Life-safety targets in underground stations

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ABSTRACT

The Swedish Transport Agency and the Swedish Transport Administration have completed the R&D project '*Common life safety targets in traffic tunnels'* in which a common life-safety target was formulated for users of road, rail, tramway and subway tunnels. As a logical continuation of this work an additional project was initiated to investigate the potential to express a safety target for underground stations connected to tunnels. This effort makes the design regulations with technical requirement more complete for this type of structures. It also provides risk control in an essential part of the construction works related to the transport system for which the Swedish Transport Agency has a mandate to formulate requirements in regulations and general recommendations.

KEYWORDS: underground station, submerged platform station, safety target, risk analysis, life-safety, severe accident, dangerous goods, fire.

INTRODUCTION

Background

The Swedish Transport Administration and the Swedish Transport Agency has initiated a project to study the prerequisites and the potential for formulating a harmonized safety target for the space surrounding underground platform stations. The safety target should be applicable to different modes of transport regarding underground/covered platform stations, such as railroad-, tramway and metro-stations, bus stops and bus terminals. Such a target needs to and facilitate the balance between risk and economic effectiveness to be operational in both regulations and design. The work is a continuation of previous research conducted in tunnels where two reports from the R&D projects "Life-safety objectives for road, rail and metro tunnels" has been previously presented. The first report in 2016 [1] showed that it is possible to formulate a common life-safety target, with a clear link to public benefit for users of road, rail, metro and subway tunnels. The second report in 2019 [2] continued the work, developing and verifying the conclusions of the first report and forming a basis for forthcoming national legislation. In these reports delimitations were made as to exclude railway, subway, and tram underground stations and limiting the proposals for life-safety targets to apply only to new tunnels.

The current regulations set detailed requirements for the design of safety measures in underground stations and, to a certain extent, requirements for risk analysis to be performed as a completion during certain conditions. However, no safety targets are stated to assess the risk which were previously also the case for tunnels. The basis of this is that safety targets for the design of safety concepts in underground stations are either lacking or too general and formulated on a highly hierarchical level in the regulations. As a consequence, unambiguous safety targets on a lower hierarchical level suitable for design work are also lacking. This provides a risk for different interpretations and uncertainties about the goals and objectives to be achieved. The result may be different risk levels in different projects and for different modes of transport. Another result can be that the approval process becomes difficult and/or that the safety level can either be too low or too high, i.e. expensive.

Optimising safety in a specific tunnel, however, relies on some form of generally accepted level for acceptable safety – a common life-safety target. This has been lacking in current rules and regulations, which risks different interpretations in relation to planning and administration when cost is weighed against public benefit. Without such a target, it is difficult to determine whether the functional requirements in the current legislation have been fulfilled.

Another issue is that the current rules and regulations for road and railroad tunnels do not address the risks that are specific to underground stations which might have severe consequences in case of an accident, including, among other things, fires and events involving dangerous goods.

With this background the Swedish Transport Agency (authority having jurisdiction) and the Swedish Transport Administration (infrastructure manager) were curious to explore the opportunity to embrace underground stations as a complement to the efforts made with tunnels and align this work with the ongoing development of the tunnel regulations.

The project results will be used by the Swedish Transport Agency as a basis for creating national requirements and issuing general recommendations and accompanying impact assessments in the coming draft of regulations pertaining to tunnel safety, underground stations included. Regarding implementation phases, the expected result is that the safety requirements in tunnels will become improved. This will reduce arbitrary interpretations and ensure that the requirements concerning risk assessment, are well-balanced, based on societal benefit, and harmonised with the national standards for other transportation infrastructure. Distinct life-safety targets lead to more efficient building processes since correct measures can be applied during planning and construction, and tunnel managers can apply efficient, risk-based working methods. This paper is reporting on some of the results from the project documentation [3].

Purpose and objective

The purpose of the work is to form a base for a forthcoming national legislation in Sweden and to improve the regulatory risk control in the current regulations. The objective is to investigate whether it is possible to propose a well-balanced safety target and suitable verification method or concept in a similar way as for tunnels. Based on experience it has been found relevant to describe how both accidents with few casualties, e.g. suicides or fall accidents, and very unlikely accidents with very large consequences, e.g. accidents involving dangerous goods or large and rapid fires, can be assessed within tunnels.

Delimitations

In this paper underground station and platform station refer to the space adjacent and/or between tunnels entering an underground station area. The space for which the safety target is derived consist of the concurrent part of the traffic system together with the underground platform station, see examples in Figure 1 and Figure 2, i.e. defined by the platform floor, the side walls, the platform ceiling and interfaces to other parts of the station facility located in the same fire compartment (“plattformsrum” in Swedish). This mean that the safety target does not cover areas as shopping facilities, restaurants, interchanges above ground or ticket offices located in other parts of the station. It does not cover the safety in areas above the station potentially used for other purposes.

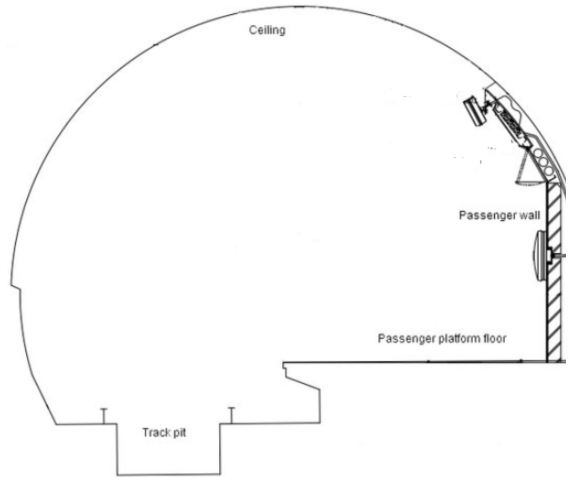

Figure 1. Cross section of a simple underground platform station for a single-track metro.

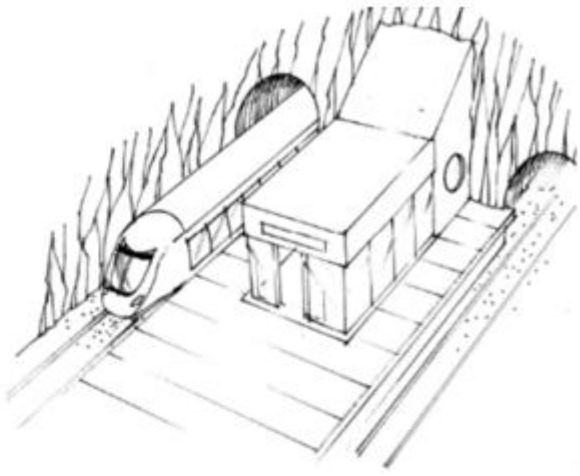

Figure 2. Underground island platform station for railway.

The project includes safety targets for travellers in underground stations according to the Swedish Transport Agency regulatory authority according to the Planning and Building Act [1]. The ambition is to contribute and clarify how to fulfil the technical essential requirements on a detailed level, i.e. regulations or general recommendations. The safety targets are not intended to be used to demonstrate fulfilment of all safety requirements covered by other legislation i.e. railway technical systems, work environment, antagonistic threats, poor air environment, etc.

Method

The work of investigating and proposing safety targets began with a literature review and a description of the regulations regarding life safety in underground platform stations and/or underground interchanges. In addition, if the approach suggested to control and design life safety measures in tunnels also can be applied on underground stations, the risk control approach in the regulations can cover a larger part of the transport system. An important complementary part of the work was to account for how safety goals are expressed for existing facilities and in ongoing projects and also to propose input to a prescriptive standard forming the base for the safety requirements. Another important input is to study and analyze the risk analysis output from various ongoing and recently completed underground station projects.

Since this work is a continuation of previous research conducted in tunnels let us begin with a reminder on what have been done. Many of the conclusions made in previous research can be useful.

LIFE-SAFETY TARGET FOR TUNNELS

General remarks

The regulation of the safety level of a tunnel can be considered as being the desire of society to ensure that the risk levels of tunnels in general do not exceed acceptable limits. Risk exposure measures used to define targets can be formulated in many different ways. In international literature, e.g. [3], the predominant risk measures for describing individual and societal risk in traffic systems are PLL (Potential Loss of Life) values and F/N (frequency-number) curves. F/N curves appear to be a relevant measure for establishing a risk profile in order to evaluate individual facilities. Other measures, such as PLL values, describe the expected total number of fatalities – which does not provide any additional information to that provided by an F/N curve.

Exposure measures constitute an important aspect of the formulation of a common life-safety target. These are the units of measurement against which risk is standardised. In the context of risk assessment, it is common for risk to be expressed per year, per worked hour, per vehicle-km, per tunnel-km, etc. One problem with standardising e.g. an F/N graph for a tunnel against year is that as many fatalities per year are "allowed" for a long, very busy tunnel as for a short, less busy one. Other units of measurement include vehicle-km, tunnel-km, etc.

During previous comparisons of different projects, the best concordance was reached through standardisation against person-km. Person-km is also an exposure measure that provides a natural connection to the public benefit of the facility by take into consideration large amounts of people that often occur in new facilities and at the same time be applicable on less complex facilities. Person-km is therefore the proposed measure.

Proposed common life-safety target for tunnels
As a starting point the result from previous research is presented. The overall target that was proposed was formulated as:

> ***'The risk during transportation in road, railway, subway, and tramway tunnels shall be equal, expressed as risk of fatality per person-km.'***

To be able to assess whether the overall target is fulfilled a quantitative criterion based on societal risk was formulated. The quantitative criterion is meant to assess risks that either are exclusive to tunnel environments or general risks which consequences could become more severe if they occurred in a tunnel compared to above ground. Based on this limitation a quantitative risk analyses should cover accidents such as fire and accidents with dangerous goods. Risks with fewer casualties, e.g. derailment or traffic accidents, are not exclusive for tunnels and the consequences do not aggravate if they occur in a tunnel. Risks with fewer casualties can be met according to detailed prescriptive requirements (in the report named "basic standard"). This can be done without further quantitative risk analysis, but must be complemented with analysis comparing available safe egress time (ASET) with required safe egress time (RSET).

The proposed common life-safety target is presented in Figure 2. As regards the upper acceptance limit (A), lower acceptance limit (B), and limit for low number of fatalities (D), this corresponds to the proposal in the first 'Life-safety targets in tunnels' report. Regarding unlikely accidents, however, no limit was proposed.

The curve can be said to be formed in such a way that the upper acceptance limit, which may never be exceeded, constitutes the common life-safety target for tunnels in different types of transport systems. Delimitations regarding the lower acceptance limit and 'low number of fatalities' constitute support for analysis, rather than actual requirement limits. This can be summarised as follows:

a. The risk may not exceed the upper acceptance limit.
b. Further risk-reducing measures do not need to be analysed for risks that fall below the lower acceptance limit.
c. Further measures targeting risks between the upper and lower acceptance limits shall be evaluated. Measures should be introduced if these can be demonstrated to be cost-efficient from a socio-economic perspective.
d. Accidents with fewer than three fatalities can be excluded from the quantitative risk analysis.
e. The upper acceptance limit has a fictional starting point of $F=1*10^{-4}$ per million person-km at N=1 and a slope of -1.
f. The lower acceptance limit has a fictional starting point of $F=1*10^{-7}$ per million person-km at N=1 and a slope of -1.

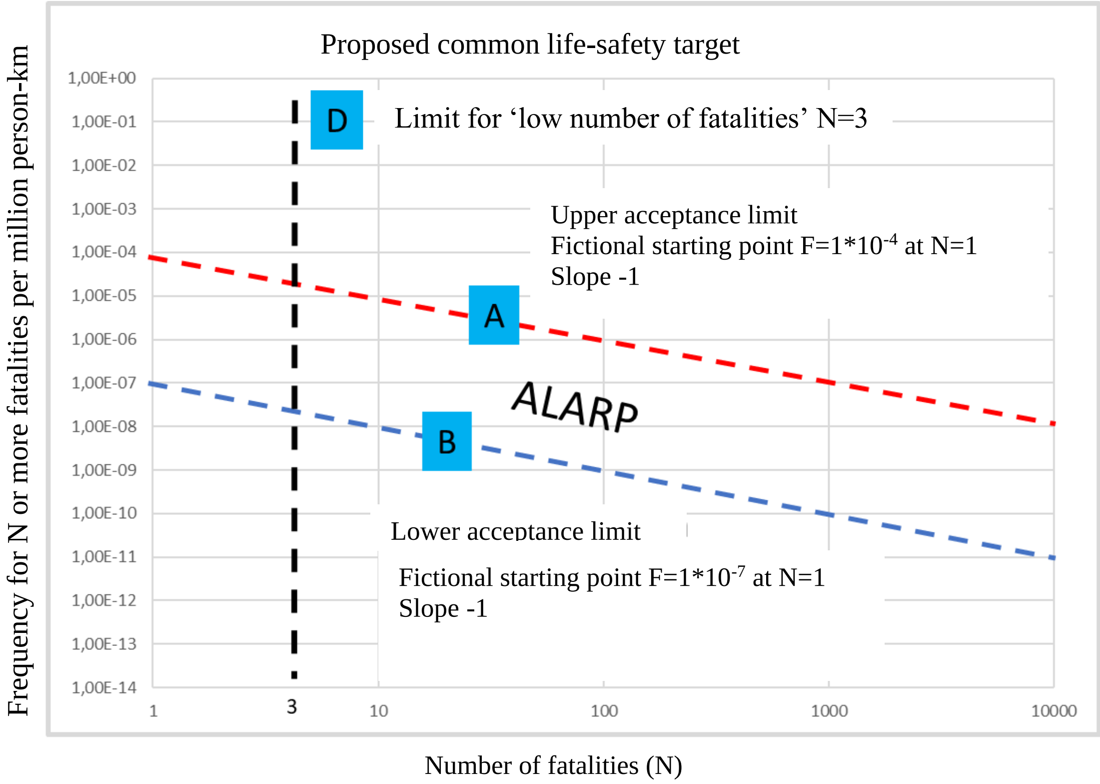

Figure 3. Proposed societal risk criterion for tunnels.

The reason for the choice of upper acceptance limit is that either lowering or raising it are assessed to have unwanted consequences. A lowering of the limit results in:

- several new or ongoing projects having great trouble fulfilling the criterion, making it difficult or impossible to demonstrate that the criterion is fulfilled,
- increased costs as compared to the present situation, and
- the position that the safety levels of new tunnels or ongoing tunnel projects will not be considered to be satisfactory in the future.

CURRENT SITUATION FOR UNDERGROUND STATIONS

Risks in underground stations

The life-safety targets must include risks that may affect life-safety in underground stations. Which risk categories are relevant to consider is partly dependent on the mode of transport in each station. Accidents with small consequences (occasional fatalities or injuries) on platforms/waiting areas and access roads are also usually not specific to underground stations in particular but depend on the infrastructure itself. These accidents will probably have the same consequences if they occur on an outdoor platform, and the requirement should be covered by other legislation. The different modes of transport have in common that fire accidents are the accident category that primarily may lead to several fatalities. Derailments and collisions at, or adjacent to, a platform station generally entail a lower probability of major consequences than if the corresponding accident occurs in the tunnel. This is partly because the consequences of these accidents depend on the possibility of evacuation and rescue efforts, which is significantly better at a underground stations than in a tunnel, and partly because underground stations and lower speeds reduce the probability that a derailment will lead to carriages overturning.

The presence of dangerous goods transport can lead to very extensive and rapidly growing fire scenarios, explosion scenarios and the release of, for example, toxic gases. The probability of a dangerous goods accident is relatively very low partly because dangerous goods make up a small part of the traffic, and partly because there are detailed rules for how dangerous goods must be packaged and handled during transport to limit the likelihood of an accident.

Accident statistics

The accident statistics compiled in Sweden give a fragmented picture of the situation for platform stations. Major accidents with several fatalities have not been identified in the statistics. According to statistics for injured and deceased persons in the various modes of traffic in Sweden between the years 2014-2019 (Trafikanalys, 2020) railway and subway suicides account for approx. 80% of the total number of deaths. The number of fatalities on the platform accounts for less than 1% of the total number of fatalities. Accident statistics for road traffic 2003-2019 [6] show that 46 people out of a total of 5 841 deaths in road traffic, connects to the mode of transport by bus, i.e. less than 1%. However, it is not clear from the statistics where in the road infrastructure these accidents occurred.

Standards, regulations and investigations

The criteria that have been identified regarding the evacuation of underground stations are mainly related to a specific time for evacuation to be completed or comparisons with time for critical conditions in case of fire. Quantitative criterion in terms of a safety target has been identified for railway tunnels in the Swedish transport agency's guidelines [7]. A Nordic collaboration [5] proposes quantitative criteria for verifying fire assessment for buildings where many people live. But overall, no quantitative criteria that are directly applicable to underground stations have been identified in regulations in Europe and United States in the review.

Safety in existing facilities and ongoing projects

The research project created an inventory of existing underground stations and current and planned projects. Inventory is mainly limited to Swedish projects. Among the identified projects, we found two examples where a quantitative social risk analysis was conducted, namely the Slussen bus station and the overbuilding (decking) of Stockholm Central Railway Station. The two projects are characterized by the presence of gas buses at the bus station and the unrestricted rail transport of dangerous goods passing the railway station. Overall, the review does not indicate that clear practices have been established, and there are few examples of quantitative risk analyses being conducted where societal risk has been studied.

ASSESSMENT OF APPROACHES TO DERIVE A SAFETY TARGET

The starting point for this work was to investigate in what way a safety target for an underground station could be derived and if it is suitable to described in a similar way as for tunnels was one of the major aspects to investigate in the project.

One conclusion from the inventory given in the previous section (Current situation for underground stations) is that it is not possible to derive safety targets for underground stations with the same approach as for tunnels. There are not enough references to develop general life safety targets covering all transport modes. Therefore, different rationales for deriving safety goals should be thoroughly considered. Such a review was conducted based on the alternatives proposed by Lundin [8].

Analysis of different safety targets and safety levels

Common practice

Common practice for risk assessment is not static and therefore it is not possible to look way too far back to estimate what is the current practice. What is clear is that it is a common practice, both in Sweden and several other countries, that in case of fire the time to evacuate the platform must subseed the time to critical conditions. This practice is regulated by e.g. Swedish Transport Agency regulations TSFS 2017:119 for subways and tramways [5] and the National Board of Housing, Building and Planning [6]. Other aspects of safety targets and measures vary significantly, e.g. how to address suicides, fatalities on platforms, etc.

Comparing the safety targets in two different projects, the underground stations in the railway tunnel Citybanan and the Slussen bus terminal, both in Stockholm, it can be concluded that they are derived with different methods. The life-safety targets for the underground stations of Citybanan are based on previous projects and the Swedish Transport Administration’s requirements for safety levels in tunnels, etc. The targets for the Slussen bus terminal on the other hand are based on comparisons to other transport systems and to the general risk level of commuting. As for new subway stations, an overall assessment is made according to regulations of Swedish Transport Agency [5], which is based on yet another approach, where the safety life-target level is not defined for platform stations.

In summary, there is no common practice for risk assessment of this type of facility present.

Analysing accident statistics
Specific accident statistics connected to underground stations and platform stations are limited. The statistics in Sweden that, to some extent, can be sorted out to apply to railway stations are limited to only include people who have died on the platform as a result of trains in motion, i.e. single deaths. This is only a part of the risks that exist in platform stations and does not cover risks with multiple fatalities, such as fire or dangerous goods.

For subway stations, it can be stated that people being hit by subway trains, including suicides, are dominant, and strongly linked to stations in relation to the subway network in general. Accident statistics for dangerous goods are very limited because accidents occur so rarely. Faveo has made an attempt to describe the probability for dangerous goods accidents in a previous report [10].

The Swedish Transport Administration used accident statistics as a basis for its first report regarding safety assessment/risk analysis in tunnels, BVH 541.3 [8]. The life-safety target in BVH 541.3 was set so that a slightly higher safety would be achieved than what the statistical outcome had been. In this way, they sought to create a contribution to increase safety.

Comparisons to other life-safety targets
The life-safety target and acceptance limits that are undeniably the closest to hand to compare with are those proposed in previous reports on safety goals in tunnels [1] and [2]. In these two reports, comparisons were made between various examples and reference cases where it turned out that risk curves from a several large number of tunnel projects coincide relatively well. Which is why it was deemed appropriate to use these reference cases as a basis for formulating a life-safety target for tunnels.

The proposal is described in the chapter ”Proposed common life-safety targets for tunnels” and illustrated in Figure 2.

The proposal is that the life-safety target should be verified with quantitative analysis for longer tunnels, while for shorter tunnels it is deemed that the safety targets can be met according to detailed requirements (in the report named basic standard), without further analysis. As for risk levels within ALARP, socioeconomic values such as ASEK should be used to evaluate different measures.

The proposal to life-safety targets in [2] do not include criteria for individual risk, since this risk measure is deemed to have a limited contribution to the risk assessment in addition to societal risk. However, it is highlighted that individual risk is a possible complement to the life-safety targets.

The proposal do not include a limit regarding very unlikely accidents, though the first report [1] highlights a need for further investigation of principles and safety targets for managing disaster scenarios.

Underground platform stations are, at least for railway stations, according to the definitions of Swedish Transport Administration part of the railway tunnel. The stations should therefore at least reach the life-safety targets for tunnels. For subways and trams, it is close at hand to compare with the railway's view of underground stations. Underground stations within road infrastructure, such as bus terminals, can be a completely independent facility and the connection to life-safety targets for tunnels given in [2] is not as obvious.

Comparisons to background risk levels
The quantitative criteria for verifying fire assessment proposed by the Nordic collaboration mentioned in the paragraph ”Standards, regulations and investigations” [5] are proposed based on comparisons to background risk. The acceptance level for individual risk is set to 10^{-6} per year, which equals one tenth of deaths due to fire accidents in the Nordic countries.

The proposal of acceptance criteria for individual risk given in 1997 by The Swedish Civil Contingencies Agency (MSB) [12] are also based on comparisons to background risk, for example, the risk of being struck by lightning or the risk of dying in natural disasters.

The different acceptance criteria for individual risk described above apply to continuous presence in a given location. This means that they are not directly applicable to, for example, travellers or staff where the impact of a specific risk source will not be continuous. If the individual risk level considers a non-continuous exposure, the acceptance criteria also should be adjusted with regard to the corresponding parameters.

For societal risk, it is not as easy to base the risk assessment on comparisons to matching background risk levels in the same way as for individual risk. This is one of the reasons why studying both societal risk and individual risk, i.e. these risk measures complement each other with respect to the factors they highlight.

Extract life-safety targets from reference cases
Extracting a quantitative life-safety target from different reference cases assumes that there are existing acceptable systems which are similar to the actual system. This basis was used to extract a life-safety target for tunnels [1].

There are existing underground stations with platforms, but few risk analyses have been carried out and the conditions vary both in terms of analysed accidents as well as different risk levels between different modes of transport. Studying possible reference cases, observations have been made regarding e.g. variations in analysed accidents and accounting exposure factors. For instance, these variations lead to a calculated individual risk for the stations of Citybanan to be less than 1 000 times lower than the specified safety target. The calculated individual risk accounts exposure factors, but the safety target doesn´t. Furthermore, the individual risk calculated for the stations of Citybanan is limited to only include train fire within, or close to, the underground platform station.

A conclusion from the inventory of identified reference cases is that it is not feasible to conduct a safety target for underground stations using their risk levels since the data is too insufficient. There are simply not enough reference cases to conduct a common life-safety target.

However, it is shown that platform stations, to some extent, can be compared to tunnels. At least as far as rail tunnels are concerned. A platform stations that connects to a tunnel becomes a natural extension or part of the tunnel. Because of this, it should be appropriate to conduct a life-safety target for platform stations that is at least equivalent to the safety target for tunnels.

Cost-benefit analysis
Cost/benefit analysis can be used to calculate an acceptable risk level. It requires that the value of a statistical life is determined. Though it is difficult to implement cost-benefit for several different reasons, which is highlighted in the report "Use of risk acceptance criteria in Norwegian offshore

industry: Dilemmas and challenges" [14]. The analysis has its greatest practical use when considering and comparing separate measures, e.g. risk level within ALARP. It is neither practical nor appropriate to only base an acceptance criteria or life-safety target on cost-benefit analysis alone.

Conclusions from assessment
None of the separate basis described above are deemed to work as a sufficiently acceptable basis for life-safety targets for platform stations. However, it could be possible to conduct parts of a safety target using different basis and, in that way, create a relatively comprehensive common life-safety target.

It is common practice that in case of fire all persons must be able to evacuate an underground platform station before critical conditions arise and this needs to be verified by fire and evacuation calculations.

Accident statistics connected to underground platform stations are limited and there are no statistics for accidents with high consequences, which means a limited possibility to draw conclusions based on recent risks.

A comparison with acceptance criteria and safety targets in tunnels seems appropriate when platform stations become a natural extension or part of the tunnel, such as railway and subway tunnels. Underground stations within road infrastructure, such as bus terminals, can be a completely independent facility and the connection to life-safety targets for tunnels is not as clear.

Background risk levels could be used to conduct acceptance criteria for individual risk.
Cost-benefit analysis could be used as a basis and part of the management of safety targets.

DESIGN OF A SAFETY TARGET FOR UNDERGROUND STATIONS

Alignment of safety targets for underground stations
The initial assessment is that what applies to safety targets for tunnels is in principle applicable to platform stations. This includes the use of a prescriptive solutions for simpler underground facilities. It may be possible to use the safety targets for tunnels without modifications, but probably this will not provide a sufficient or desired safety. Suitable adjustments could be:

- Practice of verifying fire and evacuation safety so that evacuation can take place before critical conditions arise.
- Given the uncertainty of what is acceptable risk in underground platform stations ALARP should be applied more extensively. In principle, ALARP constitutes the entire area below the upper acceptance limit.
- Given the uncertainty what is acceptable regarding risks with multiple fatalities, such as fire or dangerous goods, additional basis may be needed beyond a straight comparison of cost and benefit. Using a cost/benefit ratio B - C > 0 to assess if the measure is reasonably practicable or not may need to be re-evaluated.
- Complete the safety target with acceptance criteria for individual risk.

The establishment of prescriptive solutions should be sufficient for the majority of facilities and more extensive analysis and verifications against quantitative safety targets then needs to be done for a smaller number of underground stations. Inspired by the results from previous projects, an adapted model could be used to propose measures for platform stations, Figure 3. At least until specific acceptance criteria are developed. In order to, in the long term, establish feasible safety targets and requirements for underground stations based on their conditions instead of comparison with tunnels, the Swedish Transport Agency should continuously do follow ups on statistics and experience from ongoing projects. This is one important motive to wait until a lower boundary for the ALARP-area is introduced.

In railway and subway projects, it is normally viewed as a malfunction if trains stop in the tunnel in case of a fire. The routine is to, if possible, drive the train to the nearest station, or out of the tunnel, for evacuation. At underground stations, it is therefore standard procedure for trains to stop in case of fire. Compared to the tunnels, this places higher demands on evacuation safety within the platform stations. Verifying fire and evacuation safety should therefore, in accordance with practice, be a part of the prescriptive solutions for platform stations.

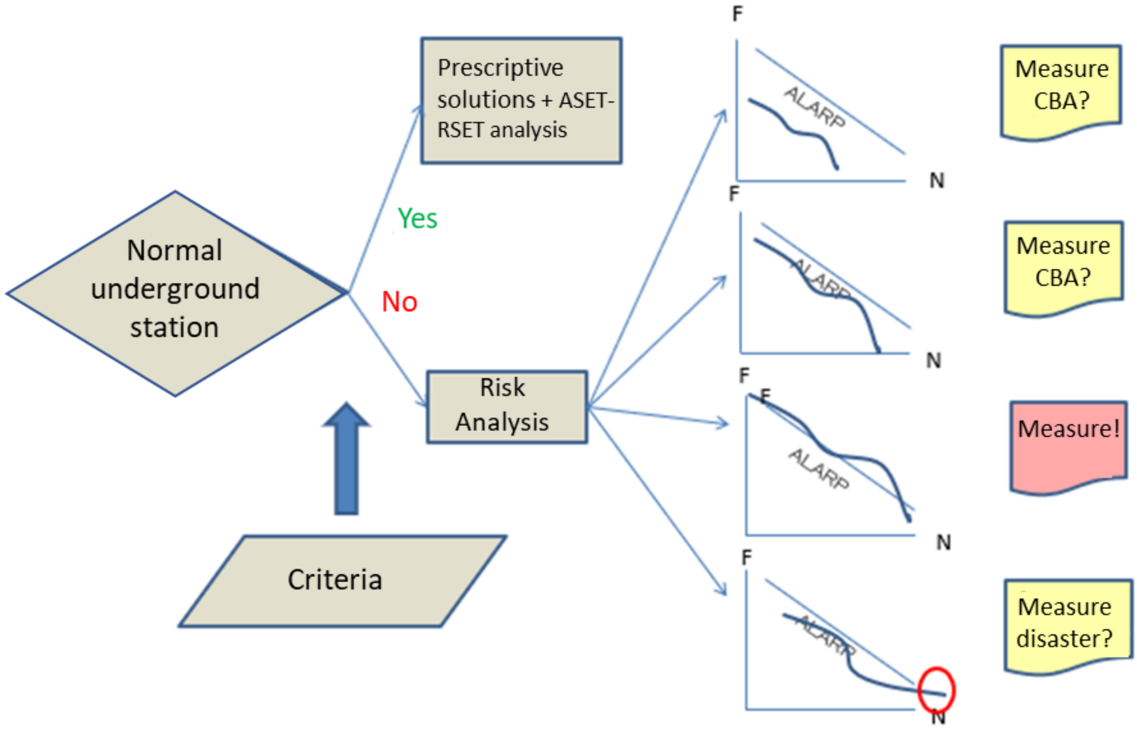

Figure 4. Proposal for process image - decision on measures, underground platform station.

As the platform station often are seen as a part of a tunnel, the safety level for platform stations should be at least as high as for tunnels, probably higher. Though there are currently not sufficient amount of reference cases to use as basis on how much higher the safety should be. For now, the proposal is that regardless of where the risk level is below the upper acceptance limit, cost/benefit analyses should always be carried out, i.e. ALARP is extended. Eventually a practice will be established for a lower acceptance limit, where it does not make sense to analyse whether further measures are reasonably practicable. Due to insufficient reference cases, it is difficult to determine a lower acceptance limit for now.

Furthermore, special additional assessments must be done for disaster scenarios, such as accidents with dangerous goods, and a basis for that assessment must be conducted. For example, there may be reasons to implement measures for such risks even if the cost/benefit ratio is not $B - C > 0$.

In quantitative risk analyses, both societal risk and individual risk are often used as the risk measures complement each other in describing the level of risk and thus provide an expanded basis for risk assessment. For platform stations, however, it is considered that individual risk could be a necessary complement to describe the extent of the risk.

Assessment of Accidents with low probability and high consequence
Accidents with, for example, dangerous goods could result in a mass casualty situation if they occur within, or close to, platform stations where large number of people are staying at the same time.

It is not feasible to evaluate such disaster scenarios for specific platform stations without considering the impact on society as a whole. Generally, accidents that could lead to such disaster scenarios with thousands of casualties are seen in society as unacceptable and should, as far as possible, be avoided. However, the knowledgebase on how to assess this design dilemma is weak at present [15].

Underground platform stations with high traffic in combination with transportations of dangerous goods or large fire scenario (e.g. heavy goods train), still means that this kind of risks have to be managed. Transportation of dangerous goods is a factor that normally means that a prescriptive solutions is not enough, but further assessment including a quantitative risk analysis is required.

Dangerous goods also means that an investigation of disaster scenarios must be carried out. The evaluation of disaster scenarios should be made considering an even more elaborate basis. Since there is no common practice and documentation regarding the analysis needed for evaluating disaster scenarios it is proposed that an overall safety target should be conducted. The proposal is that if the consequences may exceed 1 000 casualties, following analysis should be considered:

- A quantitative risk analysis must be carried out that includes societal risk and individual risk for the underground platform station. The risk analysis should primarily include risks and scenarios that are not handled through the basic standard.
- The quantitative risk analysis should include an inventory of factors that primarily affect societal risk and/or individual risk.
- The risk analysis should also describe a comparison of risk in relation to the current situation/zero alternative.
- The risk analysis should specifically highlight so-called disaster scenarios (scenarios with very large consequences) and which factors contribute to the extent of these scenarios.
- The risk evaluation and compilation of measures should specifically address the general principle of avoiding disasters.
- The risk analysis should include a systematic analysis of inherent uncertainties. If uncertainties have a major impact of the results of the risk analysis, this needs to be taken into account.
- A specific analysis of identified measures, describing all conceivable measures and possible opt-outs, justified by the fact that the measures are not reasonably practicable. The analysis should highlight certain aspects concerning cost and benefits.

PROPOSED COMMON LIFE-SAFETY TARGET

Based on the statistics described earlier (see “Accident statistics”), a couple of risks dominate in terms of contribution to the risk level, e.g. suicides, people being hit by trains or vehicles, fire and accidents with dangerous goods. Managing these risks in a good way could lead to an acceptable safety level.

To derive an acceptance criterion for societal risk in platform stations based on accidents statistics is not possible as there is a lack of sufficient basis. However, the safety in underground stations should at least meet the proposed upper risk level according to "Safety targets for tunnels" [2]. For platform stations the proposal is that assessment of safety measures should also be carried out if the risk level is below the proposed ALARP for tunnels.

Fire is a serious accident in underground stations and can provide a large risk contribution. The risk is included in the societal risk, but it is also proposed that requirements be set specifically according to the practice that has been developed. This means that a functional requirement is set that evacuation of the platform station must be able to take place before critical conditions arise for design scenarios.

Disaster scenarios such as accidents with dangerous goods in the form of, e.g. explosives are very unlikely, but can lead to extremely large consequences. The risk is included in the societal risk, but it is also proposed to be investigated and evaluated specifically. This means that a proposal should state which investigations and analysis should be the basis for decisions of measures.

Individual risk is proposed to be expressed in a quantified safety target. It is considered essential that underground stations are and can be demonstrated to be safe for the individual traveling and that the probability of an accident is not higher in the platform station than in other parts of the infrastructure system. Individual risk complements societal risk for an expanded basis for risk assessment.

As several different measures are often identified for dealing with risks within the ALARP zone, all should be evaluated in a structured manner using a simplified analysis prior to choosing whether to introduce or leave out any measure and performing in-depth studies. In Figure 3, a proposal for a methodology and procedure for a simplified method is summarised. There is a connection between the assessment of risk and ALARP here, and at the same time the assessment criteria have similarities to those of socio-economic analyses. The assessment below can be performed at two levels; either as a comparison between different options with a qualitative gradation, e.g. much worse, worse, equal, better, and much better, or using an assessment of real costs according to supporting texts.

CONCLUSIONS

Safety targets for underground stations can be derived based on the safety targets for tunnels that have been developed previously with some modifications. This is based on the fact that underground stations usually form part of the tunnel system and should have at least the same safety. Even though the work carried out so far has not been able to find sufficient data to develop a safety target for underground platform station based on statistics a strategy to be able to do so has been proposed.

- Defining which risks should be included in a quantitative risk analysis to enable a sufficient evaluation with safety targets.
- Basic standards need to be developed for railway and road/bus terminals. Specific basic standards for each mode of transport are recommended.
- The basic standard is proposed to include requirements for evacuation in case of fire. In this, dimensioning parameters such as dimensioning fire scenario and dimensioning number of people etc. should be specified to increase uniformity.
- In order to, in the long term, establish safety targets and requirements for underground stations based on their conditions instead of comparison with tunnels, the Swedish Transport Agency should continuously do follow ups on statistics and experience from ongoing projects.
- Acceptance criteria for societal risk should be complemented with a lower limit when enough basis has been collected. In the future this means a limited need for cost-benefit analyses.
- Methods for cost-benefit analysis should be adapted for safety targets in underground platform stations.
- Regarding disaster scenarios, the Swedish Transport Agency should consider whether it is suitable to introduce general requirements for measures to significantly reduce the risk level, e.g. time control of freight transport in railway facilities. More analysis needs to be done regarding how to actually reduce disaster scenarios if such are to be allowed.

According to the investigation, safety targets for platform stations need to be developed and adapted in relation to what is stated in "Safety goals for tunnels" [2], but some major improvements are proposed. The main concerns are:

- The ALARP area need to cover the entire area below the upper acceptable level of risk mainly due to limited design experience for the prescriptive regulations.
- An individual risk level is included in the proposal.
- More emphasis needs to be put on disaster scenarios and severe accidents, which might also need to be considered in more detail for tunnels too,
- Methodology for cost/benefit analyses and disaster scenarios are to be applied but requires additional guidelines.

In addition to the above conclusions related to safety targets, another conclusion is that mandatory underground platform station requirements, i.e. prescriptive requirements, should be established for each mode of transport. This is because both the current design methodology and the legal framework are based on mandatory standards covering the requirements of common single-fatal safety measures. This standard is sufficient to ensure safety in the event of multiple deaths in a simple, non-risky underground station. However, basic standards should be used for any type of underground platform station. For more complex underground platform stations and special risks, safety targets are required that include both individual and societal risk measures.

Disaster scenarios, such as accidents involving explosives or other hazardous materials, are extremely rare, but when they do occur, they can have very serious consequences. A similar scenario can occur in the event of a large and rapid fire under unfortunate circumstances, e.g. escape routes being blocked. The risk contribution from severe accidents, which is included in the social risk level, is proposed to be specifically investigated and evaluated as a result of this study. This sets the requirements for what project specific investigation to be made as a basis for decision-making from a risk perspective. It should then be formulated with a balanced assessment in relation to existing benefits and advantages.

Finally, it was concluded that the concept of verifying safety targets using risk analysis in a manner similar to tunnels is feasible. The proposal also has the potential to provide a new user-friendly basis for assessing the economics of tunnels and underground stations and optimizing safety measures. The transport sector's safety goals and objectives are supported by the proposal. Addressing quantitative targets with clear socioeconomic reference provides a basis for consultation with authorities and decisions based on rational factors.

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