The European project UpTun – improving the level of fire safety in existing tunnels

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Abstract

The European economy relies heavily upon a sustainable transportation system. In this transportation system, tunnels are a key element. The safety systems in a significant part of the existing tunnels were designed on the basis of traffic and its estimated growth of two or more decades ago. It appears however that traffic has grown more significantly and also changed in composition (more combustible and flammable goods). Consequently the safety level in existing tunnels has decreased in cases where no intermediate measures were taken to cope with the changed supply of rolling stock. This holds throughout Europe, for road-, rail- and mass-transit tunnels.

The UPTUN project main objects are therefore:

- Development of innovative technologies where appropriate and where relevant comparing to and the assessment of existing technologies for tunnel application. Focus is on technologies in the areas of detection and monitoring, mitigating measures, influencing human response, and protection against structural damage. The main output is a set of innovative cost-effective technologies.
- Development, demonstration and promotion of procedures for rational safety level evaluation, including decision support models; and knowledge transfer. The main output is a risk based evaluating and upgrading model.

The desired spin-off of the UPTUN project would be:

- the restoration of faith in tunnels as safe parts of the transportation systems;
- the levelling out of trade barriers imposed by supposedly unsafe tunnels;
- an increased awareness of stakeholders for the necessity to develop initiatives to link all relevant research.

As the project is running until August 2006 this paper will give an overview of the project and the achievements obtained so far.

Keywords: tunnel safety, fire safety, innovative technologies, tunnel upgrading model.

1 Introduction

The European economy heavily relies upon a sustainable transportation system. In this transportation system, tunnels are a key element. The safety systems in a significant part of the existing tunnels were designed on the basis of traffic and its estimated growth of two or more decades ago. It appears however that traffic has grown more significantly and also changed in composition (more combustible and flammable goods). Consequently the safety level in existing tunnels has decreased in cases where no intermediate measures were taken to cope with the changed supply of rolling stock. This holds throughout Europe, for road-, rail- and mass-transit tunnels.

In addition to this, the accidents in recent years have drawn widespread attention to the risks of fires in tunnels. This has two consequences. First, the fires themselves have resulted in fatalities, casualties and/or economic damage. They have also resulted in lengthy shutdowns of the tunnels themselves. Secondly, the perceived risk of fire is also likely to have discouraged tunnel usage in some cases. (tunnels might become an unwanted impediment for trade). Both of these consequences will have added to congestion and hence noise, particulate and airborne pollution with negative environmental and health consequences. As a result of the accidents, and the media attention they have caught, the public acceptance level of fires causing major losses has also decreased.

The main problem statement is now that unsafe, or supposedly unsafe, tunnels hamper the use and the development of sustainable transportation systems, needed in a healthy European economy. Upgrading the safety level in tunnels is, with existing technology and within the legislation and guidelines frameworks of the member states, in most cases, however either nearly impossible or too costly.

Secondary problem is that fire safety is based on a conventional rather than a rational approach. Moreover, fire safety is seldom looked upon in an integral fashion, comprising all aspects (probability of incidents, consequences of fires, human response, structural response, emergency response teams, tunnel operators) in a similar manner. This may result in adverse interaction between preventive mitigating measures or non-optimal safety investments.

2 The European context of tunnel research

Several major, high profile and costly tunnel fires have taken place in Europe in the past years that resulted in significant loss of life (about 500 persons) and damage to the structures. Channel Tunnel, Mont-Blanc, Tauern and Kaprun are examples of tunnels where accidents occurred due to fire, thus clearly indicating the inadequacy of current design procedures, that is the main technical limitation of existing tunnels, from technological, methodological and from standards points of view. The costs incurred by Channel Tunnel (in terms of repair costs and loss of business from lengthy closure of the tunnel) amounts to some 82 million Euro. Therefore several tunnel safety projects were launched.

All of these projects have been designed in a complementary way with only very few overlapping. The projects fit together like the pieces of a puzzle (see figure 1).

Figure 1: European tunnel initiatives.

Not all recently finished or still running projects and other activities of PIARC, ADAC or OECD are listed in the figure. However, they all fit into the general frame shown in figure 1 as so-called "linked projects".

Furthermore, significant results are achieved from research project and incidents in the past like SAFESTAR; FIRESTARR or FIRETUN as well as the MEMORIAL TUNNEL; OSIS and the conclusion from severe tunnel fires in Storebælt, Channel Tunnel, Mont-Blanc, Tauern and Kaprun.

The focus of these has been on life safety issues, emphasising the conditions developing in a tunnel under fire and by ventilation control. Limited work is available on design scenarios for fire, any mitigation measures or human response factors. Major knowledge gaps exist in evaluating these matters, how to implement them and to upgrade the safety of existing tunnels. Fire safety tools in general are developed for buildings and industrial plants, which are not always cost efficient when applied in tunnels. Upgrading of tunnel safety may need expensive installation or even construction work; therefore it is necessary to develop cost efficient innovative means for existing tunnels.

3 Description of the UpTun project

The UpTun project (Cost-effective, Sustainable and Innovative **Up**grading Methods for Fire Safety in Existing **Tun**nels) has two main areas of activities:

1. Assessment of existing technologies for tunnel application and development of innovative technologies where appropriate. Focus is on technologies in the areas of detection and monitoring, mitigating measures, influencing human response, and protection against structural damage.

2. Development of procedures for safety level evaluation, including decision support models; and knowledge transfer

These activities have been organised in seven coherent work packages; the management of the project defines one additional work package. This leads to the following list of work packages:

Workpackage 0: Project Management
Workpackage 1: Prevention, detection and monitoring
Workpackage 2: Fire development and mitigation measures
Workpackage 3: Human response
Workpackage 4: Fire effects and tunnel performance: system structural response
Workpackage 5: Evaluation of safety levels and upgrading of existing tunnels
Workpackage 6: Fire effects and tunnel performance: system response
Workpackage 7: Promotion, dissemination, education/training, and socio-economic impact

Within each of the workpackages, specific tasks are dedicated to ensure cross-beneficial interrelations with ongoing and future relevant projects. The UPTUN project will address all types of tunnels; where relevant in sub-tasks, a distinction will be made between road- and rail tunnels.

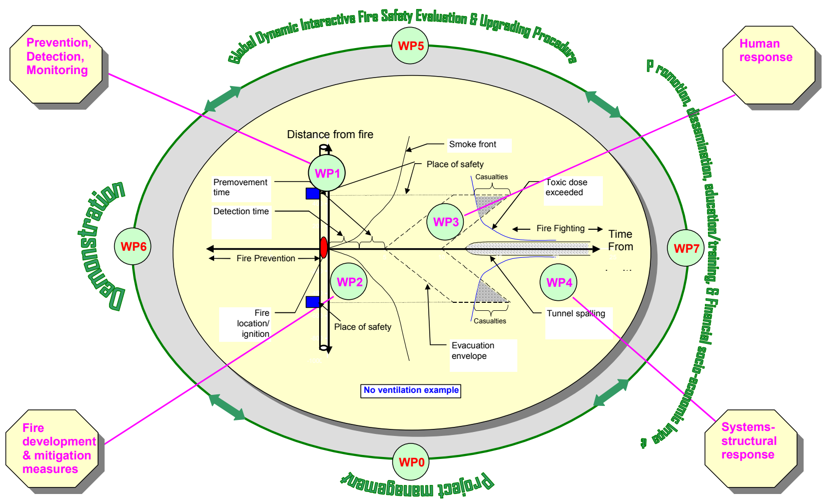

Figure 2: UpTun project overview: Roles of individual item workpackages and global workpackages.

Figure 2 shows where the work packages interact with a tunnel incident. The graph contains the location of the smoke front in an axis system with time on the x-axis, and distance to the fire source on the y-axis. Also shown is the position of people escaping towards emergency exits on both sides of the fire source. The graph shows how people starting their escape too late are overtaken by the smoke front, and where structural damage fits in. Similar graphs can be drawn up to show the influence of mitigating measures such as ventilation and fire suppression on the danger to life and on structural damage. The main objective of the figure is to show where the different work packages interact with the incident.

The project consortium comprises of 41 partners from 18 European counties. The coordinator is TNO from the Netherlands. Figure 3 shows the European dimension of the project. The partners come from all over Europe and the consortium shows a good balance between industry, consultancy, research institutes and universities (see figure 4).

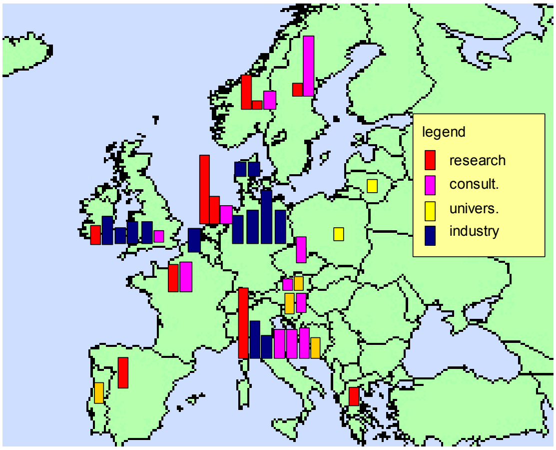

Figure 3: Regional distribution of UpTun partners.

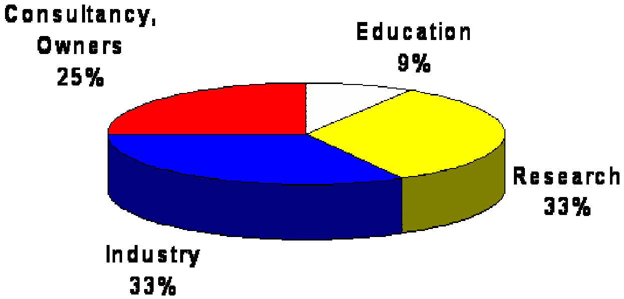

Figure 4: Composition of the UpTun consortium.

This consortium will work for four years (September 2002 until August 2006) to solve open questions and develop innovative technologies related to fire safety in existing tunnels. The project volume is about 12 million € with 50% funding from the European Commission. The amount of work foreseen has a total of about 950 man-months, which are roughly 80 man-years.

4 Technical approach

The problem of upgrading existing tunnels in terms of fire safety will be handled in a holistic way. Safety of tunnels is affected by all kinds of mitigation measures (monitoring, detection, suppression, traffic control) as well as tunnel layout and structural questions. Consequently all mentioned parts of a tunnel as well as questions on human behaviour will be investigated.

The overall aim to develop suitable upgrading recommendations for existing tunnels will be achieved by evaluating existing measures and developing innovative ones. All measures will be evaluated in terms of their contribution to cost effective safety upgrading of tunnels. This will be carried out using laboratory to just medium-scale experiments accompanied by numerical calculations. In addition the upgrading efficiency of a set of upgrading measures will be demonstrated in a real tunnel.

Close co-operation with other ongoing projects on tunnel safety issues and the advisory group of UpTun as well as the exchange of information ensures to avoid overlapping in work and a co-ordinated approach towards the aim.

Daily operation of rail and road tunnels is very different and any rescue operation especially. UpTun will therefore distinguish between the tunnel types in addressing these issues.

The main emphasis of the project work lays on innovation. Innovation, through research and development, is what distinguishes the UpTun project from its sister European funded projects. Innovation in UpTun can be divided into two categories:

- Innovation relating to individual tunnel fire safety features (e.g. fire suppression)
- Innovation relating to the fire safety of the tunnel as an integral unit (holistic approach)

Given that innovation is unpredictable in nature, the UpTun project has developed a strategy and structure for innovation based on the above two categories. It is important to introduce innovative ideas from the outset in the project proposal and ensure that the expertise and budgets for these innovations are available within the project. Furthermore, innovation is introduced into each and every work package and not just confined to a certain number of work packages. This will insure that all aspects of fire safety in tunnels are included in the innovation process of UPTUN, from detection of the fire at its earliest stages to its full consequences, including fire mitigation, human response, structural response and overall evaluation of fire safety of an individual tunnel. What distinguishes this project from all preceding investigations is its scale and comprehensive integrated innovative approach aiming at an overall solution to this important problem. To this end, new hardware and procedures need developed. While all aspects of fire safety in tunnels are important, special emphasis will be placed upon fire detection and suppression and smoke control in the early stages of the fire, this being the key “golden hour” stage of the development of tunnel fires. By far, the majority of tunnels in Europe rely upon ventilation for smoke control. Fire detection of moving fires (e.g. on trains) and fire suppression is an area requiring development. With this philosophy, innovative features such as the water mist fire suppression system and the air plug fire-smoke suppression system are incorporated into the project. The air plug innovation was a result of lateral thinking from a totally different field, namely fabric engineering as applied in, for example, the manufacture of hot-air balloons. To ensure that the know-how and manufacturing capability are available “in-house”, innovative SMEs are made a partner in the project. In relation to the holistic approach, a new model will be developed from the fields of artificial intelligent and expert systems to ensure that a holistic evaluation and upgrading procedure is developed for existing tunnels with the important output being the fire risk profile that would allow a financial and socio-economic assessment to be made. Even in the socio-economic analysis, innovation will be introduced and developed from a Nobel Prize winning theory.

In the following paragraphs a short summary of topics under investigation are given in more detail related to the different aspects of fire safety in tunnels.

4.1 Fire detection

Alternative and new technology, for detection of moving fires, detection of fires outside tunnels, and detection of the migration of fires will be explored. It may be possible to make use of existing CCTV systems, where fitted. Research will be carried out to see if they could be simply modified to automatically monitor smoke and fires in tunnels and to integrate the signals into existing Supervisory systems. Infra-red technology is widely used in commercial applications to detect heat and smoke in buildings, but the technology has not yet been used to detect smoke and fires outside tunnels on moving vehicles. Existing technology will be investigated to determine its suitability for this application. The use of fibre-optic technology to detect heat and fire along a length of fibre is emerging. This technology will be assessed for its suitability in tunnel applications, how well it performs on moving fires, how cost effective it is to retrofit into existing tunnels. The use of other technology will be assessed as it emerges. As in other areas of technology, changes are happening very quickly. It may therefore be possible in the future to retrofit one new linear system that may also be used to connect new CCTV, communications, variable message systems to in one

4.2 Fire suppression

Suppression systems installed in open and well-vented tunnels are very unusual due to the high cost involved and due to the lack of validation of mitigation effects. However, water mist in enclosed spaces has become very successful as a Halon replacement during the last 10 years. The advantage of use of water mist is much less water consumption than sprinkler and it can be released directly into the fire zones, with few negative effects on occupants. Success of water mist is strongly related to the use of the heat produced by the fire to evaporate water into an inert gas to be recycled into the flaming zone. This has been possible for enclosed spaces, similar to the use of Halon. During recent years, the efficiency of water systems has increased significantly and proved successful even for large spaces. However, for well-ventilated tunnels the systems will need improvement to provide efficient mitigation. The use of water mist in tunnels needs improvement and optimisation on droplet size, discharge rates and where to apply the mist in the venting flow. A successful use of water mist in tunnel will provide a significantly more cost efficient suppression tool for tunnels than currently is available.

An alternative system will be investigated based on fabric technology. An air plug will be developed which when inflated in a tunnel will prevent smoke from reaching people and oxygen from reaching the fire. Several air plugs may be required along the tunnel placed in the tunnel crown at key locations along the tunnel. On trains, air plugs could be placed at the end of each carriage to isolate a fire to one carriage only. Air plugs inflate at a reasonable rate (not too fast or too slow) and being made of fabric do not cause injury to people or damage to infrastructure. The logistics and mechanics of air plugs will be developed in this project to ensure their safe and effective operation.

A third system under investigation is the so-called water curtain. Similar to the tunnel plug a water curtain should prevent smoke from reaching people. The system is designed in the way that it provides easy access of the response teams to the fire zone and acceptable working conditions by cooling down the fire and at the same time avoids oxygen depletion.

4.3 Human response

The innovative character on human response consists of several features. First, the character of analysing the problem and arriving at solutions is innovative, since the development of a small process that evolves into a larger process will be followed and analysed in a stepwise and sequential manner. In this global approach, the tunnel user, tunnel operator and response teams all have to deal with each other's actions and failures. Since the combination will be made between all these parallel and sequential human responses, the problem can be approached from all possible sides, taking the dynamic process into account. Secondly, innovative measures will be used in order to arrive at a highly effective and low-cost evacuation system. Here, audio, visual and tactile channels will be used in order to promote evacuation also under low-visibility conditions. Thirdly, real-life observations will be used, such as crowd movements leaving trains, movement through airports, train stations and/or football stadiums in order to arrive at a new methodology of human evacuation behaviour in tunnels, taking more specific situations into account such as people travelling in groups, with or without luggage - and the effect on people (e.g. users and fire fighters) of smoke and temperature levels.

4.4 Structural response

One of the main structural problems in tunnels exposed to fire is the serious damage caused by explosive spalling of the concrete (e.g. Channel Tunnel, Great Belt Tunnel, Mont Blanc Tunnel). While recent developments have made progress in this area, the subject is not fully understood and solutions not optimised. For tunnels where the current structural design is not suitable, alternative innovative solutions will be suggested aimed at reducing and/or elimination of explosive spalling. Non Destructive Evaluation (NDE) of damaged concrete structure will be proposed. Radar technique and other NDE techniques (X-rays, echo pulse method, ultrasonic methods) also in combination, will be assessed.

4.5 Holistic-dynamic evaluation and upgrading model

All innovations are introduced in this task which brings together the results on individual features in a global evaluation and upgrading model. These are listed as follows:

- Modelling the influence of suppression system on fire-smoke development.
- Risk assessment of system-structural response (so far only human response has been assessed).
- Dynamic modelling of the human consequences for possible fire developments in the tunnel (so far the human consequences have been modelled only for a limited number of heat release rates)
- Use of constraint programming to optimise the number of options from the model.
- Use of expert systems.
- Use of logarithmic addition theory to optimise on safety levels
- Development of fire risk profiles for a tunnel as a whole for input into socio-economic model.
- Socio-economic model

5 Achievements so far

It is obviously too early to report on final results and achievements of the project work. However quite a lot of progress has been made up to now. Some detection and mitigation systems as well as new concretes have already been tested and proven their functionality. A detailed evaluation of the tests is currently pending so that more information can be given at conference time. Interested parties may follow the progress of the project by visiting the UpTun website (http://www.uptun.net).

But two major events in the frame of UpTun should be mentioned here. These are the fire tests carried out in the Runehamar tunnel in Norway and the demonstration test in the Virgolo tunnel in Bolzano.

In September 2003 large scale fire tests were carried out in the Runehamar Tunnel in Norway. In these tests the fire behaviour of semi-trailer cargos in a tunnel was studied systematically in order to obtain new knowledge about the fire development and fire spread in the cargos and the heat exposure to the tunnel linings in the vicinity of the fire. Information about upstream thermal conditions was also obtained during these tests. It was shown that the fire in this scenario can develop to heat release rates of 300 MW. Additional information may be obtained from the UpTun web site.

The second event took place in February 2005 in the Virgolo tunnel of Autostrade del Brennero in Bolzano, which is currently under refurbishment, Italy. The tests carried out were designed as demonstration tests for a couple of innovative technologies like new detection and monitoring systems, the water mist, water curtain and tunnel plug suppression systems and some new concrete types. The tests happened just recently so that detailed results are not available yet. The general result of the test was that all systems worked quite well and none failed. Results will be available likely at conference time.

6 Conclusion

The UpTun project passed the mid-term assessment by the European Commission and received the permission to continue for the rest of the project lifetime. The work is on a good way, which has also been recognised by the EC. It is most likely that UpTun is able to provide a set of new innovative measures to improve the fire safety of existing tunnels and therewith contribute to avoid incident like those happened in the past.

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