# COMPARISON OF FIRE SAFETY PROBLEMS FOR THE VARIOUS TRANSPORT MODES IN TUNNELS

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ABSTRACT

Several recent disaster fires in tunnel showed that all transport modes can be concerned by such dramatic events, either road, or rail, or metro. But the safety problems are quite different, because each of these modes have very distinct and specific features regarding both the tunnel infrastructure and the nature of vehicles or rolling stock, and the operating rules. The accidentology level, the consequences of a vehicle fire in the tunnel, and the means to manage the fire response are not similar. The following paper tends – without the care of any exhaustiveness – to set up a first comparison of the problems laid by the fire safety in tunnel for these three modes of transport.

## 1. INTRODUCTION

With very few exceptions a tunnel is not a dangerous risk of fire in itself, because it is nearly always of mineral constitution – rock or concrete -; the sidewalls sometimes constructed there are selected as non-inflammable or hardly inflammable, the installed facilities do not present a heavy heat release rate, and the selected electric cables do not propagate fire.
The actual danger comes from outside the tunnel, and from any mobile elements penetrating into it.
Underground structures are built to enable all terrestrial transport modes to pass through:

- on a track: pedestrians or cyclists, even skiers in mountainous areas
- on a road: motor cycles, car, buses, vans, small or large lorries
- on rail: passenger and freight trains, metros, tramways, funiculars
- on water channel: commercial or pleasure boats

The European Thematic Network on "Fire In Tunnels – FIT" decided to examine the three transport modes used in Europe which use most largely tunnels: road vehicles, trains, and metros. The Web site www.etnfit.net gives under the title "Regulations" the "compilation of guidelines for fire safe design" defined by Workpackage No.3 relative on these three modes and, in the proceedings of this Prague Congress, the contribution of D. Lacroix on "Synthesis and current harmonisation processes", along with the contributions of N.P. Hoj, P. Zuber and D. Gabay, respectively on "Compared fire safety features for road tunnels", " …rail tunnels", and " …metro tunnels".
The paper developed below proposes a comparative synthesis of fire safety problems encountered in tunnels for road rail and metro. It does not deal either with the fire behaviour aspects of structures and equipment or the drainage aspects.

The four topics dealt with successively are:
- general data on tunnels
- place of tunnels in safety of the general operation for the three transport modes
- traffic nature and potential fires
- action towards fires

## 2. GENERAL DATA ON TUNNELS

### *2.1 Length of tunnels*

In cumulated length, Europe belongs several thousands kilometres of road, metro and railway tunnels, the latter being the major part of the whole.
The information below do not concern the case of short tunnels smaller than 200 m, which have the advantage – from a safety point of view – of a short distance to go out of the structure.
For road, almost all heavily trafficked tunnels, i.e. of urban type, do not exceed a few kilometres, and present a daily traffic that may exceed 100,000 veh/day.. Inversely, in inter-urban (country) tunnels, several tunnels exceed ten kilometres (Saint-Gothard 16.9 km; Arlberg 14.0 km; Fréjus 12.9 km; Mont-Blanc 11.6 km; Gran Sasso 10.2 km), but with a traffic amount ten or twenty times lower than the first ones. Norway has long tunnels, the longest is the Laerdal tunnel, 24.5 km long, but they show a very modest traffic.
For rail, most varying lengths are encountered, the longest are once again for inter-urban (country) tunnels. The longest operated European tunnel under operation is the Channel tunnel, operated by Eurotunnel and 50.5 km long. But somewhat longer trans-alpine structures are under project or under construction, e.g. the Mont-Ambin tunnel of Lyon Turin Ferroviaire (54 km), Brenner (55 km), or the Gotthard of Alptransit (57 km).
For metro, we can consider, from the fire safety viewpoint, that an underground line is not a unique tunnel, which could then exceed easily ten kilometres, but is made of successive short tunnels separated by stations. These tunnels generally are 500-600 m long.

### *2.2 Number of tubes*

Mono-tube or bi-tube configurations do exist for the three transport modes:
- for road, heavy traffic amounts generally concern bi-tube tunnels; inversely the smaller traffic densities of the longest country tunnels use mono-tube tunnels;
- for rail, the mono-tube is the most largely used, but recent long and heavily trafficked tunnels are bi-tube;
- for metro, the mono-tube is a majority, but cities like London have many bi-tubes

### *2.3 Cross-section*

As trains and metros are driven on guided tracks, the lateral spaces with respect to the trafficked section are optimised and generally smaller than for road; the resulting tunnel cross sections are often less wide and inserted recesses are often planned to protect the personnel.
Elevated and well limited walkways are very often planned for road, while this rule generally does not exist for rail or metro.
The cross-section generally is larger for road, except when ventilation ducts are installed at ceiling (ventilation of transverse type).

## 3. PLACE OF TUNNELS IN SAFETY OF THE GENERAL OPERATION FOR THE THREE TRANSPORT MODES

### *3.1 Road transport*

The operation of road traffic underground profits by an large number of safety arrangements aimed at correcting – with respect to open roads – the inconveniences of traffic in a restricted space. Although the probability of accidents recorded underground is smaller than in open, two essential considerations led to introduce reinforced safety measures in tunnels:

- the road transport is by far the less safe of the three transport modes
- the consequences of an accident, especially a fire in a tunnel, can be much more severe than in open, and it must be endeavoured to limit them.

Moreover, even if a few long road tunnels were built early in the twentieth century, the fire safety aspects became critical only during the latest decades, as a result of the strongly increasing traffic and stronger transportation capacities of lorries.
Therefore most European countries now have minimal safety regulations, sometimes with very detailed specifications like in France.

### *3.2 Rail transport*

The railway operation in tunnels benefits from a longer experience than the road transport mode and shows the better safety level for transportation. If we dismiss the historical period where the steam traction (at a smaller degree the diesel traction nowadays) could lead to intoxication problems, passing through tunnel was not considered as a worsening risk factor, but rather like a sort of reducing factor due to cancellation of traffic hazards existing in open. For this reason, a large part of safety items in tunnel is covered generally by the rather strict rules of a railway network operation, and the safety arrangements specific to tunnels are less numerous than for road. The recent disaster fires in tunnels induced to re-examine this confident approach.

### *3.3 Metro transport*

Here also operation is based on a long experience, about one century for some cities. Inversely to road or rail, these networks are almost fully underground and the safety arrangements are especially adapted to this environment. As for rail, this mode of transport is very safe.
The safety rules are partly common with those of rail, but they are always complemented by standards regarding the design of the rolling stock and stations, especially concerning the fire risk; these standards increase the safety level in tunnel.
Resulting from the development of metros – first in large cities – a number of rules sometimes depend more from the feedback on experience and good practices than from national regulations.

## 4. TRAFFIC NATURE AND POTENTIAL FIRES

### *4.1 Specific features of traffic and its management*

While the road transportation occurs with independent vehicles, the railway traffic always uses convoys for a length possibly from about hundred metres (metro) to about 800 m and more (Eurotunnel shuttle, long goods trains).
For road, traffic is managed on the basis of signing facilities conventionally used on open roads, complemented with some specific devices or signs, permanently being improved and standardized on a European level. Except in case of toll station at the tunnel portal, the access of vehicles cannot be controlled individually. The equipment of road tunnels for traffic management is most varying according to the importance of the tunnel and its connection with a management centre with a permanent staff or not. The same is valid for the other safety equipment to be managed. The trend is to transfer information from tunnels to the nearest permanent traffic control centre.
For rail and metro, signing is always remote-controlled from a control centre and trains are followed individually under actual time conditions.
Speeds in tunnel for road, rail or metro generally are of about the same order of magnitude, except for high speed trains. These are characterized, from the safety viewpoint, by a short stay underground and a long stopping distance: this is favourable regarding safety since the probability to stop within the tunnel is low.

### *4.2 Characteristic features of vehicle driving*

The road transport mode requires by definition that the driver keeps permanently and voluntarily the vehicle on its lane.
The heel of Achilles of safety in road tunnels is the adequate behaviour of the great number of drivers passing through, a mixture of occasional and regular or professional drivers. According to statistics, however, the accident rate in tunnel is lower than that on open roads.
Railway and metro are rail-guided transportation means, for which the risk of route deviation is highly improbable and reduced to that of derailment or wrong shunting. Drivers are all professionals, permanently trained, with the possibility to make them observe safety guidelines specific to tunnel crossing.

### *4.3 Transported people*

For road, the vehicles usually transport only one or several people, but there is always a part of the public transportation (mini-buses and buses) which can concentrate from 8 to about 60 people and more on the same vehicle.
While a goods train hosts only one or two people, a passenger train transports several hundred people, even more thousand people (from 100 to 250 per coach).
For metro, as for trains, the metro trains can transport several hundreds people (100 to 150 per coach).

### *4.4 Potential fires*

Data on fire in tunnels are provided for the three transport modes on the mentioned FIT web site.

*For road:*
The road vehicles are all driven by internal combustion engines and include gasoline or gas-oil tanks (several tens litres for passenger cars and up to more than 1000 litres for some international transportation lorries). At present the liquid gas driven vehicles are in a minority. Every vehicle, of a more or less sophisticated technology, integrates in itself all ingredients that may lead to a fire: hot parts of the engine auxiliaries, brakes, fuel reserve, circulation and injection of fuel, numerous electrical circuits, more and more important quantities of plastic material and rubber… Concerning the buses, however, standards have been set up on the fire behaviour of materials used for the inside equipment (disaster fire of a bus in open in Beaune, France).
It should be noticed that the manufacturers do not integrate at all the objective of a reduction of fire risk in tunnel in the design of vehicles, the flammability of which is high.
Tunnels are sometimes reserved for only one category of vehicles, like passenger cars in reduced size tunnels, but most tunnels are passed through by a composite traffic of passenger cars and lorries. Except for lorries transporting dangerous goods, for which the access to the tunnels is strictly controlled (prohibited or authorized, but often under certain conditions), the access of vehicles is free. Concerning the lorries, this free access opens to a large variety of caloric potential of the loading, from non-inflammable or lowly inflammable (minerals, metals, plants…) up to highly inflammable (wood, plastic materials, grease…). Such loading – which can represent several tens of tons – is unknown from the operator at the fire time.
The heat release rate of a burning vehicle may be from 2 to 200 MW.
While the fire source may develop as well in a passenger car and in a lorry, the inflammation of a lorry obviously is the major risk in a tunnel, and can lead to a disaster.

*For train:*
As a general rule the traction technology is located at the end of the convoy, using electric and sometimes diesel motor coach. The fire risk is concentrated rather on these machines, with for diesel a risk component related to the presence of gas-oil, but a fire can start on wagons (hot boxes…).
As for road, some tunnels can be reserved to only one type of transportation, for instance passengers in urban undergrounds or very high speed country undergrounds, but the composite tunnels – passengers and goods – are the most numerous, they often are the most worrying considering fire safety. Operating measures can allow the passage of only one train in the tunnel at the same time (e.g. dangerous goods), but this has an impact on the line capacity.
The design of modern passenger cars with respect to the fire behaviour of the materials meets certain standards; these are sometimes still stricter in some countries when the trains are aimed to be operated underground, and therefore are operated somewhat like a metro.
Regarding the goods trains, like for road, there is an infinite range of possible loadings, also with regulations for the dangerous goods. The caloric potential loaded on each coach is close to that of lorries, knowing that this can be lorries themselves or passenger cars transported by shuttles. In this latter case the risk of fire to lorries is not so high as for road, because they are no more running and their condition can be checked before the train departure (fuel loss, hot points).

The heat release rate of a train fire may be from 20 MW (passenger trains) to about 200 MW (freight trains).
With respect to road the immediate proximity of successive wagons strengthens the problems of fire transmission between the units.
The load transported by a train is ten to over fifty times higher than that of a lorry.

*For metro:*
The trains are driven exclusively by electric traction, and – inversely to the road vehicles – built in view of operation within tunnels. The fire risk is minimised on the recent equipment especially thanks to the regulations regarding the fire behaviour of materials.
The heat release rate of a metro fire may be from 7 to about 20 MW.

## 5. ACTION TOWARDS FIRES

### *5.1 Vehicle on-board means for fire detection and fighting*

No strictly speaking smoke or fire detector is available on road vehicles, only sensors providing information on the operating conditions of the vehicle.
For rail, according to the age and nature of trains and metros, alarms can be planned for technical anomalies such as axle heating, derailment or fire detection in the engine coach. The tourist and HGV shuttles of the Channel tunnel are fitted with fire detectors in every wagon.
In the passenger coaches or metros, a starting fire can be reported to the driver, like any other danger, as soon as a passenger activates the alarm signal handle. But this signal means a severe safety problem in tunnel, because it causes braking and emergency stopping of the train.The control of air conditioning can be also a safety problem.
The extinction means planned on board generally are limited to portable extinguishers, planed systematically for rail and more indefinitely for road. Fixed on-board extinction systems – or rather mitigation systems – already exist on some locos, as well as in certain types of trains like the Eurotunnel tourist shuttles (halons) and soon HGV trains (water spray), also in the Madrid metro coaches, but such cases are exceptional.

### *5.2 Fixed means for fire detection*

In road tunnels various equipment can be used to alarm the operator: camera surveying, specific fire detectors in some tunnels (heat or smoke), pollution sensors, safety door opening alarm, etc.
In railway tunnels there generally is no detection system in the interior zone. The Channel tunnel is an exception.
In metro tunnels, detectors are available in stations, technical rooms or commercial premises.

### *5.3 Exchange of information with the users*

For road, to allow a distressed user to exchange information with the surveying operator, he must have an access by foot to the phones distributed all along the tunnel or within protected recesses. As a general rule channels of cellular phones are not re-transmitted inside tunnels.
From the control centre, the operator has no possibility to communicate with the driving users. In tunnels with the best equipment he only can send visual information via varying message signs or information audible in the vehicles on public radio channels.

Sometimes – this is less frequent or less efficient due to the reverberant sound – loudspeakers installed within the tunnel can be used.
For rail and metro, a ground-train radio-connection between the operator in the control centre and the driver is possible under normal conditions.
In the passenger trains and metros, coaches are wired for sound, thus allowing the train crew to broadcast messages audible to all the passengers. In the metro stations or underground railway stations, a loudspeaker relay allows the head of station to inform the people evacuated from the train about the adequate behaviour.
Fixed emergency phones for the users are available on the platform of metro stations and service phones are generally planned in the metro and railway tunnels.

### *5.4 Ventilation and smoke control in case of fire*

The range of ventilation modes is quite larger for road than for rail or metro.

***Road tunnels:***
Attention has been given for a long time to the sanitary ventilation of road tunnels, firstly due to the problems of dilution of high pollutant quantities emitted by the vehicles. The importance of smoke control has been recognized only during the latest twenty or thirty years.
Any road tunnel of significant length is equipped with an artificial ventilation. This may be:

- either of longitudinal type, the most simple and economical system, allowing to push smoke along the tunnel in the desired direction in case of fire;
- or of transverse type, a more expensive system, however allowing to extract smoke at the ceiling at any point of the tunnel to prevent longitudinal extension along the whole tunnel section.

*Railway tunnels:*
A mechanical ventilation there is rare because the electric traction is the most frequently used nowadays, the piston effect of trains is high, and the intermediate ventilation shafts allow proper sanitary conditions in most tunnels.
A few tunnels only are equipped with a longitudinal ventilation, principally to control smoke in case of fire; the transverse system is never used.

*Metro:*
Many lines are fitted with a ventilation for comfort and fire smoke control. All facilities are planned on the basis of the longitudinal scavenging of tubes, with various blowing/extraction models in the stations or by shaft in the central part of tubes.

### *5.5 Fixed means for fire fighting*

Portable extinguishers and hydrants - sometimes with water-hose nozzles – are generally distributed at regular interval along the road tunnels.
Metros are equipped in a similar way in each station.
This equipment is scarcely available in the interior zone of the railway tunnels.
The fixed water spraying systems in tunnel are not developed in Europe, except one or two cases, but they are under study.

### *5.6 Escape of users*

Metros and some urban road tunnels (cut-and-covers) are located at shallow depth, thus facilitating the creation of staircases to the ground surface.
In mono-tube: for railway, there is generally no other exit or access than the tunnel itself; for road, and according to the countries, there are solutions of shelters or ways independent from the traffic space and accessible to the pedestrians (parallel gallery, ventilation duct or direct communication to the surface). For metro, the stations ensure the pedestrian communication to outside via staircases or escalators; this can be the case for underground railway stations too.
In bi-tube, inter-tube communication generally exist both for road and rail, but the space is more restricted for road, about 200-400 m instead of 600-800 m and more.
The conditions to evacuate by foot the passengers from a train or a metro in the middle of the track within the tunnel cross section are more demanding (if not impossible) than for road vehicles, due to:

- the great number of people to be evacuated, which amplifies the phenomena of panic and obstruction of emergency exits
- the absence of platform and the height of the coach floor about one metre above the track
- of the often restricted passage width between the train coaches and the tunnel sidewall, and due to the difficult walking on the ballast when this is possible, for instance in a two-way mono-tube.

Moreover the trains have communicating doors between the coaches, but this escape way through the train lays a problem of quick saturation by the evacuated crowd and of a phenomenon of panic.
The logic of the emergency escape from the metro lays on the necessity for the driver to reach a station platform and from the train on the possibility ro reach the open. Especially for railway there is a risk to destroy the power supply of the locos (catenary).
The safety lighting within the tunnel and emergency exits is one of the major safety measures for all three transport modes. Under normal operating conditions, the road tunnels profit by a high pavement illuminance level required for traffic safety. For their part, metros profit by the good lighting of platforms and accesses.
The presence of cameras in major road tunnels and in metro stations allows a best assessment of the escape conditions of people in the non-smoky areas; this is not the case for the interior zone of railway tunnels.

### *5.7 Intervention of rescue services*

Concerning the intervention logistics of rescue services, the traditional vehicles can always use the road tunnel lanes when free, while the presence of rails and ballast in a railway tunnel means complicated manoeuvres. Emergency vehicles on rail or composite rail/road are not used currently. Examples of platforms that road vehicles can access to in railway tunnels do not seem to be available.
The intervention time of firemen in tunnel is optimised for metro (possibility of 5-10 min only) thanks to the urban environmental conditions and since they can access from the station. The intervention time for road can also be short if relevant staffs are available at the portals, but it can reach, like for rail, about half an hour to one hour in the other cases, thus representing a rather long time sufficient to have the fire cause human damages.
For the three transport modes, it therefore appears that, due to the intervention time of rescue services, the quick self-escape of the users is the prime priority in case of fire.

## 6. CONCLUSION

The comparative table below, inspired from a IUPT document – International Association of Public Transport - gives a brief synthesis of the typology of the main safety elements in tunnel for the three transport modes.
It appears that the approach of the safety level and its improvement for each mode corresponds to a very diverging problematics and to specific technical cultures.
Due to the risk level higher in road tunnels than in railway or metro tunnels, road required to define more important safety measures and to write out more developed regulations and guidelines than for the other tunnels.
But the potential fire does not know which type of tunnel it will start in; this is the reason why recommendations to limit its consequences should be established according to the most pertinent and unified assessment methods. This certainly is one of the major objectives of those studying now this topic on a national, also European and even international level.

| **Item** | **Metro** | **Rail** | **Road** |
|---|---|---|---|
| Length | 5 to 600 meters mean between 2 stations | 30 m to about 50km | 200 m to about 20 km |
| Location | city | city, country | city, country |
| Exits | stations | tunnel ends | tunnel ends, shelters with access to other tunnels |
| Possibilities to move from accident place to safe exit | very narrow pathways | narrow pathways | wider pathways |
| Intervention time of firemen | 5 to 10minutes | 10 to 60 minutes | 5 to 10 (firemen at the end) to 60minutes |
| Fire heat release rate | 7 to 20 MW<br>fire load under control | 10 to 200 MW(TMD)<br>fire load depends on vehicles (their load) | 2 to 200 MW(TMD)<br>fire load depends on vehicles (their load) |
| People | 100 to 250 per wagon | 150 per wagon | 1 to 100( bus) |
| Traffic control | strict control | strict control | no control to individual drivers |
| Communica-tion for alarm | driver or interphone | driver of the train | each driver of each vehicle |
| Materials | fire resistance standard | fire resistance standard | no standard |
| Firemen intervention | stations<br>cannot use cars | ends of tunnel<br>cannot use cars | ends of tunnel,<br>special accesses |

## 7. REFERENCES

www.etnfit.net and provisional reports from workpackages
www.uic.asso.fr
www.unece.org
www.aeif.org
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