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Autor: Brodin, Arne
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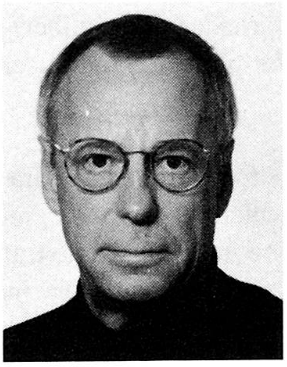
Risk Analysis and Safety Concept

Norra and Södra Länken

(Northern and Southern Link)

Arne Brodin
Fire Engineer
SwePro Engineering AB
Stockholm, Sweden



Arne Brodin, fire engineering degree 1967.
12 years active duty, municipal emergency and rescue services, including the post of deputy chief fire officer.
Since the 1980's, Emergency Service Centre Manager, SOS Alarm AB; Managing Director of Teli Mobitel Trafikledningssystem AB; Consultant in alarm and security systems, tunnel safety specialist.

Summary

The work on safety and security on Norra and Södra Länken has been performed in a number of iterative processes. The aim has been to identify weaknesses in the safety concepts proposed as well as to find cost-effective solutions within the framework of the safety level established. Various solutions have been examined with respect to structural engineering measures, safety engineering installations, restrictions and the organization of rescue services. Through the development of an evaluation model it has been possible to compare and evaluate the alternative solutions. Support for the solutions selected has been established step-by-step with the relevant authorities.

Established Goals in the Field of Road Traffic Safety

There are three supreme goals in the work on road traffic safety in Sweden:

- The total number of people killed or injured on the roads (injury number) shall be continuously reduced.
- The risk of being killed or injured on the roads (risk number) shall be continuously reduced for all categories of road-user.
- The risk of being killer or injured on the roads (risk number) shall be reduced to a greater extent for unprotected road-users than for protected road-users. Special attention shall be paid to children's safety.

The goal incorporated in the safety concept for Norra and Södra Länken is to attain a road traffic environment that is safer than that which otherwise is prevalent today. This can be achieved through both the creation of a more viable and safe traffic environment, and through the installation of systems that limit the severity of any injury incurred in an accident. The safety concept is defined by the technical and organizational measures undertaken, as well as by the regulations and specifications that are intended both to reduce the risk of undesired occurrences as well as to minimize the consequences of such occurrences.

Risk Analysis

A multi-phase risk analysis has been performed based on certain defined objectives. The goal in the initial phases has been to compare the different alternatives:

- in order to be able to judge the level of risk involved in constructing underground tunnels on Norra and Södra Länken in comparison to an above-ground construction of the urban motorway system
- in order to be able to evaluate the efficiency in the different conceivable risk reduction measures through cost-benefit analyses.

The issue of the transport of dangerous goods has been treated in subsequent phases of the risk analysis, when the objectives were:

- to examine the risks involved for people travelling in underground road tunnels as compared to their using roads above ground. This examination was based on information gathered on the quantity of dangerous goods involved as well as on their chemical properties, on information on road and tunnel geometry, etc.
- to evaluate the effect of the alternative protection measures and restrictions on the transport of dangerous goods through the Norra and Södra Länken tunnels.

Results

The acceptance level chosen gives a notable reduction in the accident rate in comparison with today's situation. This acceptance level thereby complies with the Swedish National Road

Administration (SNRA) requirement on a continuous lowering of the accident rate and it is furthermore fully in line with Vision Zero.
The acceptance level presumes 0.004 fatalities per million vehicle kilometres, which corresponds to 2.5 fatalities per year on Essingeleden, Norra and Södra Länken combined.
The following figure presents a compilation of the risks. The graph shows both the analysed scenarios (frequency and consequence) and the acceptance curve.

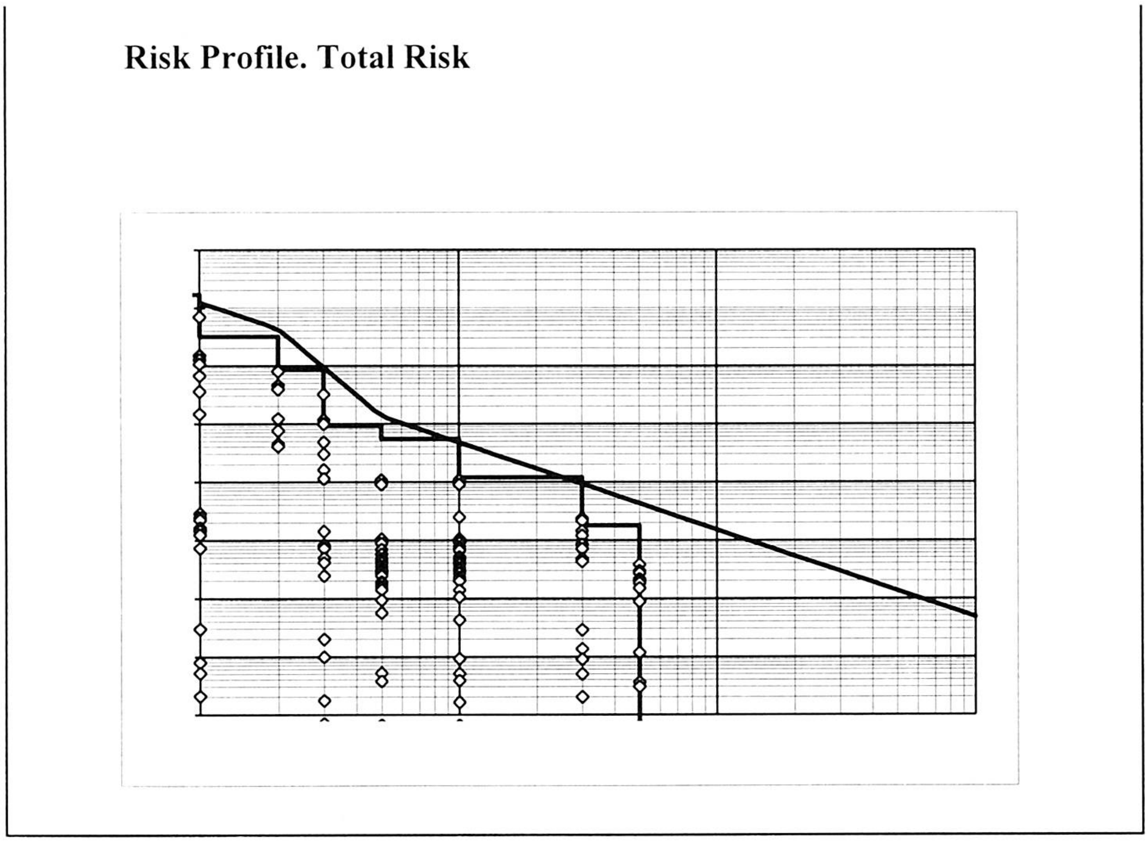


Figure 1: Risk Profile of Norra and Södra Länken

In the work on the risk analysis, what is referred to as aversion factors were used for large-scale accidents. This means that special precautions have been taken against major accidents so that their impact on the risk becomes less and less with an increase in the number of fatalitites per single accident. An example of such precautions could be the installation of sprinklers or escort units in connection with the transport of dangerous goods. In performing the risk analysis, the expected risk has been calculated according to established risk-reducing measures. These calculations include all known risk scenarios but exclude certain risk-reducing measures as presented below. The expected risk has been calculated at 0.0033 fatalities per million vehicle kilometres which corresponds to 2.1 fatalities per year.

All in all, the chosen design and construction of the tunnels and road system has been considered to provide a high safety level. Using those calculation and analysis methods available, the risk of being killed in this road system has been estimated at 0.0033 fatalities per million vehicle kilometres, 99% of which is the result of a traffic accident while the remaining 1% is due to other causes, such as accidents associated with the transport of dangerous goods.

The risk analysis and modelling of the different scenarios has not taken into consideration the positive effect on the accident rate that the implementation of the Traffic Management Centre (TMC) is expected to have; e.g., through the greater amount of traffic information that will be available to road-users, through the creation of the vehicle assistance patrol and through the effects achieved by introducing the Motorway Control System (MCS). Based on Holland's experience, the effects of the MCS alone can reduce the primary accident rate by 25%, and secondary accidents by 40%. Considering that the risk profile for underground road tunnels indicates extensive repercussions through just rear-end collisions in particular, the implementation of the MCS has great potential for making positive improvements in the picture of the risk presented in the risk analysis.

Evaluation Model

An evaluation model based on the SNRA effect index was developed for Norra and Södra Länken. Different technical, organizational and administrative solutions were tested within the framework of the safety requirements that had been set (acceptance level). In general, if a safety concept fulfils the acceptance level, its comparative cost is calculated. Calculating comparative costs for several concepts can be used to collate different "valid" safety concepts.

Additionally, the economic reliability and the functional certainty of the different technical and organizational solutions were described. These descriptions were compiled in a simulation program that applies the Monte-Carlo principle. As a result, it became possible to adopt the safety concept with the greatest calculated accuracy.

Design Scenarios

Considering the restrictions that will be placed on the transport of dangerous goods, the following design standards have been accepted for the structures and installations on Norra and Södra Länken:

- A burning lorry with an effect of 100 MW represent the design fire scenario for the evacuation and rescue routes.
- The fire ventilation system shall be able to control combustion gases from a burning lorry (100 MW). Tunnel sections with a sprinkler system shall be designed for a fire of 10 MW.
- The supporting structures shall be designed for a burning lorry (100 MW)
- The automatic fire alarm shall be designed to detect a fire in a passenger car (3 MW) at an air speed of 5 metres per second.

The reason for not designing the fire ventilation system and supporting structures for a petrol fire (300 MW) can be summarised as follows:

- The risk analysis has indicated that the probability of accidents with dangerous goods is low.

- Considering the initial rapid development of the fire, a combustion control system cannot be designed in such a way as to be able to guarantee safety. In other words, modern technology is not capable of providing a fire ventilation system with sufficient capacity for larger petrol fires. The measures planned are therefore those which first and foremost reduce the risk involved; i.e., restrictions, sprinkler systems and escort activities.

Considerations

Evacuation and Rescue Routes

The smoke ventilation in the design fire scenario shall be able to maintain a smoke-free tunnel upstream from the fire.

The traffic control system shall normally be able to divert and dissipate the traffic that is downstream from the fire so that those road-users are not affected by combustion gases.

The information and warning systems placed at the disposal of the Traffic Management Centre shall be sufficiently well developed so as to ensure that information on a commanded emergency evacuation will reach the road-users concerned.

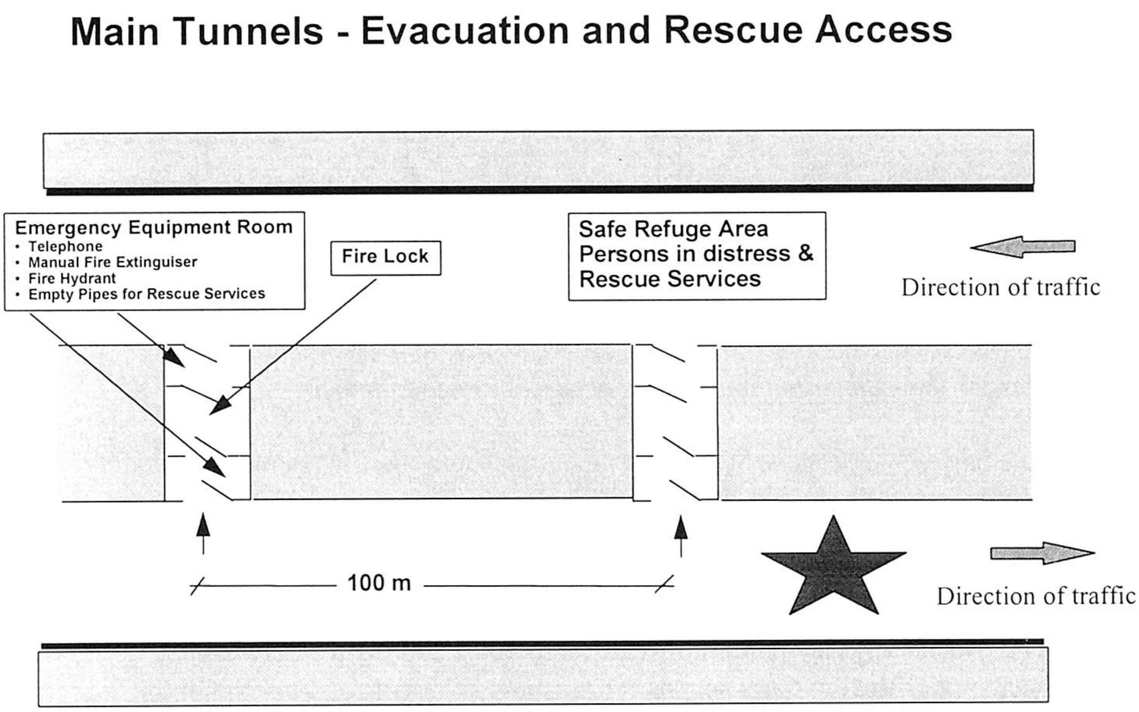


Figure 2: Principles for the evacuation and rescue accesses in main tunnels

Adaptations will be made in the design to ensure that disabled persons can make their way to the safety area without assistance, while simultaneously ensuring that these adaptations do not jeopardize the overall evacuation possibilities or interfere with the rescue services being able to perform their task efficiently.

So-called rescue rooms will be constructed in those parts of the evacuation routes where inclines are too steep.

The evacuation from the ramp tunnels will occur according to the same principles as for the main tunnels; i.e., primarily through tunnel connections to other ramp tunnels but these cross-connections can also lead to main tunnels as well.

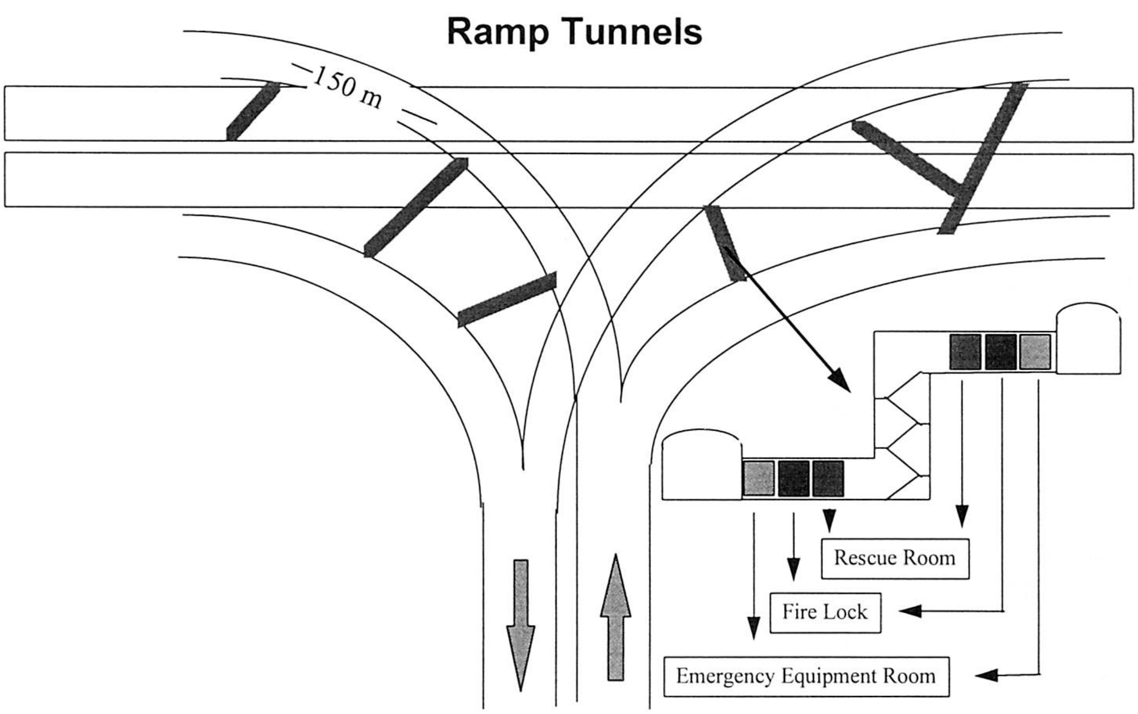


Figure 3: Principles for the evacuation and rescue accesses in ramp tunnels

The longest distance between emergency exits to evacuation routes that lead either to a safety refuge area or out in the open air shall be **100 metres for main tunnels** and **150 metres for ramp tunnels**.

Different distances between exits were tested before making the final decision. Analyses showed that from an evacuation viewpoint, intervals up to 200 - 250 metres between emergency exits were not critical with respect to the personal safety of road-users. On the contrary, the critical factor was the perception times; i.e., the time from when an incident occurs until the evacuation is actually set in motion. In other words, it is more effective to concentrate on systems that draw road-users' attention to the need for evacuation than to shorten the distance between exits. The distance finally set was based on the fire brigade's requirements on access routes.

Consignment Accidents - Fire and Explosion

According to the foregoing, a burning lorry loaded with 20 tonnes of furniture in cartons has been chosen as the design fire scenario.

The amount of energy released in connection with this has been calculated at 300,000 MJ. This fire has been estimated to last about 90 minutes.

The load-bearing main system in the road tunnels shall be calculated on the basis of a temperature cycle in accordance with the HC-curve with a 120 minute heating phase but without a cooling phase.

The fittings and fixtures in the road tunnels, including the lining, doors as well as the main bearing structural elements and the fire-sealing walls in the evacuation routes and sub-stations shall be designed according to the standard fire curve ISO 834.

Ensuring human safety is the prime consideration. As far as the protection of property is concerned, the requirements are limited so that it is only cave-ins, collapse and progressive landslides that shall be prevented in case of fire. Reparable damage to localized supporting structures is acceptable. Examples of such damage are cracking, permanent deformations, spalling concrete and individual load-bearing structural elements that have been totally destroyed.

Calculations that have been performed for an alternative solution without fireproofing have shown that there is no risk for collapse in the supporting structures as a direct result of a fire. However, due to the risk of spalling in connection with a longer fire, either fireproofing or reinforcement measures have been introduced for these concrete structures.

According to the risk analysis calculations, the design fire scenario can be expected less often than once every 150 years. Furthermore, fires larger than this can be expected less than once every thousand years. Despite this, it has been assessed that these incidents have been effectively limited by the restrictions taken (escort units and the sprinkler system).

Fires in flammable liquids that have leaked onto the roadway, will be extinguished quickly since the wastewater system has been designed to discharge 80 litres per second thereby limiting the area covered by the liquid to 250 m^2. The effect of such a fire can temporarily exceed the design fire effect. However, the released energy, which forms the basis for the design criteria for the structural elements, will probably be less than the design criteria according to the HC curve.

In practice, it shall be possible to completely restore the bearing capacity of the entire structure after the occurrence of a design fire.

The foregoing opinion has been based on the risk analysis that was performed. This shows that special measures for property protection in the case of fire are, generally speaking, not profitable, considering the expected frequency and extent of the damage.

As far as the false ceiling in the tunnels is concerned, a concrete construction has tentatively been decided upon with a partitioning capacity corresponding to EI 60.

The design scenario chosen consists of a vehicle loaded with 30 kilograms of dynamex (a brand of dynamite) that has exploded. Thirty kilograms of dynamex is the maximum consignment that may be transported without either a special permit or without being specially labelled.

According to the risk analysis calculations, such an accident can be expected less than once per 1000 years. Calculations also show that there is no risk for a collapse of the supporting structures or in a functional failure in the partitioning capacity in the evacuation routes. It has been estimated that an explosion in an illegal load (exceeding 30 kilograms) would occur less than once per 10,000 years.

Remaining Issues

Safety in the transport of dangerous goods in tunnels

There are five different alternatives for handling the transport of dangerous goods in tunnels:

1. Registration of vehicles entering and exiting the tunnels
2. Escorts
3. Sprinkler systems
4. Transport through a tunnel closed to other traffic
5. Prohibition

Escort activities and the installation of a sprinkler system are equivalent from a personal safety point of view. The alternative to these methods would be that dangerous goods would continue to be transported on the above-ground road network (instead of through underground tunnels) according to instructions from the authorities. This is not considered to be an alternative at the present time.