The Emperor's New Clothes for Tunnels

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1. ABSTRACT

I would like to expose three tunnels of different lengths (L, XXL and XXXL) and their current fire safety "imperfections". EU Dir. 2004/54/EC: all road tunnels must meet minimal safety requirements before 2019. Definition of "safe tunnel" is not always interpreted equally.
To my understanding, tunnels must be safe for all people in and around the tunnel and must also be protected from major structural damage caused by fire. Extensive fire may never be able to develop and traffic should restart in mater of hours or days, without extended repairs and higher cost.
Detection systems, ventilation, extinguishing systems, human response, and concept design are crucial for all future events in a particular tunnel. Financial resources for safety in tunnels are limited. On the other hand, our ignorance and desire for gambling with safety is not limited at all. I would like to open discussion, and prove, that safety in some tunnels may not be as expensive as it is usually presented.

2. INTRUDUCTION

Tunnels are sensitive stitches of Europe.
We may not be aware of importance of our daily benefits from road and rail tunnels, because we take them for granted. There are several tunnels that were designed more than 25 years ago, at the time when fire safety was not an important issue. Traffic density and fire load did increase since then. New materials and new safety technologies were developed after first large fire disasters in the 90`s.

The biggest problem is, that most of tunnels are public owned, so in case of large fire event all costs are paid by the state (taxpayers). There are only a few exceptions, such as Felbertauerntunnel, Eurotunnel. Astonishingly, insurance and major shareholders, as Deutsche Bank, don't show much interest in protecting its investment against fire damage.

Why do new technologies reach tunnels slowly?
It appears that final decisions are not based on expert opinion but are made by politicians and their gambling with disaster statistic. Perhaps new generation of experts will be more sensitive for safety issues as designers of old tunnels are.

Repairs or safety upgrades cost significantly less than lack of income while tunnel is closed. Example: Taueren tunnel (Austria) repair cost 10mil.€, income loss (3 months) about 25mil.€.

I don't accept separation between "not dangerous" and "dangerous" loads. Even an empty vehicle contains flammable materials that can cause suffocation of people and tunnel damage.

I would like to introduce three tunnels of different length, their current fire **"imperfections"** and potential impact on economy, in case of major fire event in those tunnels.

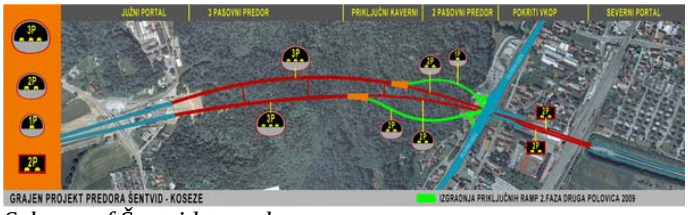
- Šentvid tunnel 1.490m, two tubes, (SLO)
- Karavanke tunnel 7.864m one tube, (SLO-A)
- Eurotunnel 50.450m two railway tubes +service tube, (F-GB)

I will also present operator's future plans and, as an alternative, show some possible much cheaper solutions that could be implemented in near future, so those tunnels can become safer for passengers as well as for investors.
I feel that there is lack of knowledge; some projects are idle for many years without evident reason. Especially in tunnels that connect two countries discussions take forever.

3. ŠENTVID TUNNEL (1490m, SLO)

Two tube highway tunnel consist of:

- Old gallery, 100 m, under railway, prefabricated construction (built 1984)
- Old gallery, 150 m, under gym hall and tennis court, prefabricated construction (built 1984)
- New gallery, 150 m, under Celovška Street (built 2004)
- Tunnel, 1090 m, under a hill
- Future connection tubes to Celovška street



Scheme of Šentvid tunnel

North portal of Šentvid tunnel: first 400m are old and new galleries; the rest is tunnel trough a hill.

Šentvid tunnel attracted first attention of Slovenian media when initial price estimate of 41 million € exploded due to project change (from 2 lanes to 3 lanes) to almost 139 million € for 1.490 m of 2 tube tunnel.

Only 6 hours after grandiose inauguration of the Šentvid tunnel on July 1st, 2008, the sprayed fire protection cast fell of the ceiling of the old gallery. Some loose areas of cast were removed and ex-transport minister of Slovenia forced the second opening immediately.

In the morning of July 2nd, 2008, I wrote an E-mail to the acting traffic minister (by profession chemical engineer), suggesting him to stop the traffic until "full tunnel repair and cast removal" is performed. As my concern was not taken seriously I did write him an "open letter" in which I informed him that new cast fall-off will happen, if not in next months of tourist season, then certainly at Queen Elisabeth's visit to Slovenia, or at beginning of winter.

August 7th, 2008, at 2 AM, 100kg chunk of fire protection cast fell on a German tourist's car travelling at 100km/h.
Car was totally damaged, luckily no casualties.

After that accident, the fire protection cast was removed completely, and tunnel was reopened with collective signature of all inspectors. Speed limit was lowered from 100km/h to 80km/h. Operator DARS did not publish reconstruction plan and ministry for transportation stated that there is plenty of time, (until 2019) to adjust tunnel according to EU directive.

4. Real facts behind Šentvid Tunnel

Construction facts

The 25 year old gallery is constructed with prefabricated, "T" shaped, 2m wide concrete beams, laid on concrete walls. Ljubljana falls in earthquake area, so dilatations between beams are obligatory.

Hydro isolation facts

Hydro isolation of Šentvid gallery has many leaks. It was built in the 80`s (exYugoslavia's import restrictions and shortage of modern isolation materials.) There is extensive water leaking problem in old and new gallery.

New gallery of tunnel Šentvid: water leaks; fire protection coating was installed on stainless steel drainage.

Surface conditions

Old gallery was not used or maintained for 25 years. (Except as extremely handy garage for stolen cars.)

Gallery: fire isolation history.

In 2005 a fire protection engineer was concerned that construction might not have enough fire protection to satisfy EU directive.

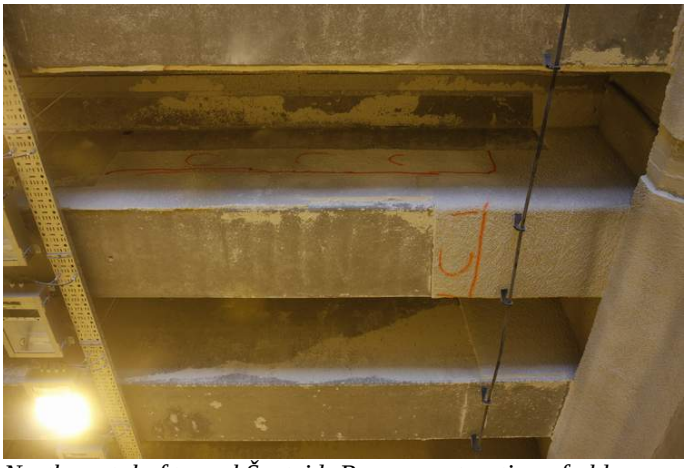
Lack of experience

There was no experience with this kind of materials in tunnels, and specific conditions in particular tunnel in Slovenia.

Design of fire protection

First option:
First choice was artificial limestone board fire protection, simply attached to beams. First design didn't consider ribbed ceiling as potential cause of vibration problems.
Official reason for rejection of Promat boards was that mounting screws were not certificated.

Second option:
Because of faster implementation, fire protection mortar based on latex bond and vermiculite cast was selected. Chosen material was "Fendolite-M11" produced by Cafco. National highway operator DARS has ordered fire protection in galleries to the contractor SCT, and chose English subcontractor - company Ceramicoat.



North portal of tunnel Šentvid: Beam construction of old gallery with marked area with loose vermiculite fire protection

Fire protection mortar was sprayed from March 12th until April 14th in eastern tube and between April 14th and May 16th (one month later) in western tube.

"Yesterday I have seen works in the tunnel. To be honest, works have nothing to do with serious fire protection coating."
*"From my point of view: handling is a disaster and **I** fear that Fendolite-MII cast will partially fall off soon after tunnel opening."*
Ing. Fritz Kukula, Promat

It looks the bad news may not be considered; translation from E-mail sent by F.Kukula Promat to L.Pajek Promat Slovenia on Wednesday, April 30, 2008 8:01 AM

Cost of isolation was around 1.5 mil. €.
All extra costs and work in new gallery could be avoided by simply adding polypropylene fibbers into construction concrete.
Total cost of this additive would be 16.000 €, compared to cast + removal + new protection of new gallery, totalling in 1-1,8mil€.

Gallery Šentvid; removal of vermiculite fire protection. Bonding layer on the left side remained on concrete (white latex), on the right side bonding was absent or it remained on fire protection.

Political aspect
Due to parliament elections in September of 2008, the political pressure to finish building of the tunnel and afterwards to reopen even dangerous tunnel was tremendous.

Impact on transportation
Old gallery is built under important railway so bigger fire in gallery could also interrupt railway connection Ljubljana (SLO) - Munich (D).
Gallery itself is important northern access to Ljubljana, and is also a bypass that relieves part of the city from daily traffic peaks and summer transit traffic.

Fire and corrosion isolation
On some places there is only 8 mm of concrete protecting reinforcement (required 50-60mm).

Old sins
The beams were cast in a metal mould and old oil or diesel fuel was used for easier separation. The surface also had some dust, dirt, and algae.

Temperature at the time of cast installation was above freezing point and was rising.

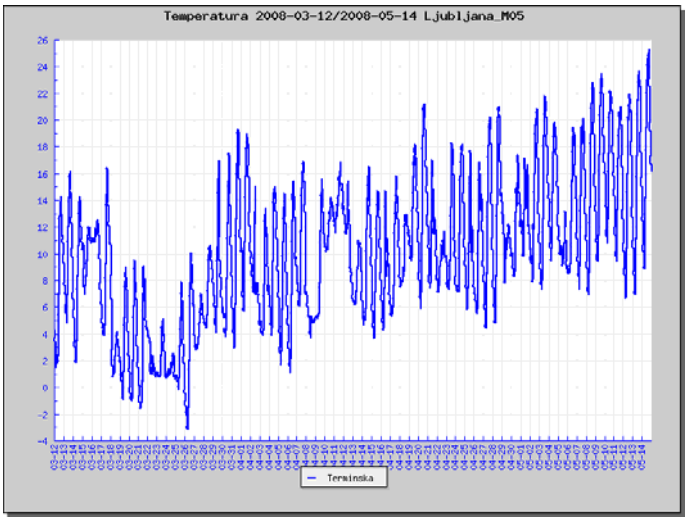
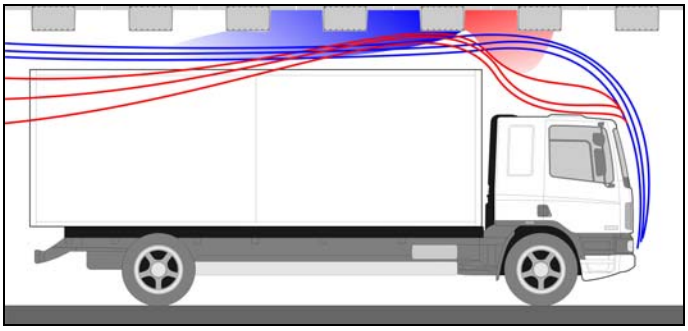


Diagram of temperature during spraying of fire protection
Source: http://www.arso.gov.si/

Hidden vibrations

The lowest part of ceiling is less than 0.5 m above the top of heavy goods vehicles (HGVs). Speed at witch those HGVs are traveling (100 km/h) causes high pressure wave and low pressure areas. Result is resonation between beams that causes vibrations. Additional vibrations are caused by heavy trains (possibly with damaged bearings), driving above the gallery. There is no vibration absorption layer between railway and beam structure. Solution is a layer of shredded old tires under railroad.

Additional vibrations are produced by sound of traffic and fans in gallery. All these vibrations have their specific frequency and interfere.



Schematics of air pressure zones

Exhibition hall Earls Court, London: 3 m clearance to fire protection, speed 30 km/h (due to different conditions cannot serve as reference for Šentvid tunnel gallery)

After fall–off, many random loose areas, with no clear pattern to understand causes, were noticed. There were more loose areas in western gallery. According to all recommendations the cast had enough time to harden and reach final quality.

At the time of spraying traffic was limited to requirements of building site only.

After the installation of fire protection cast, preparations for laying asphalt started.

We examined other possible solutions

There are passive isolations and active fire suppressing systems available on the market. Designers of this gallery didn't take this fact into consideration. Lack of know how and/or time pressure?

Reasonable service life of fire protection mortar system can be obtained by means of sufficient roughness of concrete surface (providing exposure of the aggregate) and/or by mechanical fixation, using wire mesh and anchors. Required surface roughness is generally achieved by hydro-demolition, using water pressure between 2000 and 3000 bar. In Šentvid tunnel neither was done before application of fire protection cast. Only cleaning with 400 bar one year in advance and with cold water (160 bar) three days before the application have been carried out.

Sprayed mineral fire protection mortar

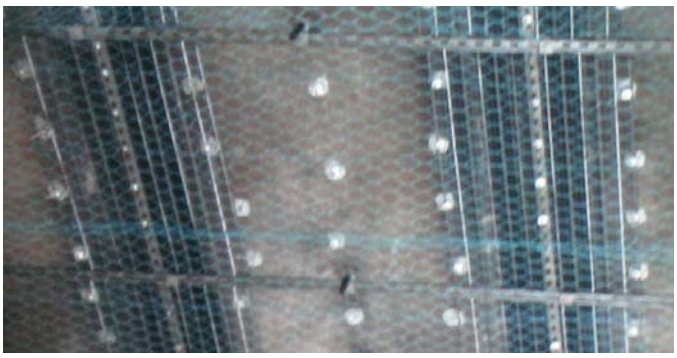
Is more compact, les isolative; therefore about 20% thicker coating is needed. It is implemented on wet surface.

Cross section of fire protection (left) and concrete; rough surface of concrete after 3000 bar cleaning treatment guaranties good bond.

Ultimate facts

In Germany, after troubles with fire protection fall-off any kind of sprayed fire protection in tunnels is not allowed! (Source STUVA)

In England, wire mesh, anchored in the ceiling, is used to reinforce sprayed fire protection mortar.

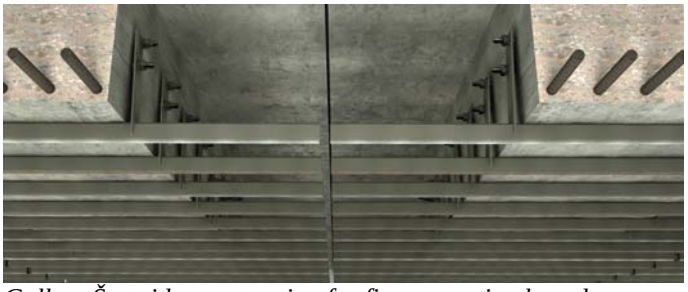


M25 Holmesdale Tunnel, England: The same product is installed using reinforcement mesh attached to construction

Concrete glass fibre reinforced boarding

After first testing, concrete boarding showed higher resistance against freezing and high temperatures as limestone plates. In particular gallery of Šentvid

tunnel, special strong stainless steel auxiliary construction would be needed for both products. Result would be expensive installation.



Gallery Šentvid; construction for fire protection boards

Wet material freezing test after 100 cycles: limestone fire protection boards (left) glass fibre reinforced concrete (right)

Wet material freezing (-28°C) and heating (+250°C) 1 cycle: glass fibre reinforced concrete (below)
limestone fire protection boards (above) showing splitting

Perforated steel plates

This fire protection system was developed in Germany, but never reached serial production. Advantages are sound absorption, easier monitoring of primary construction, and no need for extra construction. Elements can be easily removed for maintenance. In Šentvid tunnel humidity could cause growth of mold on organic fire protecting coating.

Example of fire protection with special coated perforated steel elements

Future plan

DARS didn't publish any plans for upgrade yet. There are two alternative solutions:

- **Passive fire protection:** 2 - 3,5mil.€
  Fire protection for: 2-3hours, lasts for 30 years

- **Active fire protection:** 1 – 2 mil. €
  Fire protection for: as long as water and energy are available
  Faster end easier installation

Lifespan of construction in galleries can be extended for additional 30 years with proper cleaning and application of protective coating. When construction will become unsafe, replacing it with new one will have to be considered, as an alternative to repairs.

5. Karavanke Tunnel, 7.864 m, (SLO-A)

one tube, single fire zone.

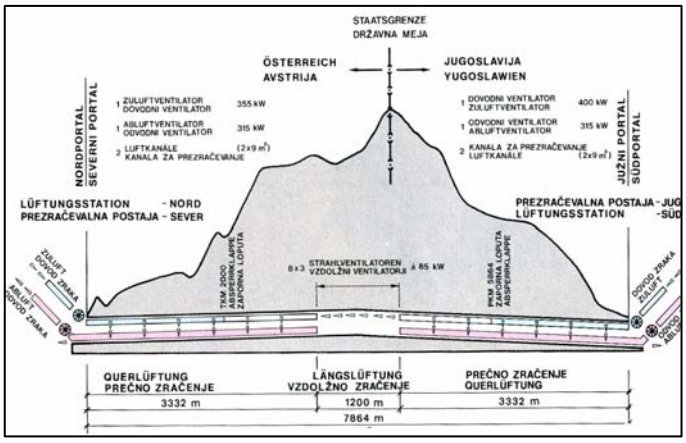
There are three major options for upgrade to EU directive that requires smoke free escape.

- To build second tube (340 mil €)
- To build service tube (60 mil €)

Alternative solution

- To upgrade ventilation into 2K reversible (15 mil. €)

Smoke management in case of fire does not meet current standards. Firstly, no smoke extraction is available in the middle section (1200 m) of the tunnel. Secondly, the smoke-extraction rate is only 65 m^3/s /km. Ventilation test on November 15.2007; measurements revealed 80% leakage of exhaust channel.



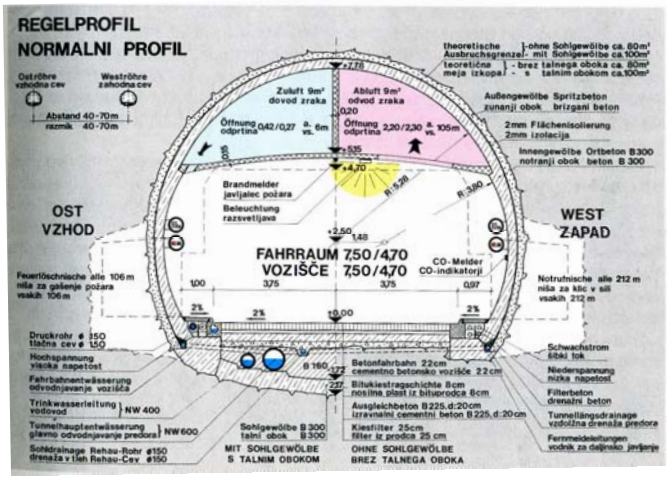
Longitudinal cross section of Karavanke tunnel;
left Austria, right Slovenia.

Last year's single car fire did prove that poor ventilation could turn the tunnel into deadly trap. Rescue action was poorly managed as closer located,

professional Slovenian firemen were sent into smoke.
Fire test carried out on November 15th, 2007 exposed following deficiencies of ventilation system:

- **System control**
  unsuitable opening/closing of exhaust flaps, unsuitable start procedures for portal fans, wrong measurements of wind speed, unsuitable determination of priority for different fire detection systems
- **Sensor technology**
  verification, calibration and possible replacement of air speed measuring devices
- **Structural elements**
  (test measurements revealed 80% leakage of exhaust channel)

On attempt to seal leakages workers were poisoned with CO_2.
When exhaust fan failed, tunnel was operating on one fan for more than a month.



Cross section of Karavanke tunnel;
left fresh air 9m², right exhaust 9m².

Upgrade to 2K reversible ventilation requires:

- Connection of air ducts (new ceiling) across 1.200 m of middle section.
- Installation of 160 new flaps into fresh air and exhaust ducts.
- Installation of 180° variable-pitch fans or new stronger fans
- New control system.
-

Comparison of systems	Escape tube	2K reversible
Depends on power supply	Yes	Yes
Max smoke zone	7.764m	100m
Fire damage	?	100m
Smoke escape route	250m	50m
Price	60 mil. €	15 mil. €
Construction time	5 years	1 year

6. Eurotunnel 50.450m
Two railway tubes + service tube, (F-GB)

How cheap is fire safety for Euro tunnel?
There were three major fires in the past years; last one was burning for 17 hours. At the moment, fire extinguishing of La shuttle trains for trucks is based only on outside help that is located far away. Last time it took firemen 75 minutes to reach the point of fire. Repairing cost was 60 mil €.
Response time is to long even for a house fire, not for tunnel fire where heat and smoke are accumulated in tunnel tube.

After second Eurotunnel fire this year we reviewed facts in the rescue concept.

- Smoke detectors are installed on tunnel wall, so it is impossible to pinpoint exact location of fire on train moving at 80-160km/h.
- Current rescue protocol: Train stops at rescue passageway. Because of piston effect caused by train, surrounding air travels along with it. Denser smoke is brought from fire forward to front carriage that is transporting HGV drivers.
- In second fire event in Euro tunnel, fire brigade arrival time was 75 minutes witch does not appear a good fire safety concept to me.

Some years ago a test of using on board water mist was performed. The problem with water mist is that it is not efficient in windy conditions, 150 m³ of water and expensive pumps must be transported all the time, propulsion of pumps (electrical or internal combustion) will stop functioning in stronger fire, as wires melt and gases dilute oxygen in the air. Not to mention that 30 wagons have at least 90 joints of high pressure installation.

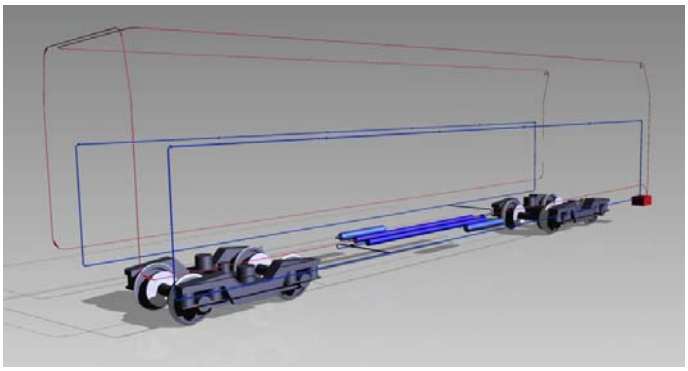
Statistically, trucks (especially HGV with large fire load) can be frequent source of fire; increase of international terrorism represents an even greater threat to safety. Set fire in South Korean subway did show fire fragility of tunnels.

We have developed a new safety concept, capable of improving fire protection level even in very long tunnels.

Our concept consists of:

Integrated fire detection system
Composed of sensor cable and newly developed flame detector. This system is capable of pinpointing the location of fire with great accuracy and is false-alarm proof.

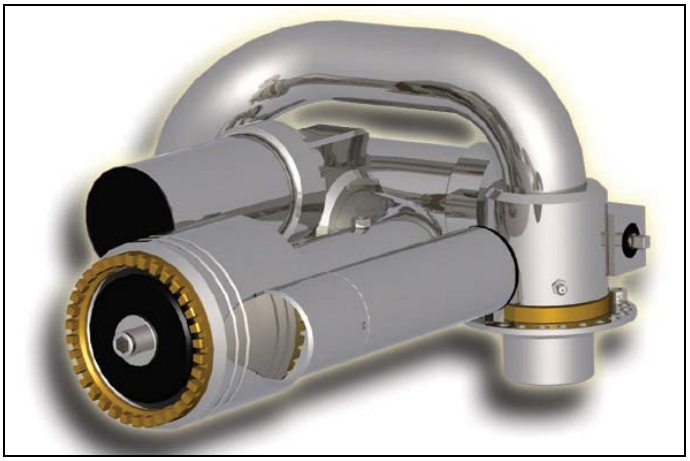
On board BONPET liquid extinguishing system
Highly efficient on both, coaches and truck carrying Shuttle wagons. Main components are two pressurized cylinders underneath each coach/wagon with a total capacity of 200 litters/wagon. Each wagon can function as a basic self-sustained unit. All wagons are interconnected with flexible tube, so fire on a single or a group of wagons can be extinguished by entire composition of wagons.



Schematics of on board BONPET fire extinguishing system

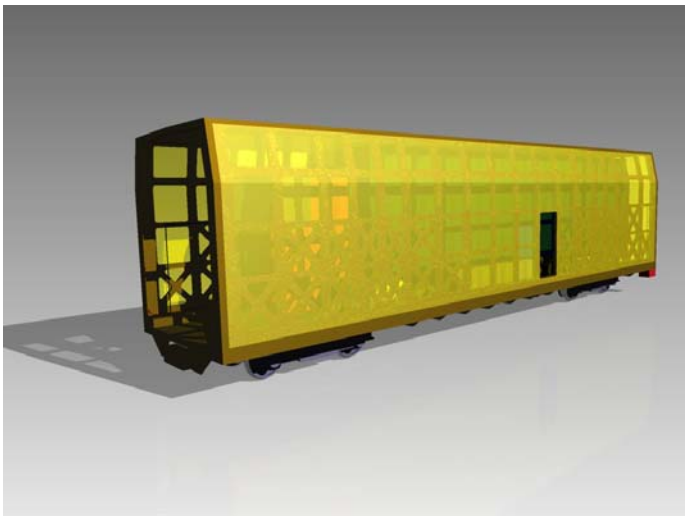
Material cost for future on board detection and extinguishing system for entire fleet of 16 La shuttles, with 30 wagons each, is about 6 millions € or 10% of concrete damaged by last fire, or about 1% of their yearly income.

Automated fire extinguishing section in tunnel
This system dramatically reduces time needed to start extinguishing. Better performance on open Shuttle wagons for carrying trucks then on closed coaches is expected.



Automated UniFire extinguishing monitor

Fire cages add-on for Shuttle wagons
can significantly reduce damage to tunnel in case of fire, and also provide better conditions for automated fire extinguishing inside the shuttle train.
Metal perforated membrane is translucent and allows gas exchange at loading and off loading of HGVs. In fire conditions perforations close and stop hot smoke and flames from spreading.



Fire cage that stops spreading of flames into tunnel

Company Ekovent from Croatia will carry out 3K reversible ventilation test for tunnels in an old railway tunnel on CRO-SLO border in 2009. The 3K ventilation is safest ventilation solution, especially for road tunnels and for underground railway stations.
There is an option to carry out extinguishing testing for Eurotunnel, but, sadly, they did not show even a bit of interest.

We do believe that there are better solutions than having nothing on board against fire. Responsible people should be aware they did not do enough to prevent future fires.

The safety concept for Eurotunnel was created 25 years ago. I do not know of any person that is driving 25 years old car (except old-timers) or is using 25 years old desktop computer. I do believe that mega structure, such as Eurotunnel, needs some upgrade, fine tuning and up to date technology in the field of fire safety.

"The safety boats are too expensive to be afforded."
Titanic investors

"Tunnel safety upgrade is too cheap to be ignored."

Events round closing and opening Šentvid tunnel was like bad joke of ex minister, his gambling with safety for of election maters was tragic and cost us a lot of public money.

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