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Summary

A questionnaire study was carried out with the main purpose to collect information related to the fire protection of underground rail transportation systems in different countries. Thirty representatives were invited to participate in the study. However, only seven responded and finally completed the questionnaire. The questionnaire was available on the Internet and included a total of 16 questions, which were both close-ended and open-ended. Among other things, the questions were related to typical underground stations, safety instructions and exercises, and technical systems, installations and equipment. In the final question of the questionnaire the respondents were also given the opportunity to influence future evacuation research by giving suggestions based on their own experience.

In this report the respondent's answers are presented. The answers have been divided into different sections, mainly determined by the layout of the questionnaire. Included in most sections are also a discussion of the respondent's answers with a special focus on how the answers relate to generally accepted theories and models on human behaviour in fire. It is argued that the respondents' answers, accompanied by the discussion, are of great value to operators and owners of underground rail transportation systems, not only in the everyday operation of these systems but also in the design of new systems. Furthermore, the information presented in this report should be used in the design phase of evacuation experiments in underground rail transportation environments in order to increase the validity of the results in such experiments.

Preface

This work is a part of METRO, a Swedish research project about infrastructure protection. The focus of the project is on the protection of underground rail mass transport systems, e.g., tunnels and subway stations, and both fire and explosion hazards are studied.

METRO is a multidisciplinary project where researchers from different disciplines cooperate with practitioners with the common goal to make underground rail mass transport systems safer in the future. The following nine partners participate in METRO: *Mälardalen University, SP Technical Research Institute of Sweden, Lund University, Swedish Defence Research Agency (FOI), Gävle University, Swedish National Defence College, Swedish Fortifications Agency, Greater Stockholm Fire Brigade and Stockholm Public Transport (SL).*

The total budget of METRO is 14.2 million SEK (about € 1.5 million), and the project runs over a period of three years (December 2009 to December 2012). METRO is funded by the following five organisations: *Stockholm Public Transport (SL), Swedish Civil Contingencies Agency (MSB), the Swedish Transport Administration (Trafikverket), the Swedish Fortifications Agency (Fortifikationsverket), and the Swedish Fire Research Board (Brandforsk).*

The work in METRO is divided into seven work packages (WPs) which address different aspects of the studied topic:

- WP1 – Design Fires
- WP2 – Evacuation
- WP3 – Integrated Fire Control
- WP4 – Smoke Control
- WP5 – Extraordinary Strain on Constructions
- WP6 – Fire and Rescue Operations
- WP7 – Project Management

More information about METRO can be found at the following web page:

http://www.metroproject.se

This report is a part of the second work package (WP2 - Evacuation). WP2 – Evacuation is also a part of KESØ (Kompetenscentrum för evakueringssäkerhet i Öresund), which is funded by Interreg IV A (Öresund – Kattegatt – Skagerrak).

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Table of contents

1. Introduction

In recent years, the number of underground rail transportation systems has continuously increased, and during the last 20 years there has been a trend to build exceptionally long tunnels. Examples are the 50.5-kilometre long Channel Tunnel between France and the UK, and the 57-kilometre long Gotthard Base Tunnel in the Swiss Alps, which is expected to open in 2016. By moving these types of transportations systems underground a more effective flow in traffic can be achieved, distances and travel time can be reduced, and the environment above ground can be preserved. However, the relocation from above ground to underground also introduces a demand on society to handle fire and evacuation safety in often more complex and inaccessible environments.

Previous incidents demonstrate that a fire in an underground rail transportation system can result in devastating consequences in terms of both economic damage and loss of life (Fridolf, Nilsson, & Frantzich, 2011). This is clearly illustrated by for example the the Baku subway fire of 1995 (Carvel & Marlair, 2011; Rohlén & Wahlström, 1996), and the Kaprun funicular fire of 2000 (Carvel & Marlair, 2011; Larsson, 2004; Schupfer, 2001). In order to avoid these types of devastating events in the future, i.e., to reduce both the probability and consequences of a fire in an underground rail transportation system, operators and property owners must together maintain a high fire response performance.

It is argued that the fire response performance of an underground rail transportation system is dependent on human features and building features, as well as fire features (Kobes, Helsloot, de Vries, & Post, 2010). Thus, there are many potential ways to improve the fire response performance. The minimum requirements, i.e., the level of risk, are often expressed in legal frameworks and related documents, and can include general principles on what a train driver should do in the event of a fire as well as information on how an underground rail transportation system should be designed (European Commission, 2008). However, due to the sovereignty of countries, requirements and recommendations can vary significantly from one country to another.

A questionnaire study was therefore carried out in order to reveal potential differences, in terms of both everyday use and emergency operations, between underground rail transportation systems in different countries. The study was performed as an online survey in which metro operators, metro owners and transport authorities were invited to anonymously answer questions related to underground stations, safety instructions, technical installations and equipment, and future research.

1.1. Purpose

The main purpose of the study was to collect information related to the fire protection of underground rail transportation systems in different countries. The aim was to use this information in order to compare the fire response performance of underground rail transportation systems in different countries, and also to use the information in the planning of future evacuation experiments.

1.2. Method

An online questionnaire was developed in order to collect data on the fire protection of underground rail transportation systems in different countries. The questionnaire included a total of 16 questions, which were divided into four parts. The questions were both close-ended, i.e., multiple-choice questions, and open-ended, i.e., questions where the responders were asked to write freely. Relevant questions had been identified in a previously performed literature study (Fridolf et al., 2011), and were finally selected after discussions with the owner the Stockholm Public Transport. Care was taken during the formulation of the questions to make sure that the topic had been clearly defined, that the questions were relevant for the purpose of the study, that the questions were not biased and that the risk of misinterpretation was minimal (Foddy, 1993). A printed copy of the questionnaire is available in Appendix A.

The first part of the questionnaire included general background questions for internal identification, e.g., name, job description and employer. The second part included questions related to underground stations, safety instructions and exercises, and the purpose of the second part was to get a picture of the typical underground station. The purpose was also to collect information on the general evacuation possibilities in each country.

The third part of the questionnaire included questions related to technical systems, installations and equipment. The purpose was to identify which technical systems, installations and equipment that can be expected in different countries. Finally, the fourth part of the questionnaire included questions on organizational and technical changes that had been implemented during the last years at the time of the questionnaire, and why they had been implemented. The final part of the questionnaire also included an open question in which the responder could specify what he or she wanted future research to focus on.

A total of 30 underground rail transportation system representatives were contacted and invited to the questionnaire study, see Appendix B. Initially, only metro operators were contacted by mail, email or telephone. In most cases contact was established through the head office, but in some cases where contact information to the safety manager was available, he or she was contacted in person. However, due to a low answering frequency and forwarding issues of mails from head offices to safety managers, the invitation was eventually also sent to metro owners and national transport authorities who were related to the underground rail transportation system in each country.

The invitation was always the same and included information about the project within which the questionnaire was carried out, the purpose of the study, and how the information would be used. Furthermore, it was made clear that participation would be anonymous, and that the answers left by potential responders would be treated confidentially. Participation was also highlighted as an opportunity to actually influence future research. Factors that affected the selection of metro operators were the size of the underground rail transportation system, and if there had been any previous fire incidents. In addition, a number of metro operators were selected due to the fact that they were using unique technique, e.g., driverless trains.

Eight people eventually responded to the invitation, of which 7 completed the questionnaire study. One representative was forbidden by national legislation to participate. In Table 1 information on the country, metro and company of the respondent is presented. In the presentation of the answers below, the answers will not be linked to the respondents.

Table 1. A description of the participants.

Country	Corresponding Metro	Employee of respondent
Finland	Helsinki Metro	Helsinki City Transport
Germany	Munich U-Bahn	Stadtwerke München, GmbH Public Transport Division
Netherlands	Rotterdam Metro	Rotterdam Elektrische Tram
Norway	Oslo Metro	Oslo T-banedrift
Singapore	Mass Rapid Transit Singapore	Land Transport Authority
Spain	Madrid Metro	Metro de Madrid, S. A.
Sweden	Stockholm Metro	Stockholm Public Transport

2. Results

In the following subsections the results of the questionnaire study, i.e., the respondents' answers, are presented.

2.1. Underground stations

In the second part of the questionnaire the respondents were asked about the stations in their underground rail transportation systems. More precisely, they were asked how many of their underground stations had platforms with *one everyday exit*, *two everyday exits* and *three or more everyday exits*. The term everyday exit had been defined in the beginning of the questionnaire as an exit/entrance that is used during normal operation, e.g., the main entrance. Furthermore, according to the definition, every day exits do not include exits that only are used in emergency, i.e., emergency exits. The respondents' answers are presented in Table 2.

Table 2. Respondents' answers to questions 4-6.

	Number of platforms with		
	1 everyday exit	2 everyday exits	3 or more everyday exits
Metro #1	19 (38%)	27 (54%)	4 (8%)
Metro #2	5 (31%)	4 (25%)	7 (44%)
Metro #3	9 (60%)	4 (27%)	2 (13%)
Metro #4	0 (0%)	28 (65%)	15 (35%)
Metro #5	4 (57%)	3 (43%)	0 (0%)
Metro #6	0 (0%)	76 (84%)	14 (16%)
Metro #7	28 (11%)	85 (34%)	137 (55%)

2.1.1. Comments

The affiliative model, developed by Sime (1983, 1984, 1985), suggest that people in a fire are likely to be drawn to places or people that are familiar to them. Thus, it can be expected that people will evacuate a building or a facility the same way they entered due to its familiarity, and not always the shortest evacuation route. In an underground station with only one everyday exit there is therefore a risk that the majority of the evacuees in a fire will choose the same exit, which may cause queues and prolong the total evacuation time. A station with two or more everyday exits, i.e., two or more familiar exits, is therefore a better solution in terms of evacuation and fire safety.

The respondents' answers, reproduced in Table 2, demonstrate that a rather large percentage of the platforms in five of the seven underground rail transportation systems only are equipped with one everyday exit. It is recommended that these stations should have at least one emergency exit, which is designed in a way that encourages usage in a fire. Recommendations on how to design emergency exits have been given in previous studies (Filippidis, Lawrence, & Galea, 2008; Xie, Filippidis, Galea, Blackshields, & Lawrence, 2009), and a framework that can be used in the design of emergency exits and similar technical installations are the theory of affordances (Gibson, 1977, 1979; Hartson, 2003; Nilsson, 2009; Nilsson, Frantzich, & Saunder, 2008).

2.2. Safety instructions

The respondents were asked about the availability of safety instructions in the second part of the questionnaire. Safety instructions can for example include details on how passengers in an underground rail transportation system should behave in fire emergencies. The question was a multiple choice question and respondents could choose one or more of the alternatives (a) Yes, at stations, (b) Yes, at platforms, (c) Yes, on trains, (d) Yes, inside tunnel tubes and (e) No, there are no safety instructions. Furthermore, the respondents had the possibility to answer an open question

(f) Other:. A tunnel tube had, in the beginning of the questionnaire, been defined as a tunnel between two stations. The respondents' answers are presented in Table 3.

Table 3. Respondents' answers to question 7.

	Metro						
	#1	#2	#3	#4	#5	#6	#7
Stations				O	O		
Platforms		O		O			
Trains		O	O	O	O		
Tunnel tubes							
No instructions	O					O	O

2.2.1. Comments

Surprisingly, three of the seven respondents reported that there are no safety instructions available at all in their corresponding underground rail transportation system. Of the other four, all provide their passengers with safety instructions on-board the trains. Furthermore, three of the respondents answers that there are safety instructions available at their platforms. Due to an unfortunate definition of the station, see Appendix A, this also means that there are safety instructions on the station since the platform is considered as a part of the station.

In the beginning of a fire the situation is often ambiguous and it is not always clear to everyone that there is a fire, and thus that they should evacuate. It has for example been demonstrated that an alarm bell is not always enough to initiate an evacuation (Proulx, 2003). This can furthermore be explained by the behaviour sequence model, developed by Canter, Breaux and Sime (1980). In the early stages of a fire, when information and fire cues are scarce, the decision that a person makes is associated with great uncertainties. However, as a person receives more information the uncertainty is subsequently reduced.

Safety instructions can help passengers in an underground rail transportation system to identify emergency situations. Furthermore, the instructions can aid a person in the decision making process in a fire, which can lead to better and more appropriate decision. It is argued that this may reduce the total evacuation time in a fire emergency in an underground rail transportation system, independent of the location of the fire.

2.3. Evacuation drills

The topic of the final question in the second part of the questionnaire was evacuation drills, and the respondents were asked if evacuation drills were carried out in their underground rail transportation system. In addition, the respondents were asked to include the participants in such drills. The question was a multiple choice question and respondents could choose between one or more of the alternatives (a) Yes, with the police, (b) Yes, with the ambulance services, (c) Yes, with the fire department, (d) Yes, with train staff, (e) Yes, with station staff, (f) Yes, with everyday tunnel users, i.e., passengers, (g) Yes, with volunteers/recruited participants and (h) No, we do not perform fire or evacuation drills. Furthermore, the respondents had the possibility to answer an open question (i) Other:. The respondents' answers are presented in Table 4.

Table 4. Respondents' answers to question 8.

	Metro						
	#1	#2	#3	#4	#5	#6	#7
Yes, with the police		o	o	o		o	o
Yes, with the ambulance		o	o	o		o	o
Yes, with the fire dept.		o	o	o	o	o	o
Yes, with train staff	o	o	o	o		o	o
Yes, with station staff	o	o	o	o	o	o	o
Yes, with passengers						o	
Yes, with volunteers			o	o		o	o
No, we do not perform drills							

2.3.1. Comments

All of the respondents stated that they performed evacuation drills in at their underground stations. However, the involvement of actors varies. All operators seem to involve their station staff in the drills, and five of the seven respondents stated that the police, the ambulance services, the fire department, the train staff and the station staff are taking part in the drills. Representative for Metro #3 added to his or her response that shop keepers in stations, neighbours to stations and staff of central traffic control rooms are also involved in the drills.

The way a specific individual will respond to a fire has been shown to depend on the everyday role of that person, e.g., if the person is a staff member or a passenger (Canter et al., 1980; Tong & Canter, 1985). Tong and Canter (1985) argue that peoples' actions are guided by a set of expectations they have about their purpose in a given context, i.e., their role. This role is associated with guiding principles, i.e., rules. Due to their roles, it is likely that passengers will look for information among staff members in a fire situation in an underground rail transportation system. It can also be expected that members of the staff, who have an authority position during normal operations, will keep this position in a fire situation and act according to the associated rules. It is therefore important to involve staff members in for example evacuation drills, because they will then have rules determining their actions in a fire situation. This may have a positive effect on the behaviour of the passengers in an underground rail transportation system in an evacuation situation, which can contribute to a reduction of the total evacuation time.

2.4. Technical installations

The first three questions of the third part of the questionnaire were about technical installations, systems and equipment on stations, in tunnel tubes, and on the trains. The questions were multiple-choice questions, and the respondents could choose between one or more of the alternatives (a) Fire detection systems (any kind), (b) Water sprinkler systems, (c) Water mist systems, (d) Smoke control systems, (e) Fire alarm buttons, (f) Emergency telephones, (g) Emergency lighting, (h) Hand rails, (i) Emergency exit signs, (j) Fire fighting equipment, e.g., fire extinguishers, fire blankets, etc., (k) Tools for breaking windows in an emergency, e.g., hammers, axes, etc., (l) Signs showing distance to emergency exits, i.e., distance signs, (m) Safety shelters/Rescue chambers, (n) Elevators that can be used in a fire evacuation, i.e., evacuation elevators, (o) Surveillance systems, e.g., CCTV systems, (p) Emergency exits that lead directly to the surface, (q) Platforms alongside the track at train height, i.e., evacuation platforms, (r) Ladders for getting down from train to track level, i.e., emergency ladders, (s) Equipment for aiding people with movement disabilities, e.g., wheelchair lifts, and (t) Evacuation alarms. In addition, the respondents were encouraged to add other technical systems, installations or equipment in an open text question, namely (r) Other:. The requirement for selecting an alternative was that the installation, system or equipment was installed in at least one station, in one tunnel tube or one of the trains. Note that the alternatives varied on the location in the underground rail transportation system. The respondents' answers are presented in Table 5, Table 6 and Table 7 respectively.

Table 5. The respondents' answers to question 9, i.e., what technical installations, systems and equipment were installed at the stations.

	Metro						
	#1	#2	#3	#4	#5	#6	#7
Fire detection systems	o	o	o	o	o	o	o
Water sprinkler systems	o			o	o	o	
Water mist systems						o	o
Smoke control systems	o	o	o	o	o	o	
Water hydrants	o	o	o	o		o	
Fire alarm buttons	o	o	o	o	o		
Emergency telephones		o	o	o	o	o	o
Emergency lighting	o	o	o	o	o	o	o
Emergency exit signs	o	o	o	o	o	o	o
Fire fighting equipment	o	o	o	o	o	o	o
Evacuation elevators		o	o	o			o
Safety shelters				o			
Surveillance systems	o		o	o	o		o
Evacuation alarms	o		o	o			

Table 6. The respondents' answers to question 10, i.e., what technical installations, systems and equipment were installed in the tunnel tubes.

	Metro						
	#1	#2	#3	#4	#5	#6	#7
Fire detection systems	o				o		
Water sprinkler systems							
Water mist systems							
Smoke control systems	o	o		o	o		
Fire alarm buttons					o		
Emergency telephones	o		o	o		o	
Emergency lighting	o	o	o	o	o	o	o
Hand rails		o	o			o	
Emergency exit signs	o	o	o	o	o	o	o
Fire fighting equipment			o	o	o		o
Distance signs	o	o	o		o	o	o
Safety shelters			o	o			
Evacuation elevators		o					
Surveillance systems							
Exits to surface	o	o	o	o	o	o	o
Evacuation platforms			o	o			o
Evacuation alarms							

Table 7. The respondents' answers to question 11, i.e., what technical installations, systems and equipment were installed on the trains.

	Metro						
	#1	#2	#3	#4	#5	#6	#7
Fire detection systems	O	O	O	O		O	O
Water sprinkler systems							
Water mist systems						O	O
Fire alarm buttons		O	O				
Emergency telephones	O	O	O	O	O	O	O
Emergency lighting	O	O	O	O	O		O
Emergency exit signs	O	O		O			O
Fire fighting equipment	O	O	O	O	O	O	O
Tools for breaking windows		O			O		
Surveillance systems	O			O	O		O
Emergency ladders	O	O		O	O		O
Equipment for the disabled							
Evacuation alarms							

2.4.1. Comments

Technical installations, systems and equipment that seem to be most popular at stations in underground rail transportation systems are some kind of fire detection and smoke control system, emergency telephones, emergency lighting, emergency exit signs and some kind of fire fighting equipment. These are all valuable to the overall fire response performance. The fire detection and smoke control system will, designed correctly, prolong the available safe escape time in a fire emergency. Furthermore, emergency telephones, emergency lighting and exit signs may reduce the required safe escape time. Other installations that were mentioned by two respondents in the open question were multiline LED displays and dry risers. Respondent of Metro #3 also stated that there is a cabinet with equipment to short circuit the live traction rail on every platform in that underground rail transportation system.

Inside tunnel tubes, evacuees in a fire emergency are most likely to be aided by emergency lighting, emergency exit signs and distance signs. Furthermore, six of the seven respondents state that there are emergency exits leading directly to the surface in their underground rail transportation system. Although the principle is to drive a train to the nearest station in a fire emergency (Burnett, 1984; European Commission, 2008), previous accidents have shown that this is not always possible (Carvel & Marlair, 2011; Fermaud, Jenne, & Müller, 1995; Larsson, 2004; Rohlén & Wahlström, 1996; Schupfer, 2001). Installations and other systems aiding evacuees are therefore deemed both necessary and useful in terms of reducing the consequences of a fire.

Three of the seven respondents state that they have evacuation platforms in their tunnel tubes. This type of installation is particularly valuable for children, senior citizens and persons with disabilities to leave the train when evacuation is necessary inside a tunnel. However, the effects on the overall evacuation time are unclear. Previous evacuation experiments have, for example, shown that the exit height may not be the limiting factor during a train evacuation inside a tunnel (Oswald, Kirchberger, & Lebeda, 2008; Oswald, Lebeda, Schneider, & Kirchberger, 2005; Oswald, Schjerve, & Lebeda, 2011). Another installation that was mentioned in the open question was lighting LED. Furthermore, respondent of Metro #7 stated that there was a guidance prototype installed in their tunnel tubes.

The most common installations, systems and equipment on board trains seem to be some kind of fire detection system, emergency telephones, emergency lighting and fire fighting equipment. Emergency telephones, or similar installations to communicate with the train driver, are deemed very important in terms of fire and evacuation safety. In the Kaprun fire of 2000 the passengers noticed the fire long before the train driver. However, they had no possibility to communicate this to the train driver, as there was no communication system installed (Bergqvist, 2001; Larsson, 2004; Schupfer, 2001). This prolonged the total evacuation time several minutes.

Five of the seven respondents state that there are emergency ladders available in the trains that can be used in the event of an emergency. The ladders are certainly an aid to all people as the obstacle of jumping up to 1.4 meter from train to track level is reduced, especially when evacuation is necessary due to other factors than fire. However, studies have shown that the flow rate of people in a train exit is reduced when the ladder is present (Frantzich, 2000), and maybe this ought to be considered in the fire safety design process.

2.5. Tunnel floor surface

In the final question of the third part of the questionnaire the respondents were asked about which floor surface material inside the tunnel tubes that passengers are most likely to evacuate on in a train evacuation inside a tunnel. The question was a multiple-choice question and respondents could choose one or more of the alternatives (a) Macadam/Pebbles/Shingle, (b) Paving stone, (c) Asphalt, (d) Concrete, and (e) Rock surface. Furthermore, the respondents had the possibility to answer an open question (f) Other:. The respondents' answers are presented in xxx.

Table 8. The respondents' answers to question 12.

	Metro						
	#1	#2	#3	#4	#5	#6	#7
Macadam/Pebbles/Shingle	o				o	o	
Paving stone		o	o				
Asphalt							
Concrete			o	o		o	o
Rock surface							

2.5.1. Comments

The most common materials inside the tunnel tubes of the seven underground rail transportation systems are, according to the respondents, macadam/pebbles/shingle and concrete. Two of the seven state they use paving stone, and one answered wood and metal in the open text question. The effects of different floor materials on movement speed, if there are any, have not been examined. However, it is likely that people with movement disabilities will prefer a smoother material instead of a coarse material if they are to walk longer distances, which can be expected if a train is evacuated inside a tunnel.

2.6. Organizational changes

The first question of the final part of the questionnaire was about organizational changes that had been implemented during the last five years at the time of the study. The respondents were asked to answer freely in an open question, and their answers are summarized in this section without further comments.

Two of the respondents stated that they had increased the co-ordination and/or co-operation with rescue departments, e.g., the fire department, ambulance services, and the police. One of them explained that the focus had been improved in terms of preparation, i.e., being prepared to cope with an emergency. Other topic that were considered were:

- Implementation of a systematic fire protection work, which both the owner and the operator of the underground rail transportation system performed on a daily basis.

- Stringent requirements for the use of flammable material on stations, platforms and in trains, including advertisement material.
- Increased amount on staff on underground stations due to closing of the entrances to the platforms with ticket controls.
- Introduction of a new safety principle; No train can leave a station as long as the next station is occupied with a train.
- Increased training of train- and station staff.
- Incorporation of emergency plans.
- Improvements of information management.
- Lessons learned.

2.7. Technical changes

The second question of the final part of the questionnaire was about the most important changes related to technical systems, installations and equipment. The respondents were asked to answer freely in an open question, and their answers are summarized in this section without further comments.

Many of the respondents reported having installed new fire detection systems, e.g., a gas detection systems inside the tunnel tubes, heat and smoke detection on stations, a fibre laser heat detection system inside the tunnel tubes. Some of the respondents also mentioned having installed mechanical smoke ventilation at stations and inside several tunnel tubes. Two respondents stated that they had installed CCTV systems, including the rolling stock, i.e., in the trains. One respondent mentioned having installed both a water mist system in passenger compartments, and a nitrogen fire fighting system under the floor of the trains. Other things that were mentioned were:

- Firewalls between platforms and escalators.
- Evacuation signs with distances to closest exits inside the tunnel tubes.
- Emergency exit pressurization systems.
- LED signals and intelligent guidance systems.

2.8. Future research

The respondents were asked about their opinion on future tunnel evacuation research, based on their own experience. The purpose was to give operators of underground rail transportation systems a possibility to influence, for example, future evacuation experiments in these this of facilities.

Two of the respondents stated that they wanted future research to focus on total evacuation times. One of them was a bit more specific and said that future research also should focus on human behaviour inside tunnels. A third respondent said that research should focus on how to initiate evacuation in for example stations, and how to get people to realise that they should evacuate. Finally, a fourth respondent wanted future research to study passengers' ability to evacuate independent of for example fire fighters or other rescue personnel.

Three of the respondents suggested that future research should focus on heat release rate curves, and the maximum heat release rate of trains and constructions in an underground rail transportation system. Both argued for their suggestion with the fact that they wanted to improve the ASET/RSET calculations. Other things that were mentioned as important for future research to study were:

- Prevention of train stopping inside tunnels due to lack of power in an emergency situation.
- Panic limiting measures in extreme events in underground rail transportation systems that could cause mass evacuation under pressure.

- Improvements of evacuation facilities, e.g., platforms close to emergency exits, fresh air supply for possible emergency exit routes in tunnel areas, and CCTV surveillance.
- Prevention of fire- and smoke spread.
- Smoke spread and propagation inside tunnel tubes.
- Ventilation.
- Exit signage and guidance to in order to reduce time of response, e.g., sounds, lights, and signals.

3. Concluding remarks

The result of the questionnaire study, i.e., the respondent's answers, has been reported, summarized and presented above in their corresponding sections. These sections were to a great extent determined by the layout of the questionnaire and the questions that the respondents answered when filled out the questionnaire. In most cases, a discussion of the results has also been added as general comments to the respondents' answers. This discussion is primarily focused on how the respondents' answers relate to generally accepted theories and models on human behaviour in fire. It is argued that the discussion adds a value to the reported answers as they are not only reproduced, but also put into a context. In the discussion it is, for example, explained why an underground station with two main entrances may perform better than an underground station with one main entrance and two emergency exits in an evacuation situation, why it is important to perform evacuation drills, etc.

One of the major limitations of the study is the limited number of respondents. Out of 30 invited metro representatives, only seven finally answered the questionnaire, some after numerous reminders. The data presented in this report should therefore be treated with care. It is also important to mention that no effort was made by the authors to double-check the information left by the respondents. However, the respondents were encouraged to invite colleagues when answering the questionnaire if uncertain of the answer to a specific question. Should the report receive much attention in the future, there is always the possibility to resume study and to invite additional metro operators or as the questionnaire now have been developed.

Despite of the study's shortcomings presented in the previous section, it is still argued that the study reveals both interesting and valuable information about the fire safety in different underground rail transportation systems. In addition, the study enables a comparison of designs and solutions between different countries. It is argued that the results, in terms of the respondents' answers, and the comments to the results, are of great interest to both owners and operators of underground rail transportation systems. Not only in the everyday operation of these systems, but also in the design phase of new underground rail transportation systems. In addition, the information presented in the report may also be used to increase the validity of the results of future evacuation experiments carried out in similar environments.

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Appendix A: The questionnaire

Introduction

METRO Questionnaire

This questionnaire includes 16 questions which are divided into four sections. The questions are both free text questions, i.e., open questions, and checkbox questions, i.e, multiple choice questions. We ask that you take your time and answer the questions to the best of your ability. Please involve your colleagues if you feel that you cannot answer a question on your own.

Some terms that can be interpreted in different ways are used in the questionnaire. In order to minimize misinterpretations these terms are defined in the text and figure below. You will **not** be able to consult these definitions when you have continued to the next page. We therefore recommend that you take the time to study the definitions and figure carefully before you continue.

Definitions

Station: An underground facility that includes everything, such as escalators, ticket machines, platforms and tunnel tubes.

Platform: The part of the station where people disembark/board the trains.

Tunnel tube: The tunnel between two stations.

Everyday exit: An exit/entrance that is used during normal operation, e.g., the main entrance. Everyday exits do not include exits that only are used in emergencies, i.e., emergency exits.

See figure at http://www.metroproject.se/Pics/Station_web.jpg

When you have read and understood the information above, please continue to the next page.

Continue »

METRO Questionnaire

Background questions

In this part of the questionnaire we ask that you answer general questions about yourself and your employer. The purpose is to facilitate our collection of the data. Your answers will be coded, i.e., the information you provide will not be possible to trace back to you or your employer in the presentation of the results.

What is your name?

First name, last name

Describe the tasks you are working with, i.e., what is your job description?

Who is your employeer?

« Back   Continue »

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Part II

METRO Questionnaire

Stations, safety instructions and exercises

The following five questions relate to your stations, safety instructions and exercises. The purpose is to get a picture of your typical underground station. The purpose is also to gather information about tunnel occupants' evacuation possibilities. Please observe that we are only interested in information about your underground stations. If your transport system includes stations above ground we therefore ask you to disregard these stations when answering the following questions.

How many stations have platforms with only one everyday exit?

E.g., 13 stations.

How many stations have platforms with two everyday exits?

E.g., 13 stations.

How many stations have platforms with three or more everyday exits?

E.g., 13 stations.

Are there instructions for passengers how to behave in fire emergencies, i.e., safety instructions?

You may choose more than one alternative. If safety instructions are provided elsewhere, please state so in the text box.

- ☐ Yes, at stations
- ☐ Yes, at platforms
- ☐ Yes, on trains
- ☐ Yes, inside tunnel tubes
- ☐ No, there are no safety instructions
- ☐ Other:

Do you perform fire or evacuation drills on your stations?

You may choose more than one alternative. If other actors than those mentioned below are included in your drills please state so in the text box.

- ☐ Yes, with the police
- ☐ Yes, with the ambulance services
- ☐ Yes, with the fire department
- ☐ Yes, with train staff
- ☐ Yes, with station staff
- ☐ Yes, with everyday tunnel users, i.e., passengers

- [ ] Yes, with volunteers/recruited participants
- [ ] No, we do not perform fire or evacuation drills
- [ ] Other: ______

« Back   Continue »

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Part III

METRO Questionnaire

Technical systems, installations and equipment

The following four questions relate to technical systems/installations/equipment at your stations, in your tunnel tubes or on your trains. Furthermore, we want to know something about the floor surface in your tunnel tubes. Th purpose is to identify what technical systems/installations/equipment can be expected in underground facilities and on trains. Please observe that we are only interested in information about your underground stations. If your subway includes stations above ground we therefore ask you to disregard these stations when answering the following questions.

Which of the following technical systems/installations/equipment are used at your stations?

Please select the matching alternatives. You may choose more than one alternative. The only prerequisite is that the technical system/installation/equipment is installed at at least one of your stations. If other technical systems/installations/equipment are installed at your stations, please state so in the text box.

- ☐ Fire detection systems (any kind)
- ☐ Water sprinkler systems
- ☐ Water mist systems
- ☐ Smoke control systems
- ☐ Water hydrants
- ☐ Fire alarm buttons
- ☐ Emergency telephones
- ☐ Emergency lighting
- ☐ Emergency exit signs
- ☐ Fire fighting equipment, e.g., fire extinguishers, fire blankets, etc.
- ☐ Elevators that can be used in a fire evacuation, i.e., evacuation elevators
- ☐ Safety shelters/Rescue chambers
- ☐ Surveillance systems, e.g., CCTV systems
- ☐ Evacuation alarms
- ☐ Other: ________

Which of the following technical systems/installations/equipment are used in your tunnel tubes?

Please select the matching alternatives. You may choose more than one alternative. The only prerequisite is that the technical system/installation/equipment is installed in at least one of your tunnel tubes. If other technical systems/installations/equipment are installed in your tunnel tubes, please state so in the text box.

- ☐ Fire detection systems (any kind)
- ☐ Water sprinkler systems
- ☐ Water mist systems
- ☐ Smoke control systems
- ☐ Fire alarm buttons
- ☐ Emergency telephones
- ☐ Emergency lighting

- ☐ Hand rails
- ☐ Emergency exit signs
- ☐ Fire fighting equipment, e.g., fire extinguishers, fire blankets, etc.
- ☐ Signs showing distance to emergency exits, i.e., distance signs
- ☐ Safety shelters/Rescue chambers
- ☐ Elevators that can be used in a fire evacuation, i.e., evacuation elevators
- ☐ Surveillance systems, e.g., CCTV systems
- ☐ Emergency exits that lead directly to the surface
- ☐ Platforms alongside the track at train height, i.e., evacuation platforms
- ☐ Evacuation alarms
- ☐ Other: ________

Which of the following technical systems/installations/equipment are used on your trains?
Please select the matching alternatives. You may choose more than one alternative. The the only prerequisite is that the technical system/installation/equipment is installed on at least one of your trains. If other technical systems/installations/equipment are installed on your trains, please state so in the text box.

- ☐ Fire detection systems (any kind)
- ☐ Water sprinkler systems
- ☐ Water mist systems
- ☐ Fire alarm buttons
- ☐ Emergency telephones
- ☐ Emergency lighting
- ☐ Emergency exit signs
- ☐ Fire equipment, e.g., fire extinguishers, fire blankets, etc.
- ☐ Tools for breaking windows in an emergency, e.g., hammers, axes, etc.
- ☐ Surveillance systems, e.g., CCTV systems
- ☐ Ladders for getting down from train to track level, i.e., emergency ladders
- ☐ Equipment for aiding people with movement disabilities, i.e., wheelchair lifts
- ☐ Evacuation alarms
- ☐ Other: ________

In the event of an emergency evacuation in your tunnel tubes, on what floor surface are the evacuees likely to evacuate?
Please select the matching alternatives. You may choose more than one alternative. The only prerequisite is that the type of surface material is present in at least one of your tunnel tubes. If other surface materials are used in your tunnel tubes, please state so in the text box.

- ☐ Macadam/Pebbles/Shingle
- ☐ Paving stone
- ☐ Asphalt
- ☐ Concrete

- [ ] Rock surface
- [ ] Other: ____________

« Back | Continue »

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METRO Questionnaire

Final questions

The following four questions relate to organizational and technical changes that you have implemented the last years. We also want to know what you think future research should focus on. The purpose is to identify the areas that metro operators up to now have focused on, but also to learn what is important and hence should be studied Please observe that we are only interested in information about your underground stations. If your subway includes stations above ground we therefore ask you to disregard these stations when answering the following questions.

In terms of fire protection and underground evacuation, what are the most important organizational changes that have been implemented at your metro during the last five years?

In terms of fire protection and underground evacuation, what are the most important changes related to technical systems/installations/equipment that have been implemented at your metro during the last five years?

Based on your experience, what should future evacuation research focus on?

We would like to come in contact with you after the questionnaire to ask follow up questions. Could you please provide us with your contact information (email and telephone)?

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Appendix B: Included underground rail transportation systems

Representatives from the following 30 underground rail transportation systems were contacted either by telephone, mail or email, and were invited to participate in the questionnaire study, see Table 9.

Table 9. Invited metro operators.

Metro	Country
Vienna U-Bahn	Austria
Baku Metro	Azerbaijan
Minsk Metro	Belarus
Beijing Subway	China
Prague Metro	Czech Republic
Copenhagen Metro	Denmark
Helsinki Metro	Finland
Paris Metro	France
Lille Metro	France
Berlin U-Bahn	Germany
Frankfurt U-Bahn	Germany
Munich U-Bahn	Germany
Athens Metro	Greece
Budapest Metro	Hungary
Rome Metro	Italy
Tokyo Metro	Japan
Rotterdam Metro	Netherlands
Oslo T-Bane	Norway
Warsaw Metro	Poland
Moscow Metro	Russia
Saint Petersburg Metro	Russia
Singapore Rapid Transit	Singapore
Barcelona Metro	Spain
Madrid Metro	Spain
Stockholm Metro	Sweden
Lausanne Metro	Switzerland
London Underground	United Kingdom
Tyne and Wear Metro	United Kingdom
New York City Subway	United States
Washington Metro	United States