Safety in railway tunnels and selection of tunnel concept

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Abstract:
A number of serious tunnel accidents have put tunnel safety on the public agenda. Concerns have been directed towards the safety of both road and rail tunnels. The choice of tunnel concept for double tracked rail lines has been given much attention.
Two alternative tunnel concepts are discussed in a safety perspective in this paper:

1. *Single bored tunnel, i.e two parallel tracks in the same tube with escape ways to open air through the tunnel portals or through intervening cross cuts.*
2. *Parallel twin bored tunnels, i.e two parallel tubes with one track in each with intervening connections between the two tubes equipped with fire doors or smoke traps.*

The risk and safety arguments for various concepts are examined and pros and cons for each of the concepts are discussed.
An investigation of known tunnel and metro fires is used to assess how the choice of tunnel concept may have influenced the outcome of the accidents.

1. Introduction and scope

Several serious accidents in tunnels have recently years put safety in tunnels on the public agenda, both in Norway and in other countries. Concern has been directed towards both road and rail tunnels, and the scope is here limited to safety in rail tunnels.

The choice of tunnel concept for double tracked rail lines has been given much attention. Two alternative tunnel concepts are discussed in a safety perspective:

1. Single bored tunnel, i.e two parallel tracks in the same tube with escape ways to open air through the tunnel portals or through intervening cross cuts or specially designed escape ways.
2. Twin bored tunnels, i.e two parallel tubes with one track in each with intervening connections between the two tubes equipped with fire doors or smoke locks.

From a fire safety view of point the argument has been that twin bored tunnels are safer than single bored tunnels and that new tunnels should be built according to the twin bored concept. Twin bored tunnels with frequent intervening connections have some obvious safety advantages, but also some disadvantageous properties, which are not equally obvious. Assuming the intervening connections for each parallel tube in a twin bored concept are built as large as for one single bored tunnel for double tracked rail, two parallel tubes will be advantageous in any aspects, except economy. Such concepts would be extremely expensive and increase environmental impacts caused by depositing and are not discussed in this paper.

The actual approach is therefor to evaluate pros and cons for each of the two given concepts, where the main approach to the problem is to assess the following:

- Double track single bore tunnel: Large cross sectional area and long escape way

- Twin bore tunnels: Reduced cross sectional area and escape way

Evidently, the cost difference is important in choosing concept, given that the safety is acceptable in all alternatives. For additional safety measures beyond this, it is necessary to evaluate cost/benefit for the initiatives to ensure that scanty resources are uses in a reasonable way.

This presentation deals with following issues:
- Discussion of advantages and disadvantages for different concepts
- Relevant safety measurers in rail tunnels
- Today's status for a selection of countries with examples of different solutions
- Description of tunnel accidents and how the choice of tunnel concept may have influenced the outcome of these accidents

2. Advantages and disadvantages for different concepts

The tunnel concept depends on the extent of traffic, length and soil or rock conditions.

2.1 Single bored tunnels without meeting track or block stations

This is the traditional railway tunnel with one single track, normally without special technical installations for signal or traffic in the tunnel, except necessary technical installations required for operating the trains. During normal traffic there will be only one train in the tunnel and in general three will not be any traffic controlling signals in the tunnel preventing the train to drive out of the tunnel if it is inside the tunnel in the first place.

The traffic direction is deciding the ventilation direction in the tunnel, as long there is a train in motion in the tunnel. If a train, of any reason stops inside the tunnel, the air flow will quickly decrease because of the speed of the train and the ventilation direction may be turned, depending on the topography and temperature conditions inside and outside the tunnel. A fire may contribute to change the ventilation direction.

2.2 Single bored tunnels with meeting track and/or block posts

These tunnels are in principle the same as the tunnels described in 2.1, but with traffic controlling installations, like block posts and/or meeting track with signal installation making it possible to handle more trains in the tunnel simultaneously. Traffic controlling signal installations will be present in such tunnels, and this may cause trains to stop in the tunnel. There will be switches near the meeting track in the tunnel, and these may be an element of increased risks. In case of an accident, several trains will make the rescue work more complicated, but only one train will be present in each tunnel section (signal section).

On the high mountain section of Bergensbanen several advantages are achieved during winter operation by placing the meeting track in a tunnel. Normally one of the trains has to stop and wait for the other train when meeting in these tunnels. This is unfavourable if there is a (small) fire in the train that has to stop.

The ventilation direction in the tunnel may be unpredictable if there is possibility for several trains in different directions in the tunnel. When a train drives into the tunnel, the flow pattern may be changed rapidly.

2.3 Double track in single bored tunnel

Both tracks are located in the same tube. For tunnels blasted in rock this gives the lowest initial expenses. Many factors are contributing and among these are:

- Less work faces during construction
- Less total mass to remove
- Less rock surfaces to seal and secure.

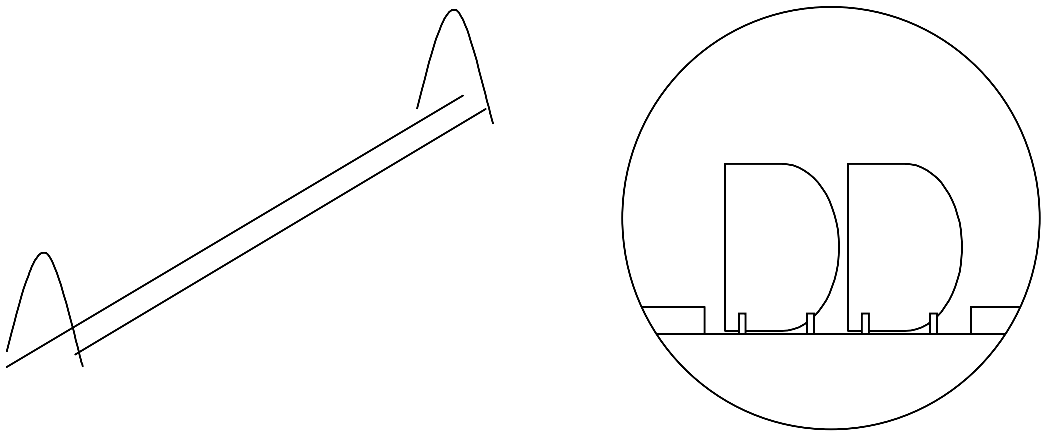


Figure 1: Sketch of double track in single bored tunnel concept

This is the traditionally tunnel concept for double tracked rail tunnels blasted in rock in most countries. In general the cross sectional area for common railways is big (80 – 115 m^2 for new tunnels) with big air volumes under the tunnel roof. The cross sectional area is normally substantial less for metro tunnels. This concept gives good opportunities for installations of connections between the two tracks. The tracks are normally equipped with one or more block stations to handle subsequent trains and in longer tunnels it is possible to build one or more connections between the tracks within the tunnel.

Normally there will be more than one train in the tunnel and if an immediate evacuation from a train in the tunnel is necessary, it is important to regard any possible traffic on the other tracks. The natural ventilation direction ion the tunnel is relatively unpredictable with several trains in different directions in the tunnel, but the tunnel has large extent of air volumes which normally will give good smoke stratification during the first phases nearby the fire.

In Norway, most of the metro tunnels, Romeriksporten, Lieråsen and the Oslo tunnel, and several other relatively short tunnels on double tracked lines are of this type. This concept is chosen for the tunnel on the section Sandvika –Asker on the new double track from Skøyen to Asker.

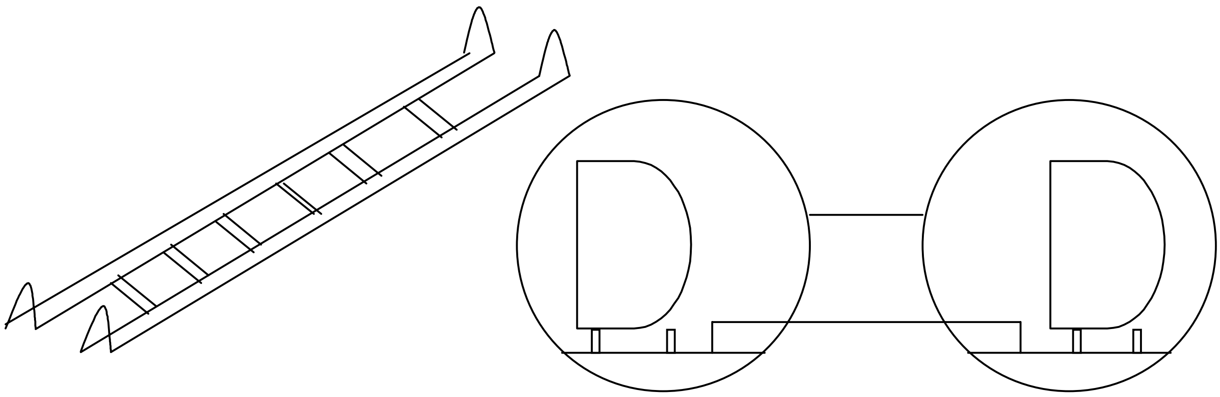
2.4 Twin bored tunnels

In this concept there are two parallel tubes, one for each track, with possibility for intervening connections and escape ways between the tunnel tubes. This tunnel concept is especially suitable for very long (15 –20 km) tunnels, without any possibility for cost effective escape ways to open air. In full profile bored, it may also be used in shorter tunnels because the total costs may be quite different, and there may be some problems during operation with double track profiles.

The tunnel concept may also be used in other tunnels were two tracks are required, but will normally not be a cost effective solution for tunnels which are made from traditional rock blasting techniques. The tracks will be equipped with block stations to handle subsequent trains. Often in longer tunnels one or more connections between the tracks may be necessary.

The interior wall between the tunnel bores near these must be broken. The ventilation direction in the tunnel tube will be predictable and are given by the traffic.

The cross sectional area in each bore is substantial less than in a single bored tunnel compared to a double track bore, and the smoke accumulation will occur much more rapid, especially in head height. This may be an element of safety importance. A tunnel concept with two single track bores is seldom used in railway tunnels in Norway, but is used to some extent abroad. The tunnels under Storebælt and Øresund and the new metro in København are of this type. The same concepts are used in tunnels on the new high-speed rail in the Netherlands from Amstedam to Antwerpen. The Hallansdås tunnel in Sweden is built according to this concept. Twin bores tunnels are also chosen in the extremely long tunnels in the Alps which are under construction or being planned. For more detailed information, see chapter 3. For road tunnels this is a common concept in Norway on distances with high level of traffic.



Figur 2: Sketch of twin bored tunnel

2.5 Double bored tunnel with service tunnel

For long tunnels under water or high mountain massifs with high level of traffic it may be difficult to ensure access to the tunnel. In such tunnels it may be relevant to evaluate a separate service tunnel through the whole distance or part of it for operation and maintenance activities and for evacuation and rescue purposes. The concept has not been evaluated for rail tunnels in Norway, but the concept is used for the tunnel under the English Channel.

A concept with service tunnel is often combined with separate traffic tunnels for each direction, but there are also examples were service tunnels are combined with a double tracked traffic tunnel. The subsea part of the Seikantunnel in Japan is of this type. A concept with service tunnel has obvious many advantages regarding safety and rescue and access for inspection, tests and maintenance of technical equipment, but such service tunnels also represent a considerable element of increased costs.

1. Experiences regarding selection of tunnel concept

3.1 Switzerland

Switzerland has today many and long rail tunnels. In addition, several rail tunnels on different types of rail distances are being projected and built. There are no fixed rules for selection of tunnel concept. According to Mr. Lorenz Riesen, Bundesamt für Verkehr, is the tunnel solution discussed in each project regarding selection of tunnel concept, depending on level of traffic, length and soil conditions (double track vs twin bored).

The new long tunnels in the Alps, Gotthard (57 km) and Lötschberg (35 km) are built as twin bored tunnels with frequent cross connections. In the basis tunnel of Gotthard cross connections between the parallel bores are planned for every 375 m.

Single bore tunnel with double track is the primary selected tunnel concept for other long tunnels with high level of traffic. Among others:

- Grauholztunnelen (6301 m), Bern – Olten
- Tunnel Murgenthal (4297 m), Bern – Olten
- Önzberg tunnel (2365 m), Matstetten - Rothrist

Also for the Zimmerberg phase 1 from Zürich to Thalwil (approx. 10 km) a full profile bored double track tunnel has been chosen. The diameter is approx. 12 m. Final solutions for the other tunnels on the approach lines to the basis tunnel of Gotthard are not yet decided because the construction work is in the near future. Actual tunnels are Mt Ceneri (15 km) and Zimmerberg phase 2 between Zug and Thalwil (10 km). During the pre-project double track tunnels were discussed, but especially for Mt Ceneri there is reason to believe that a twin bored tunnels concept may be chosen.

During the last 10-20 years the standard cross sectional area for a double track single bored rail tunnel in Switzerland increased from 70 m^2 to 115 m^2. The reason for this increase is first of all a hope to open for larger cargo profile and to allow higher speed limits on new section of the railway.

Autumn 1999 the Rhätische Bahn opened the 19,1 km long narrow-gauge (1000 mm) Vereina tunnel between Selfranga and Sagliains on the new line from Klosters to the Lower Engadin Valley. The tunnel is mainly single track, but with 2 km double track sections at each end and in a meeting track in the middle of the tunnel. In addition to other trains a car shuttle train is using the tunnel every 30 minute in each direction. From available information it seems that there is no escape or rescue access to the tunnel, but the operator has a rescue train available. The northern part of the tunnel is drilled, and the southern part is made by conventional rock blasting.

The federal Swiss Government (Bundesamt für Verkehr) has recently carried out a study of the safety in the Swiss rail tunnels, /1/. This study included 689 tunnels that were in operation per January 1st, 2000. The result was published last year (2001). Following elements from the results can be mentioned:

- In general rail traffic in tunnels is safer than rail traffic in open air, especially because of the absence of level crossings and non-authorised pedestrian traffic in the tunnel.
- 579 of the tunnels represent no significant safety aspect and do not require special or additional safety initiatives. Most of these tunnels are less than 300 m long.
- For 84 of these tunnels it is required that the operator carries out a cost/benefit evaluation of the safety initiatives. The actual tunnels in this case are between 300 and 300 m long.
- For 26 tunnels, most of them more than 3000 m long it have been suggested to evaluate the need for improved safety initiatives. This should also be done in relatively new tunnels, like Vereina and Grauholz. Examples of initiatives are improvement of walkways and rescue ways, signs, fire extinguishing systems and communication systems.
- The quality of all rolling equipment is an important safety factor and will influence on the safety in rail tunnels.

The report from the study points out that the most effective way to improve the possibility for easy escape is to shorten the distance between the escape ways, in addition to ensure good conditions for communication.

3.2 Great Britain (Channel Tunnel Rail Link)

A new railway is built from London (St Pancras) to the Channel Tunnel. For tunnels near the centre, i. e. the tunnels under the eastern parts of London and the river Thames, the tunnel concept is based on drilled twin bored tunnels (D=7,15 m). The intervening crosscuts are planned for every 750 meters. For the shorter North Downs tunnel of 2 miles (3,2 km) a concept with double track and a diameter of 12,8 m is chosen.

Risk assessments are carried out for the London tunnel /2/. After a balanced evaluation of different factors, among other the soil conditions and availability for escape ways, a concept of twin bored tunnel with intervening crosscuts between the bores was selected. For the twin bored solution, the risk assessment showed no safety benefit for more frequent intervening crosscuts than for every 100 m. Anyway, to correspond with other installations in the tunnel it is decided to have intervening crosscuts for every 750 m.

3.3 France

Despite of great emphasis on construction of new high-speed rails in France, few conventional railway tunnels are built, except the Channel Tunnel. Constructing the new high-speed rails with more gradients than most other countries has made it possible to avoid use of tunnels in the relatively flat landscape in northern France.

In the new LGV (Ligne a Grand Vitesse) Mediterrannée (Valence – Marsille) that recently was opened there are 12,5 km tunnels in total. The longest, "Tunnel de Marseille" is 7,8 km. This and other tunnels on LGV Mideterranée are built as single bore double track tunnels.

3.4 Austria

Most of the rail tunnels in Austria are built as double track tunnels, and this has been the main tunnel concept for tunnels under construction. In a lecture from 1995, ØBB`s concept for safety in rail tunnels was presented /3/.

According to this presentation, twin bored tunnels with frequent intervening crosscuts are only relevant in extremely long tunnels, > 20 km. For medium long tunnels a more specific evaluation in each case is recommended. Intervening crosscuts with even spacing to open air are recommended for shallow tunnels.

Among the planned long tunnels we may mention:

- Brenner basis tunnel (52 km) on the line from Innsbruck to Verona
- New Semmering (23 km) on the line from Vienna to Steiermark.

We do not know what concept have been used for the planning of these tunnels.

There has been an increased focus on tunnel safety in Austria after the accident with the cable car tunnel to Kitzsteinhorn in November 2000.

3.5 Germany

On the new Neubaustrecken for high-speed train in Germany which was built in the in the eighties, there are several long tunnels as long as 10 km. The tunnels were built as double track tunnels. On this rail there are both gods train and high-speed trains. The maximum speed limit in the tunnel is 250 km/t and 280 km/t outside the tunnel. To avoid risk of displacement of containers and other load when two trains meet in the tunnel, some restrictions on the traffic have been introduced. Today's status on this is not known.

The tunnels on the new "Neubaustrecke"on the section Køln-Frankfurt and Nürnberg-Ingolstadt, which in general are shorter, are mainly built as double track tunnels with larger cross sectional area. The centre track distance is 4,70 m. In addition, the tunnels will be equipped with escape and rescue access to open air for every kilometre where the overburden is less than 60 m. The escape and rescue accesses are constructed either as an inclined tunnel access or as a vertical shaft with stairs.

3.6 Italy

In Italy there are many long tunnels, among others under the Apennines as long as 18,5 km (between Bologna and Firenze), and the southern part of the Simplon tunnel which in total is even longer. All tunnels are double tracked, except the Simplon tunnel. This is the concept that is preferred for new tunnels, including the Vaglia tunnel being constructed on the high-speed line between Bologna and Firenze. In Italy there are several tunnels under construction, , among others on the line between Verona and Brenner. Recently the new 7,3 km long Fleres tunnel 'was opened. All these tunnels are double tracked tunnels.

Between France and Italy a new basetunnel (52 km) between Lyon and Torino are being projected. This tunnel is planned as a twin bored tunnels, but it is possible that only one bore is built in the first step.

3.7 Denmark

Historically, Denmark does not have many rail tunnels. Under Copenhagen centre, between Vesterport and Østerport, there is a local rail track and main rail track in a buried culvert which is 1,5 km long. Nørreport station is located in the middle of this tunnel.

For the crossing of Storebælt and Øresund, and in connection with the construction of a new metro in Copenhagen, several new tunnels have been built in Denmark during the last years. These tunnels are either full profile bored or submerged underwater tunnels and all are built as twin bored tunnels. This concept is not chosen just because of safety reasons because two parallel bores for the actual tunnel also had other benefits. The tunnel under Tårnby between Hovedbanegården and Kastrup on the onshore part of Øresund link on the Danish side is built as a double track "cut & cover" tunnel, but this tunnel is not particular long.

The tunnel in the new Metro in Copenhagen as built as a twin bored tunnel and has relatively small cross sectional of 19 m^2 (D=4,9 m). The tunnels are equipped with 0,7 m wide walkway on one side of the train through the hole tunnel. There is no separate intervening crosscut between the tunnels, but stations or escape ways for every 600 m.

3.8 Sweden

Traditionally there are few long railway tunnels in Sweden, but new railway projects involve several tunnels. Hallandsåstunnelen (7,6 km) are built as twin bored tunnels. The construction work is now to resume again after having been stopped for several years due to ground water leakage. The same concept is planned in the City tunnel under Malmø centre. Recently there has been built double track tunnels in a single bore on Grødingebanen and single tracked tunnels of considerable length are being planned on the new Botnia line.

Regulation of tunnel safety matters in Sweden belongs to the Building Authority and rail tunnels are dealt with as an ordinary building. This leads to requirements for frequent escape ways and the maximum distance to an escape ways should be no longer than 150-200 m. This requirement is considered as extremely strict, almost impossible to comply with, and is not greeted with pleasure by the Swedish Rail Authority (Banverket).

3.9 Summery of experiences in various countries

A summery of this chapter is as follows:

- Different concepts may be used for new tunnels to ensure desired safety level
- Double track tunnels is far the most used concept in short and medium long tunnels, sometimes in addition to requirements for maximum distance between escape ways to open air.
- Twin bored tunnels (also with service tunnels) are mainly used in extremely long tunnels where it is difficult top make escape ways to open air with reasonable distances because of topographic conditions. Soil conditions and construction method may also benefit twin bored tunnels under certain conditions, especially for full profile bored tunnels in soft soil or submerged underwater tunnels.

4. UIC-recommendations

UIC (Union International de Chemin de Fer) is an international rail organisation for promoting standardisation within rail traffic and sets specifications for rolling stock for international traffic. In 2001 UIC issued a draft version of the document "Safety in Railway Tunnels – Recommendations for Safety Measures". /12/.

Various safety measures were evaluated and some recommendations made. Some of the safety measures evaluated are listed below according to their relevant category:

Infrastructure measures:

- Accident preventive measures:
  - Train detection and traffic control equipment
  - Communication
  - Inspection and maintenance of infrastructure
- Consequence reducing measures:
  - Twin tube/bored tunnels
  - Increased cross sectional area
  - Fire safety measures
  - Ventilation
- Measures to improve escape and self rescue:
  - Prepared escape ways
  - Emergency lighting
  - Emergency telephones
  - Separate service and escape tunnels
  - Emergency exits
  - Internal connections (double tube concepts)
- Measures to facilitate external rescue work:
  - Tunnel access conditions
  - Earthing/grounding equipment
  - Water and electricity supply
  - Communication equipment
  - Rescue areas and rescue equipment

Rolling stock measures:

- Accident preventive measures:
  - Fire safety design

- Incident detection systems
- Consequence reducing measures:
  - Emergency brake neutralisation
  - Onboard fire extinguishing equipment
  - Ventilation control
  - Derailment detectors
- Facilitation of escape:
  - Escape equipment and design of coaches
  - Door control and emergency opening devices

Operational measures:

- Accident preventive measures:
  - Regulation for operation (passenger/freight train)
  - Regulations/restrictions for transportation of hazardous goods
- Consequence reducing measures:
  - Swift traffic control measures upon indication of incidents (e.g. stop of following or encountering trains outside tunnel)
- Facilitation of escape:
  - Emergency information for passengers (preparation for emergencies)
  - Training of train crew
- Facilitation of rescue:
  - Emergency and rescue plans
  - Exercises with rescue services
  - Information on transport of hazardous materials

5. Experiences from accidents in rail and metro tunnels

A study of known tunnel and metro accidents may be a contribution to evaluate the conditions connected to the accident and may also gives an indication on which initiatives that considerably could have reduced the consequences. Data from the accident is collected from references /4/-/10/.

During the period from 1940 and up to today, 26 serious accidents in rail and metro tunnels are identified from different references. A list of these accidents with more detailed description and data of each accident are given in tables 1 & 2. This overview is not complete and there are no uniform criteria for selection of these accidents, except that they occurred in tunnels or in subsea spaces of tube systems. It is reasonable to believe that the most serious accidents during this period are included. The author has not detailed knowledge about the actual tube system and tunnel concept for several of the oldest accidents. In table 3 there a list of fires in Metros during the period 1970-87, /11/.

Totally approx. 1400 people have been killed in these identified accidents. From the information about each accident, it seems like 90% of them were present onboard the train or within the station area. Just a few of the total were killed in the tunnel, outside the train. Even in fire accident most of the people were killed inside the train. Therefore it is equally important to ensure the possibility to evacuate the train and to ensure safe escape from the tunnel. The following chapters are a short summary of the accidents:

5.1 Fires in trains etc.

The most serious accident occurred in the Armi tunnel, Italy, in 1944 were 400-500 people were killed because of carbon monoxide poisoning caused by the smoke from 2 steam railway engines which did not drive through the tunnel. Finally, the train had to reverse but by this time, most of the passengers had died. This incident is not a traditionally fire accident and is not likely to be relevant for tunnels today, but the combustion and smoke formation in the two steam engines may be comparable with incidents with completely flash-over of a passenger wagon in today's train.

Among other serious accidents, it is worth to mention the fire in the Metro of Baku in 1995 (289 people killed) and the fire on the cableway to Kitzsteinhorn, Austria, in 2000 (155 people killed). Both tunnels had relatively small cross sectional area (Kitzsteinhorn 10 m^2 and Baku Metro 28 m^2). This seems to be a considerable contribution of the consequence of the accident because most of the people that died did not manage to get out of the train. Partly, this was caused by problems with opening the doors, but fast development of the fire and smoke accumulation also made a considerable contribution. Larger cross sectional area may have given better time for evacuation before the heat and smoke became unbearable. Intervening cross cuts or more frequent escape ways would not reduce the consequence in general, but may have save a few persons.

Regarding the accident in the Baku Metro it should be mentioned that most of the people that were killed as a result from mechanical damages (i.e. they were trampled because of panic onboard the train).

Another serious accident occurred in 1972 in the double tracked Hokuriku tunnel (13,9 km) when a fire started in a restaurant wagon ion a night train. The train stopped halfway in the tunnel to disconnect the actual wagon, but was not able to drive further from this place. The train carried more than 700 passengers and 30 of these were killed. The tunnel was not sufficient equipped regarding ventilation and lightning and this were heavily criticised after this accident.

There are also examples of serious train fires in trains that have stopped inside a tunnel and were the passengers by themselves have rescued themselves out of the tunnel both in double tracked and twin bored tunnels.

The accident in San Francisco in 1979 shows that twin bored tunnels with frequent intervening cross cuts is not a warranty for safety in a case of fire and do not necessarily lead to sufficient working conditions for the rescue team. This actual tunnel had a service tunnel in addition to two single tracked tubes, but still one person from the rescue team was killed and several were injured in this fire.

The tunnel fires with the highest number of fatalities have all occurred in tunnels with either one single tube (single or double track) and/or a narrow profile.

A total of 18 fires are included (including one collision + fire, and the CO-toxification in the Armi tunnel).

For 11 of the 18 fires a technical failure or use of the emergency brake forced the train to stop in the tunnel. In two of the accidents the train stopped in the tunnel because the emergency brake had been pulled. These two stops in tunnel could potentially have been avoided if the emergency brake could have been overridden by the driver, or if passengers were instructed not to use emergency brakes in tunnels.

For the remaining 9 fires where the train was forced to stop in the tunnel (i.e. un-wanted stop) the train must have stopped quite arbitrarily along the tunnel. Hence, to promote safe evacuation in these cases there must be possible to carry out rapid evacuation out of the train at all locations in the tunnel, and the distance between to intersections to a second tube must be quite short. Except for one fire (Hokuriku, 1972) all the fires with multiple fatalities occurred when a train was forced to stop in a tunnel.

For the 7 fires where there has been a deliberate stop in the tunnel, the escape into a parallel tube has taken place twice (Eurotunnel 1996, BART 1979). For the other accidents the tunnel concept has not allowed such actions.

5.2 Other accidents

In addition to fire incidents there have also been about the same number of other incidents in tunnels. Most of these incidents can be placed in one or more of the following accident categories:

- Front-tail collision between two trains, partly with a following fire (Batignolles 1921, Torre 1944, Mexico City 1975)
- Structural collapse of tunnels (Vierzy 1972)
- Collision with end of line buffer stops and/or runaway trains (Moorgate 1975, Gare de Lyon 1988)
- Fires within the station area away from the trains (King's Cross)
- Several passengers crowding together (Minsk 1999)

Most of these incidents are to a very small extent influenced by the selection of tunnel concept. On the other hand the rescue work may have been influenced by the tunnels concept. It is not obvious what concept will give the best and most effective conditions for rescue in different accident scenarios that may occur.

6. References

/1/: Bundesamt für Verkehr;
Bericht zur Sicherheit in den schweizerischen Eisenbahntunnels, Bern, 2001.

/2/: Scott, Paul & Richard Stokes;
The design of a high speed rail tunnel in an urban environment.
3rd International Conference on Safety in Road and Rail Tunnels, Nice, France, 9th – 11th March. 1998, pp 291-99.

/3/: Wehr, Hans, Charles Fermaud & Hans Bohnenblust:
Risk analysis and safety concept for new long railway tunnels in Austria.
2nd International Conference on Safety in Road and Rail Tunnels, Granada, Spain, 3rd – 6th April 1995, pp 3-10.

/4/: Semmens, Peter,
Railway disasters of the World

/5/: Kichenside, Geoffrey
Great Train Disasters – The Worlds worst railway accidents

/6/: Hall, Stanley
Hidden Dangers – Railway Safety in the Era of Privatisation

/7/: First International Conference on Safety in Road and Rail Tunnels, Basel, Switzerland, 23rd – 25th November 1992

/8/: Second International Conference on Safety in Road and Rail Tunnels, Granada, Spain, 3rd – 6th April 1995.

/9/: Third International Conference on Safety in Road and Rail Tunnels, Nice, France, 9th – 11th March 1998.

/10/: Department of Transport; Investigation into the King's Cross Underground Fire, HMSO 1988.

/11/: Railway Gazette International, January 1989.

/12/: UIC (International Union of Railways). Safety in Railway Tunnels; Recommendations for Safety Measures. October 2001. Ernst Basler & Partners.