Designing evacuation for deep underground stations including escalators

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ABSTRACT

This paper addresses challenges as adopting existing regulations and standards to fire safety designs in underground station. The key questions in this paper are; when designing evacuation for underground stations including escalators, are considering conventional walking speed or capacity in escalators good enough? Is there a need to consider other issues to ensure an acceptable safety level in the fire safety strategy? There is no clear-cut ready-to-use regulation to be implemented when designing fire safety in deep underground stations today, particularly concerning ascending egress using escalators. The focus of this paper is the usage of escalators as part of the egress strategy for deep underground stations in case of fire or other emergencies. Conclusion drawn from the evaluation in this paper is to update regulations concerning technical aspects with regards to escalators. Pedestrian flow in stopped escalators should vary as a function of the total vertical height rather than being dependant on each individual escalator height.

KEYWORD: deep underground stations, pedestrian flow, fire safety, egress, evacuation, escalators, upward movement, fatigue, fire safety strategy, ascending evacuation, code compliant

INTRODUCTION

There is no recognised regulation, neither international nor national, that has a comprehensive design approach to be implemented when designing fire safety in deep underground stations today. Especially with regards to ascending egress using escalators. Available research and regulations regarding underground stations and egress using escalators is not hitherto compliant for deep underground stations. Furthermore, countries that do not have regulations covering deep underground stations end up with a choice of what design strategy to use. Either the choice is to use the conventional national building code, not applicable to underground stations, or international regulations/standards from other countries, which is not always applicable in a different country from what the regulation or standard was written for. In addition, a combination of national and international regulations may be chosen.

Presented in this paper is an analysis as a case study using pathfinder [1] to shed light on the identified design aspects. In the field of fire safety it is argued that there are flawed codes covering egress strategy from underground stations. Example, NFPA 130 that do not to properly specify the egress flows in escalators with regards to length of the escalator. Far reaching consequences can be expected due to faulty or inappropriate standards as well as misuse of the standard [2, 3]. This paper addresses such challenges as adopting existing regulations and standards to fire safety designs in deep underground station when designing new stations.
IDENTIFIED DESIGN ASPECTS TO BE EVALUATED

When designing deep underground stations and buildings there are many challenges in developing a fire safety strategy. This is due to the lack of both comprehensive available research as well as standards and regulations, leaving it up to the fire engineer to find a suitable design method for each specific project. Consultants designing deep underground stations often refer to prior work done and regulations used to find support in their design method. This cause problems since it leads to new research findings not being implemented in new design. Through available regulations and the latest research as well as experience the following aspects has been identified as challenges when designing fire safety strategies for deep underground stations:

1. Research indicates that pedestrian flow in stopped escalators due to fatigue is affected by depth of the station (e.g. length of escalators).
2. Designing fire safety strategy without valid or with non-applicable standards and regulations for deep underground stations.
3. Basic prerequisite for design of egress using escalators often recommends blockage of one escalator when calculating egress time. However, there is a risk that more than one may be blocked during maintenance due to escalator configuration.
4. Escalators, being a technical installation, potentially generate additional sensitivity scenarios to be incorporated in the egress analysis such as technical failure.
5. Identified aspects in number 1 – 4 for egress may cause knock-on effects if landings between escalators do not have sufficient area to allow for queuing. Which in some cases can result in a "domino-effect" of people falling backwards in escalators.

EVALUATION OF PROBLEMS THAT IDENTIFIED DESIGN ASPECTS MAY CAUSE

1. Research indicates that pedestrian flow in stopped escalators due to fatigue is affected by depth of the station (e.g. length of escalators)

When available regulations for underground stations was written the research for pedestrian flow in upward or stopped escalators was insufficient and no consideration was taken neither to long transitions upwards or more than one consistent rise. Due to lack of space available for expanding cities there is a need to build deeper underground which results in longer vertical transitions.

New research regarding egress flow in stopped escalators indicates that movement speed upwards is affected by fatigue due to length of the escalators. People’s walking speed in a stopped escalator significantly decreases when the vertical height reaches over 20 – 30 meters. [4, 5]

Standards and regulations today only specifies walking speed and pedestrian flow in vertical transition with no regards to the specific height of one escalator nor any consideration to continued vertical escalator rises [3, 6, 7]. Figure 1 illustrates escalator rise, landing and total vertical height.

![Figure 1. Escalator rise and total vertical height.](image-url)
In line with available regulations and guidelines today’s egress analysis and evaluations, of pedestrian flow in escalators for of deep underground stations, are assumed based on a single vertical rise in the context of limited amount of vertical movements in each separate vertical height. The assumption means that no adjustment is done with regards to the total vertical height. This results in that fatigue, due to total vertical height transportation during egress, is not accounted for which may lead to flawed pedestrian flows in escalators being used in calculations. Using a higher pedestrian flow in egress calculations may result in designs that are not compatible with real life or best practice in fire safety strategy, where a worst case scenario should be considered. Real life egress times may therefore be significantly longer since the specified capacity in one escalator rise used for design does not consider aspects like fatigue as much as actually required. Consequently, movement speed and pedestrian flow in escalators should vary as a function of the total vertical distance.

2. Designing fire safety strategy without valid or with non-applicable standards and regulations for deep underground stations

Since there is no comprehensive international regulation regarding fire safety in deep underground stations, national standards and regulations not intended for these types of facilities might be used due to this lack of guidance when designing fire safety strategies. Example, there is a gap between Swedish national building regulation and Swedish tunnel regulation leaving the interpretation and adoption of guidance, hence level of safety, to be decided by each specific design group [8-11].

Due to lack of national or comprehensive fire codes, for deep underground stations, engineers and project managers might find themselves adapting different approaches when designing fire safety design. This can result in methods such as:
- a pick-and-choose approach, combining whatever they find convenient from different regulations, or
- applies and interprets building standards not valid for deep underground station, or
- add-on approach, with excessive fire safety measures to adjust for the uncertainty in lack of guidance.

The different approaches can cause a discrepancy in safety level for different projects where some follow and applies for example NFPA 130 to its full extend even for deep underground stations. The pick-and-choose method can also lure engineers into a false sense of security that consideration has been taken to all aspect regarding fire safety. Whereas an add-on approach can result in complex and unnecessarily expensive designs.

When there is no single regulation to fully comply with there is a risk that the overall fire safety design does not fulfill an acceptable level of safety. As a consequence, the fire safety level might be minimized and based more on cost effectiveness than on an acceptable fire safety level. The partial integration of different standards and regulations could even prove counterproductive for the overall project. Either with an add-on approach resulting in excessive fire safety measures or a stripped design resulting in not enough safety measures.

Furthermore, the funder or client of new underground facilities is not always the same as the owner or organization accountable for building maintenance and operator in terms of fire and safety management. The different organizations being responsible for different phases of the station often have diversely aims with the project. The difference in objective priorities is frequently separated between cost respectively functionality and operability. This may result in a diversion of assumed operation of escalator in the design phase not being implemented in real life operation. The risk is that during normal operation steering of escalator’s direction is reversed for more efficient commute flow resulting in lower egress capacity in escalators than required in the fire safety strategy [12-16].
3. Basic prerequisite for design of egress using escalators often recommends blockage of one escalator when calculating egress time

Maintenance on escalators has to be considered when calculating necessary egress capacity from underground stations. NFPA 130 for an example specifies that at least one escalator should be disregarded due to blockage caused by maintenance when calculating egress capacity. A factor that has a direct effect on number of escalators blocked during maintenance is the available space between escalators. Example, in reality more than one escalator may be blocked during maintenance if there is not enough width between escalators. How many escalators that are blocked during maintenance depends on the manufactures technical requirements on their escalators as well as the escalator configuration [17, 18]. Therefore, it is important to follow up that the fire safety strategy is fully incorporated into the overall design and adopted to the specific escalators used in each project.

NFPA 130 states that one escalator should be considerate as out of service in each rise. It is not credible that one escalator in each rise is blocked of during maintenance. Assuming that one escalator in each rise is out of service instead of in one rise will also bypass the risk and consequence of domino-effect of people falling backwards in escalators. This domino-effect is due to difference in pedestrian flow in the different rises as oncoming escalator to a landing can exceed outgoing escalator from the landing, see Figure 2. The cross indicates an escalator out of service and the arrows indicates directions of escalators prior to evacuation.

![Figure 2. Incoming pedestrian flow to landing is higher than outgoing pedestrian flow from landing.](image)

Hence, a stopped escalator from the landing will cause queuing, on the landing, reaching back towards the upcoming escalators if landings between the escalators do not have sufficient area to allow for queuing. If the capacity to the landing exceeds the capacity from the landing the queue on the landing will increase over time and eventually block people in upcoming escalators. Resulting in people falling backward as there is no way to go at the top of the escalator but the escalator continues to bring people to the landing.

4. Escalators, being a technical installation, potentially generate additional sensitivity scenarios to be incorporated in the egress analysis such as technical failure

When designing the fire strategy for deep underground facilities the possibility of failure of technical installation, such as escalators, should be taken into account [19]. Furthermore, NFPA 101 specifies that egress evaluation in buildings should be done with regards to that a technical system could fail during an egress. This is usually interpreted as failure of systems as fire suppression or fire ventilation. Technical system failure in egress analysis should also be interpreted as an escalator could fail during egress. This to make sure that the planned egress strategy is fulfilling acceptable fire safety level even if an escalator fails prior to or during egress.

There are other more exceptional scenarios to be considered however more unlikely. For instance due to an accident in an escalator in Stockholm’s subway system all escalators from the same manufacturer where stopped during investigation of the cause [20]. This resulted in several stations where all escalators where stopped. People had no other choice than to walk up the stopped escalators
as this was the only means of exit. People in wheelchairs are unable to use stopped escalators and are reliant upon access to elevators to be able to evacuate or exit an underground station on their own. Numbers of elevators in underground stations in Stockholm are usually limited to one per each platform entrance, which causes long queuing both during normal usage as well as during egress. To ensure people’s safety in case of a fire and if an elevator would be taken out of service this is often combined with a safe area on the platform where people are supposed to wait for assistance. In case of technical failure or stopped elevator this would mean that people dependent on elevators would have to wait for assistance until the emergency is over. Another risk with people waiting a longer period of time for an elevator or assistance is that they might block parts of the required egress width required.

5. Identified aspects in number 1 – 4 for egress can cause knock-on effects which may in turn result in a “domino-effect” with people falling backwards in escalators

The prerequisite in standards and regulations for egress can for deep underground stations result in knock-on effects caused by the aspects described above in number 1 – 4.

If a simplified analysis or hand calculation is used to prove that acceptable fire safety level is reached in design of deep underground stations there is a risk of underestimating queue formations, because people queuing are not standing in an optimized manner.

As an example, unwanted queuing on landings between escalator rises will occur when an escalator from the landing fails and full capacity still proceeds in escalators coming up to that landing. This may result in a domino-effect of people falling backwards onto and in the incoming upward escalators. The size of the escalator landings between each escalator rise should be designed to prevent this risk of domino-effect. When using standardized values for pedestrian flow in escalator to and from a landing to evaluated dimensions needed for each escalator landing queue formations will be misjudge due to people not standing in an optimized manner.

The effect of people not standing in an optimized matter might also cause longer que times in front of escalators than for example a hand calculation will show. The queuing itself may impede people’s possibilities to reach an escalator since the queuing blocks people from loading the escalator. Research done on pedestrian flow in escalators often do not take this into account. When pedestrian flow and walking speed is measured in experiments it is usually during controlled forms with a few volunteers and not with the larger amount of people as stations should be designed for. This should however be taken into consideration since this is an important factor that may affect the real pedestrian flow in the escalators. Additionally, egress flow on pathways tend to be reduced as the density of people increase. Even densities of two people per square meter more than halves the pedestrian flow [21, 22]. This will have an effect not only on the flow in pathways but also on pedestrian flow onto the escalators.

Selected critical key problems

Based on the discussion above the following aspect has been identified as the most critical to analyze since they may lead to consequences in deep underground stations.

a) Lack of comprehensive research coverage of what might affect pedestrian flow in stopped escalator and how this might affect egress capacity in escalators.

b) Risk of domino-effect of people falling backwards in escalators due to not enough area on landings.

Analysis of key problems

Available regulations states that escalators operating in the opposite direction from the egress direction should for evacuation be able to be stopped [3, 6]. This is becoming more and more common to rely upon when designing underground stations due to the possibility of reducing project
construction costs. This as less escalators is needed to reach sufficient egress capacity since people can walk upwards in stopped escalators. When stopped escalators are incorporated in a calculation of egress capacity, limited amount of data is used to assume pedestrian flow in stopped escalators. New research findings indicates that pedestrian flow rates used in calculations today for stopped escalators are too high and do not take fatigue into consideration. The latest research available [5] of pedestrian flow in stopped escalators is presented in Table 1.

Table 1. Pedestrian flow rates based on latest available experiment in stopped escalators [5].

<table>
<thead>
<tr>
<th>Height</th>
<th>Pedestrian flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10 m</td>
<td>46 people/min</td>
</tr>
<tr>
<td>10-20 m</td>
<td>23 people/min</td>
</tr>
<tr>
<td>20-30 m</td>
<td>14 people/min</td>
</tr>
<tr>
<td>&gt;30 m</td>
<td>12.5 people/min</td>
</tr>
</tbody>
</table>

Case study – Dimension of landings between escalator rises to prevent domino-effect of people falling backwards in escalators

As the depth of the station increases pedestrian flow rates in stopped escalators decreases due to fatigue of people walking in the stopped escalator. For a required total vertical rise over 30 meter the rise usually has to be divided into two. This to avoid unnecessary high cost due to enlarged construction and installation requirements required for an escalator to manage a long rise.

Since longer vertical rises usually tend to be designed as two escalator rises it is with increased depth more critical to ensure that landings between escalators are designed to prevent domino-effect caused by higher capacity in oncoming escalators than capacity in escalator from that landing. In cases of a difference in escalator capacity in incoming and outgoing escalators the area of the landing in between needs do have sufficient area to allow for queuing. Otherwise, a domino-effect of people falling backwards in escalators can occur. This chapter consists of a case study where egress calculation has been carried out with the latest available research on pedestrian flow rates used in stopped escalators. This to illustrate the required area for landings between escalators to prevent a domino-effect. The purpose of landing spaces is to pull passengers away from escalators to provide a clear landing area for the following passengers [7]. Landings are also used to allow queuing area in the event of a system failure because the space provides a reservoir in which passengers can accumulate safely.

One way to determine the required area of a landing is to analyze expected queuing with regards to allowed density of people during a queuing situation. For this case study a density of 3 persons per square meters is assumed when people are queuing on the landing. [6, 21, 22]

Simulations have been executed to calculate required area to prevent domino-effect [1]. Specified pedestrian flow rates in escalators operating upwards during egress vary between 55 – 120 people/minute*meter dependent on the velocity of the escalator [3, 6, 7, 21, 22]. The average pedestrian flow of 75 people/minute*meter is used for this study [3]. The escalators running in the opposite direction of the egress flow are assumed stopped and the flow rate is set to pedestrian flow as presented in Table 1. Simulations are carried out with three escalators in each rise and both rises has the same height, e.g. same pedestrian flow rate. The total vertical height is divided into two separate escalator lifts with a straight landing in between. In Figure 3 to Figure 5 directions of escalators before evacuation is shown on the left side. The right side of the same figures shows which escalators that are stopped, blocked or continued with full capacity during an egress situation. The blocked escalator is not used during egress, but people are assumed to walk in stopped escalators. People are also assumed to walk in an escalator that stops due to technical failure, indicated with a dotted arrow in the figures. The escalators that continues to run are assumed to have full capacity. Figure 3 illustrated a scenario where one escalator in the second rise is out of service, one stopped and one with full capacity. Figure 4 illustrates a scenario with technical failure in the second rise where two escalators before egress are operating upwards. Figure 5 illustrates a scenario with technical failure in
the second rise where two escalators are before egress operating downwards. The dotted arrow indicates stopped escalator that people walks in and the bold arrow indicates continued upward operating escalators. In the two scenarios with technical failure, an upwards operating escalator is assumed to fail, indicated with a thin arrow.

**Figure 3.** Scenario out of service. The left side shows the escalator running prior to egress. The right side during egress with one escalator out of service. Bold arrows illustrates moving escalator and dotted indicates stopped escalator. The cross indicates escalator closed off for maintenance.

**Figure 4.** Scenario technical failure up. The left side shows the escalator running prior to egress. The right side during egress with one escalator stopped due to technical failure. Bold arrows illustrates moving escalator and dotted indicates stopped escalator. Thin arrows indicates an escalator that has stopped due to technical failure.

**Figure 5.** Scenario technical failure down. The left side shows the escalator running prior to egress. The right side during egress with one escalator stopped due to technical failure. Bold arrows illustrates moving escalator and dotted indicates stopped escalator. Thin arrows indicates an escalator that has stopped due to technical failure.

Presented in Figure 6 to Figure 8 is the result of the case study, which illustrated the increase in required area to prevent domino-effect due to increase of total vertical rise. In each graph 100 % is based on shortest length of landings commonly used, based on regulation as well as constructional limitation. Technical failure up indicates a higher capacity upwards i.e. there are more ascending escalators than descending prior to egress. Whereas technical failure down indicates the opposite, a higher capacity downwards i.e. there are more descending escalators than ascending prior to egress.
Figure 6. Increase of required minimum area for queuing on landings* with regards to total escalator rise simulated with 1000 pedestrians.

Figure 7. Increase of required minimum area for queuing on landings* with regards to total escalator rise simulated with 1500 pedestrians.

Figure 8. Increase of required minimum area for queuing on landings* with regards to total escalator rise simulated with 2000 pedestrians.

*Based on minimum 10 meters clear width of landings for pedestrians to queue on.
The graphs shows that with increase of total vertical height the required area of the landings to prevent domino-effect due to queuing increases. The slope of the increase differences between scenario with technical failure and out of service. It is also shown that a large impact of the increase of landing area is due to how the escalators are running prior to an evacuation.

In the simulations the escalator rises are the same height whereas in reality the rise usually varies. It is common to design escalator rises from a deep underground station with one shorter rise from the platform and one longer second rise. If the first vertical rise is the shorter one this will require a larger landing area due to the difference in pedestrian flow rates in the two rises.

The possible positive impact on pedestrian flow rate in stopped escalators due to people resting on landings while queuing has not been accounted for in this case study.

**CONCLUSION AND SUGGESTED SOLUTIONS TO IDENTIFIED TECHNICAL ASPECTS**

Standards and regulations internationally for deep underground stations do not have a comprehensive method to be implemented when designing fire safety in deep underground stations today. The egress capacity calculated from pedestrian flow in escalators in underground stations is only valid up to a certain depth.

To prevent domino-effects of people falling backwards in escalators the case study shows that the analyzed size of escalator landing in deep underground stations between each rise is larger than the required size according to today’s available regulations in design of underground stations.

There is a limited amount of research in how fatigue effects pedestrian flow in stopped escalators. New research indicates that people walking in stopped escalators are affected by fatigue, which will decrease pedestrian flow rates [5]. These new research findings are not today represented in standards and regulations such as NFPA, LU and Singapore code of practice [3, 6, 7]. Furthermore, the research available on this do not represent a higher number of pedestrians. This in turn does also have an effect on pedestrian flow rates in escalators, presumably decreasing the pedestrian flow even further.

In egress analysis, based on available guidance today, and evaluation of safety in underground stations pedestrian flow rates in escalators are assumed based on single vertical height. This pedestrian flow or movement speed is not adjusted according to the total vertical rise even though there might be consecutive escalators. The assumed pedestrian flow rate or movement speed in each separate escalator is based on the vertical height of a specific escalator, regardless of total number of escalators or total vertical height. Since regulations is written in the context of limited amount of vertical movements in each separate vertical height and not according to the total vertical height, it is inappropriate to apply existing codes to deep underground facilities. The pedestrian flow rate or movement speed in stopped escalators should vary as a function of the total vertical distance.

Egress including escalators are dependent on several factors where technical failure and out of service are shown to be two important design aspects for determining the landing dimensions between escalators. It is also shown that a large impact of the increase of landing area is due to how the escalators are running prior to an evacuation. Further, there is a difference if escalator rises are the same height or if the consecutive rises varies.

Since today’s international and national requirements are inadequate with regard to evacuation incorporating escalators, from deep underground stations, suggestions in Table 2 are to be considered when revising regulations and recommendation for designing safe egress.
Table 2. Summary of suggestions and recommendations for revision of regulations regarding evacuation incorporating escalators in deep underground stations.

<table>
<thead>
<tr>
<th>Design aspect</th>
<th>Suggested requirement</th>
<th>Uncertainties</th>
</tr>
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<tbody>
<tr>
<td>A. Pedestrian flow in escalators affected by fatigue.</td>
<td>Incorporate new research into relevant design codes regarding egress flow in escalators affected by fatigue.</td>
<td>There is only one study carried out with a limited amount of pedestrians.</td>
</tr>
<tr>
<td>B. Pedestrian flow, in escalators, affected by fatigue does not take several rises into account.</td>
<td>Incorporate new research into relevant design codes regarding egress flow, in escalators, affected by fatigue due to total depth of the station and length of escalators.</td>
<td>Lack of research regarding effect of fatigue due to several continued rises.</td>
</tr>
<tr>
<td>C. Some codes specify that egress evaluation should be done with regards to that a technical system could fail during egress [19].</td>
<td>Escalators, being a technical installation, should generate additional sensitivity scenarios to be incorporated in the egress analysis such as technical failure of an escalator. Incorporate technical failure of an escalator in egress calculations. The risk of someone activating the emergency stop for an escalator should also be considered as a sensitivity scenario.</td>
<td>This may be considered a sensitivity analysis and should be treated as such. Making sure that the planned egress strategy is working even if an escalator is out of service at the same time as an escalator fails is neglected in egress evaluations. The possibility of this happening at the same rise is not small enough to be neglected. Despite this, that aspect is not considered in egress analysis.</td>
</tr>
<tr>
<td>D. Blockage of one escalator due to maintenance.</td>
<td>Incorporate the blockage due to maintenance of one escalator in one rise rather than one in each rise. If an escalator in each level or rise is assumed out of service the risk of domino-effect is not accounted for. This should not be considered a sensitivity analysis and should be incorporated as a design scenario.</td>
<td>There is a risk of more than one escalator being blocked during maintenance depending on type and configuration of escalators. The project should make sure that there is enough space between escalators to allow for maintenance only blocking one escalator at a time.</td>
</tr>
<tr>
<td>E. Required area of landings between escalators.</td>
<td>Designing required area of landing between escalator rises so that the risk of domino-effect of people falling is prevented.</td>
<td>The area is dependent on total vertical height and the relation of vertical height between rises. Furthermore, chosen prerequisites for the direction of operating escalators prior to evacuation in combination with placement of the blocked and/or technical faulty escalator are important factors. Required area are not a fixed value and are required to be analyzed for each specific project.</td>
</tr>
<tr>
<td>F. Refugee area for people dependent on elevators.</td>
<td>In case of failure or stopped elevator people dependent on elevators have to wait for</td>
<td>-</td>
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assistance until the emergency has passed. While waiting a longer period of time there is a risk of people dependent on elevators blocking parts of the required egress width in front of the escalators. Specifying refugee area for people dependent on elevators should be incorporated in required area in front of escalators.

| G. | Maintenance consideration into the design. | Type and quality of an escalator should be required to be chosen so that the required need for maintenance of the specific type of escalator does not interfere with the assumed prerequisites used in the fire strategy. | The developer of the project is not always the same as the operator. The communication/understanding between the two are important during the design face. |
| H. | One can be as accurate as possible in a design. However if the prerequisites used in the design are not considered in the following stages of a project the results will differ. For instant if the entrepreneur choose cheaper technical installations and components not considering the overall fire safety strategy an analyzed and working design may still fail if not considered further along the timeline of the project. | It should be mandatory that the engineer responsible for the design follows it through during the tender and construction face as well as prior to initiating operation. | The constructor, entrepreneurs as well as operators knowledge and understanding of the importance of implementing a fire strategy is crucial to get the required safety level throughout a project. However, this is not always the case and many aspects are lost over time. It is shown that a large impact of the increase of landing area is due to how the escalators are running prior to an evacuation. If this is not implemented in the day to day routine and operation it can have a significant impact on egress. |

**FURTHER STUDIES AND RESEARCH**

Based on the presented suggestions and recommendations in the conclusion the following has been identified as further research needed:

- Develop or update regulations covering deep underground stations as suggested in Table 2, preferably based on a cost-benefit analysis.
- Further studies of fatigue due to long transition in escalators, preferably with larger amount of people.
- Further research regarding effect of fatigue on pedestrian speed and pedestrian flow in stopped escalators using a variation of pedestrians that represent society’s variation.
- Further research regarding effect of fatigue on pedestrian flow in stopped escalators due to several rises of escalators. How the effects of people being able to rest while queuing on the landings affect pedestrian flow in stopped escalators?
- A holistic approach while developing or rewriting regulations and guidelines for design of deep underground stations is crucial. It is otherwise easy to miss important dependencies in prerequisites used. The more complex a design is allowed to be the more likely dependencies
in prerequisites are subject to generate flaws in a regulation and/or design. Hence future work should strive towards keeping complexity in technical systems to a minimum to be able to constructively consider important dependencies.

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