your knowledge” (local and general to get out), “Avoid jamming and use the local shortest path”; “use quickest path”; “use comfortable way”.

Some of these strategies are being considered in fire safety regulations and even in present evacuation simulations, yet not consequently. Additional strategies were reported by people with special needs, e.g. from a person with visual impairments: “avoid walking in the middle of a group” [29]. – while accessibility and visibility are commonly of high relevance [20], e.g. high-contrast pictograms, commonly used word-based signage, tactile guidance systems.

Exits and level-transitions inside an infrastructure, e.g. stairs and elevators, have to be marked and visible along the evacuation routes. Signage should display accessibility restrictions, e.g. pointing out barrier free routes. This will enable persons with special physical needs, e.g. persons using wheelchairs, travelling with children in a pram, or having other mobility restrictions, to choose an appropriate route quickly, not having to rely on the support by others. It must be kept in mind, that understanding signage depends on evacuee’s knowledge and culture.

3.9 When help is needed – assisted evacuation

Many persons with special needs will be able to evacuate safely if they receive appropriate information and if structural design allows for self-rescue. Someone who doesn't understand the local language, e.g. in loudspeaker announcements, can use other persons as a source of information [16]. Here, herd-like behavior is useful.

But sometimes help is needed: A person may need assistance by others, e.g. guidance. This may be the case when a blind person has to walk unknown routes without tactile information. Another example for assisted evacuation is a family with several small children – others may help by carrying a child. A person with leg injury may be able to climb stairs when supported.

Sometimes, assisted evacuation is not possible and a person may have to be carried – e.g. in old buildings without ramps, smoke-proof elevators or safe spaces, wheelchair users have to evacuate via the stairs. In this case evacuation chairs may be helpful, but still two or more helpers are needed to succeed.

In any of these cases people rely on other people's help. Luckily, in many societies people will support each other in emergencies, e.g. [30]. In crowds, leadership may be necessary as people often do not know if they can and should help, they may need encouragement. Sometimes leadership only evolves as emergency services arrive on scene [31]. Organizations Evacuation planning in organizations should prepare their staff to take over leadership so that everyone in need will be assisted quickly.

3.10 Safe evacuation for all needs knowledge and practice

If safe evacuation for all is to be a realistic goal, knowledge and practice need to be considered in several different areas:

- Authorities need knowledge about users' characteristics and needs, e.g. movement times, space requirements, speech perception. And they should know available organizational and technical solutions. They should insist on plans for barrier-free evacuation.
- Fire fighters need trainings and practice how to evacuate different occupants, e.g. wheelchair users, blind persons. Some need only assistance, some need to be carried. Yet do date, there are very few studies that could support the planning of staff and technical resources. From what is known, it is clear that first responders or fire services cannot rescue all persons with mobility impairments, especially not in an aging society and when barrier-free access is granted. So, safe spaces, where persons can wait, are to be planned. This must come together with organizational solutions and communication strategies.
- Persons with mobility impairments should be included in evacuation drills. In drills where the authors participated or observed, wheelchair users often stayed in the building as it was assumed that evacuation could be too stressful or dangerous for them.
- Technical solutions like evacuation chairs are only useful if building occupants, traffic users and others know how to utilize them and how it "feels" to help a person to evacuate with one of those chairs.
- In the context of evacuations, the term panic is readily used. Practitioners and researcher sometimes assume to cause panic, e.g. by alarms. The (psychological or sociological) concept of mass panic has still not been sufficiently investigated. There is little empirical evidence for competitive or irrational behavior patterns. A sense of duty, helpfulness and altruism has been found [30, 32, 33]. Even if there seems to be a number of events which are in retrospect referred to as mass panic, real mass panic occurs very rarely. Although scientific literature agrees on this, the basic assumption is tenacious.

4. Conclusion

Safe evacuation includes many persons that currently are not adequately considered in evacuation research. Due to the lack of data and statistical numbers it is still a challenge to implement agents

with special needs in simulation models. Today, participants in field studies and experiments are usually healthy, young volunteers. The authors hope that in future studies, also persons with special needs are included whenever this is possible without putting them at risk.

Considering persons with special needs will not only help these persons to evacuate safely. It will also make evacuation easier and faster– including different occupant groups, enough space, understandable and visible signage, information via several sensory channels in several languages, elevators equipped to be used in case of fire, and other (technical and organizational) solutions are essential requirements. Implementation of Design for All will help everyone to evacuate safely.

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