Improvement of accident prevention in road tunnels through Intelligent Infrastructures and Intelligent Vehicles cooperation

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ABSTRACT
Main user needs analysis results of SAFE TUNNEL IST-EC (aimed to road tunnel safety improvement) research project are presented. Different classes of users have been analysed through direct interviews, questionnaires, literature data analysis and driving simulation.

Furthermore the system architecture for the implementation of four applications (vehicle prognostic - vehicle telecontrol - dissemination of emergency information - Moving spot light system) is described.

INTRODUCTION
As described in a previous paper (1), SAFE TUNNEL is a three years project funded by the European Commission (IST) started in Sep-2001, which has the main objective to demonstrate the feasibility of innovative applications based on the cooperation between intelligent infrastructure and intelligent vehicles for enhancing accident prevention in tunnel.

System concept is based on the development of four applications:

- The vehicle prognostic
- The Vehicle Telecontrol
- The Dissemination of emergency information
- The Moving spot light concept

The first three of them will be demonstrated in reality in a test site equipped within the Frejus tunnel area, while the fourth of them will end its development at feasibility level only.
The development of these application implies the use of state of the art of ITS technologies both concerning vehicle and infrastructure side and a strong cooperation between these two different world through a public mobile telecom network which must supply the needed communication services.

**TECHNOLOGICAL CHALLENGES**

In the last year ITS occupied a relevant role in the development of new application to support the driver and the road operator in the performing of their tasks.

Until now, cooperation Vehicle-Infrastructure has been achieved mainly in the field of automatic debiting mainly through Dedicated Short Range System, while traffic monitoring systems based on floating cars data are often restricted to reduced pilots.

SAFE TUNNEL, for the first time in Europe, has the demanding objective to enhance traffic safety by a strong cooperation between Intelligent Vehicles and Intelligent Infrastructures.

SAFE TUNNEL have not, as main objective, the task to develop new technologies, but it is targeted to use in an innovative way what are today state of the art technologies applied to Heavy Goods Vehicles (HGV).

From a vehicle side, SAFE TUNNEL will take benefit by the use of new bus architecture, mainly the SAE J1939, to collect information from the various internal sensors which can be already available on the market, available at prototype level often at a very early development stage. This information is elaborated and formatted by a logic unit for a preventive diagnosis of vehicle systems failures.

In a final system elaboration will be performed in co-operation by local control unit (engine, brake, gearbox control unit) in co-operation with a telematic unit that will manage also the communication for access control application.

Together with these functions, HGVs will be equipped with Adaptative Cruise Control features where control parameters (max speed and min distance) are fixed by the infrastructure.

A suitable HMI complete the technological on-board facilities.

From the road side, SAFE TUNNEL will help road operator in Access Control facilities, allowing the stop of HGVs with on-board anomalies which could cause incident in the next future.

This application can be easily embedded in one control centre devoted to road traffic control and surveillance.

Communication system is based on a cellular public network. At beginning of the project, the chosen technology was UMTS, but the late deployment of UMTS network and the results of the needed throughput analysis, makes possible the use of suitably dimensioned GSM or GPRS network (the last one will be used for demonstration).

However the modular approach proposed for the design will allow an easy transition path from existing technology towards new coming ones (GSM → GPRS → UMTS).

**THE USER NEEDS ANALYSIS**

A complex system like SAFE TUNNEL has requested, in the system requirement definition, a deep analysis of user needs.
The first step in the investigation about user needs is a clear identification of who are the users of the SAFETUNNEL applications.

Generally speaking, although the user definition is difficult, the Intelligent Transport System community is used to classify the user according to four main classes:

- Policy Makers
- Network Operators (Tunnel Operators)
- System Operators
- Driver

This is actually the kind of classification adopted by the project.

**Tunnel operators and system operators point of view**

User needs analysis has been structured in six different steps:

- Classification of the tunnel infrastructure (based on UN/ECE and SITAF-SFTRF data)
- Accident statistics and analysis (based on literature and data collected at Frejus, Monte Bianco and Gottardo tunnels)
- Analysis of literature: (based on the analysis of the tunnel safety measures proposed by main international bodies like UN/ECE, OECD, National bodies, CETU, …)
- Analysis of fire accident risk: the fire is the worst risk for a tunnel infrastructure.
  Together with the high number of human lives, the fire constitutes a real danger also for tunnel infrastructures which risks to be damaged even irreversibly. The analysis has been based on literature data and internal document of Frejus tunnel operators.
- Interview campaign: the activity consists of the interview of a group of tunnel operators and a group of expert in tunnel safety with different skills.
- User forum: design and implementation of a web site which has the objective to became a “meeting point” for the “authorized personnel” in tunnel safety.

**Drivers point of view**

The User Needs analysis is defined as the process of collecting and exploiting information of the needs of prospective users.

The user needs analysis from the driver point of view consists of two main items:

- The interview of a sample of drivers through structured questionnaires
- The analysis of the perceived time headway in the distance keeping tasks and the estimation of potential benefit of a moving point of light through a driving simulator.

**Interviews – methodological approach**

The collecting of information was done by a survey which took place in three different European tunnels: the Frejus tunnel, the Pfandern tunnel, the Arlberg tunnel.

On the whole 212 tunnel users were interviewed, 108 of them were truck drivers, 104 passenger car drivers. A cross section of drivers with different nationalities was interviewed.

To solve the task of considering the users perceived safety of road tunnel on general as well as achieving a preliminary estimation of the user acceptance of the new safe tunnel concepts, three different interview guides were developed:
Interview guide for the assessment of the established preventive safety measurements
Interview guide for the assessment of the new preventive safety measurements for passenger car drivers
Interview guide for the assessment of the new preventive safety preventive for truck drivers.

To get the most authentic statements and estimations concerning perceived safety from the driver point of view, it was decided to carry out the survey at the three road tunnel. The drivers were interviewed directly after they had passed the tunnel at the toll station or at the next fuel station.

Driving simulator – methodological approach

In light of the present knowledge about drivers' abilities to estimate headway, and especially given the very long headway recommended in tunnel driving, it was impossible to predict the benefits of an innovative Moving Spot Light system, relative to more traditional methods, such as equi-distant lines painted along the tunnel walls. Therefore, the purpose of this study was to evaluate 3 methods for keeping the desired safe headway of 150 meters, relative to a control condition consisting only of verbal instructions. The three methods were:

- Repeated line markings on the road.
- Equi-distant lines were marked on the tunnel wall every 50 meters and the driver had to maintain a gap of 4 lines behind the lead car.
- Moving Point-of-Light (POL). In this innovative method an image was projected on the wall of the tunnel at a constant distance of 150 meters behind each vehicle and the following driver had to remain slightly behind the image and not pass it. This is the basic concept behind the moving spot light system as defined in SAFE TUNNEL.

A fixed base driving simulator was used in the study, and it consisted of two components: A computer software package "STI-SIM", manufactured specifically for driving research by Systems Technology, Inc. and the cab of a real car in which the driver was seated when 'driving' the simulator.

In the simulator the driver has interactive controls of the steering wheel and the brake and accelerator pedals, while the gearshift is automatic. The roadway is displayed on a wide screen located in front of the car and provides the driver with a true 40-degree horizontal field of view.

Experimentation has been performed at Ben-Gurion University, Tel Aviv (IL).

Impact of user needs on system requirements

User needs has been a crucial point in the definition of system requirements and an interesting list of recommendations has been derived from this analysis.

For space reason, only a choice of these recommendations is here provided, but detailed user needs results are available on the internet site of the project (www.crfproject-eu.org).

Main recommendations derived from the analysis of user needs from the tunnel and system operator point of view are:

- The system must not only prevent accidents, but also the occurrence inside the tunnel of any type of vehicle failure which can cause a stop.
• The tunnel needs a control centre.
• Mono-tube tunnel – two ways tunnel are far more critical than bi-tube tunnels
• The number of accidents is higher outside than inside tunnels, but the accident severity is normally higher inside than outside tunnels
• In long tunnels, collisions between cars are significantly less than collisions with infrastructures, and the size of the tunnel section is often small; a lane keeping system can help to reduce them dramatically
• Collisions between vehicles are mainly rear end collisions; an adaptative cruise control can help to reduce them dramatically
• The risk caused by fires is very low, but the consequences of a big fire are unacceptable
• In case of fire accident the first 10 minutes are crucial, after this time the possibility to extinguish the fire are considerably less
• The fire load of an HGV is potentially some tenth more than a passenger vehicle

Main considerations related to interviews are:
• The two panels had in general a positive attitude towards the SAFE TUNNEL applications and in general to the ITS.
• Great expectation is devoted to the SAFE TUNNEL applications, in particular to providing “Prognostic” and “Dissemination of emergency information”
• The Telecontrol of the speed and the distance is judged positively, but less than “prognostic”,
• Some doubts about the Moving Spot Light System are encountered, especially because of the estimated high cost of the solution.
• The awareness of all the interviewed persons is that new solutions to improve the safety in tunnels should incorporate ITS.

About the driving simulator approach, main considerations/results obtained are:
• Driving in the tunnel is more attention-demanding than driving on the open road, and consequently more tiring. While driving in the tunnel drivers tend to have less spare capacity to respond to non-driving tasks than in the open road
• In the absence of supplementary cues to headway distance, it is very difficult to maintain long headway, such as the 150 meters required in the Frejus Tunnel.
• Without any headway guidance methods, drivers under-estimate a long distance such as 150 meters.
• Of the three guidance methods evaluated, the dynamic point-of-light is the best one as reflected by all three measures employed in this study:
  • Average headway with this method is closest to the desired one of 150 meters
  • The variance in the headway is lower than with the other methods
• The amount of attention that the task requires is less than with the other methods, leaving the driver with more spare capacity to handle other driving and non-driving tasks.

And finally main recommendations related to the interview of vehicle drivers are:

• An interesting result concerns the distance and speed behaviour of the tunnel users and their own estimation of their behaviour. As confirmed by many scientific studies, the subjective estimation of the own perception ability and actual perception ability itself is prone to errors, mainly in distance keeping.

• The geometry and the design of the tunnel has a great importance in the safety perception of the drivers.

• Concerning new safety measurements, the automatic speed and distance control (tele control) and the Moving spot light system were considered as the most important new measurement by 25,71% (in each case) of the truck drivers. Also the driver check before entrance was assessed as the most important one by 22,86 %.

• The user acceptance from the truck drivers point of view towards SAFE TUNNEL applications is rather positive.

• The driver’s attitude towards an implementation of the moving spotlight system can be estimated as positive: about 75% of the whole sample would follow the recommended speed.

• The truck drivers’ acceptance of an implemented tele control showed also a positive tendency: about 77% of the subjects would be willing to follow the recommendations.

• The willingness to pay more money for more tunnel safety is small.

**General Architecture**

The system is based on:

- An intelligent system which manage on-board ITS facilities
- ITS infrastructures working on different field of applications
- A communication system

The following picture describes the general system architecture:
System concept

SAFE TUNNEL is working to demonstrate the feasibility of the cooperation vehicle-infrastructure through a public network; this concept, very easy to understand, but difficult to formalize, has forced persons with different cultures and technical languages to speak together and fix a first framework of this concept.

As anticipated in the introduction, SAFE TUNNEL concept plans four applications able to work together or in a stand alone mode.

The simultaneous use of more applications should guarantee greater efficiency because of the possibility to share the same installations for many applications. This concept will be more clear later in the paper.

The four applications are:

- The vehicle prognostic
- The Vehicle Telecontrol
- The Dissemination of emergency information
- The Moving spot light concept
Vehicle Prognostic

The application consists of two main parts: an on board equipment and a control centre which, on the basis of the information received from the vehicle, decides a suitable access control strategy.

The application name summarizes the two basic features of this function:

Vehicle function diagnosis: the main objective of this application regards the development of a diagnostic system capable of detecting the critical signals of on board sensors with the objective to identify those parameters that may indicate a failure of a system component.

Vehicle function Prognosis: the objective is to use the data collected till a given time to estimate probable vehicle or component failure well in advance.

The strong interaction between these two functions allows creating the conditions for a new concept of vehicle maintenance and road regulation. This estimated information is displayed to the driver and communicated to a control centre with the objective to allow to the traffic operator a better control of vehicles potentially dangerous especially in “safety sensitive” areas like tunnels, bridges, or slopes.

According to these considerations emphasis will be devoted to those occurrences that can cause system breakdown and fires on board vehicles.

In case of failure (detected or forecasted) the vehicle data are transmitted to a control centre which decide if stop or check the vehicle before the tunnel entrance according to the anomaly severity. By means of a phone call or a message exchange the road operator may contact the driver and manage the planned actions.

Access control facilities or enforcement facilities can help the road operator to control if the vehicle is following the decided actions.

The following two figures (2 and 3) illustrated shortly what has been described..

Fig. 2 : vehicle prognostic application diagram
Vehicle Telecontrol

Main objective of vehicle telecontrol is to help the driver in the longitudinal and lateral control tasks and in the same time to allow a better compliance with the road code.

Two operational solutions have been analysed:

- Vehicle telecontrol – driven by a wireless communication link -- devoted to equipped vehicles
- Optical link based on infrastructures – moving spot light system (MSLS) -- devoted to not equipped vehicles

For both applications a control centre is needed, it manages the applications through the transmission to the vehicles of a recommended speed and distance and the area (starting and ending point) where these recommendations are valid. When needed (emergency, traffic conditions, …) these recommendations could change and a new message or new commands to the MSLS and/or the vehicles are given.

The equipped vehicles work in a similar way to the well known Adaptative Cruise Control, of which they use the technology (SAFE TUNNEL plans to use, when possible, PROMOTE-CHAUFFEUR II demonstrator vehicles), but the control algorithm is new because SAFETUNNEL vehicles have to control both distance and speed.

As far as Moving Spot Light System is concerned, the solution envisaged in SAFE TUNNEL is based on an optical signal installed along the tunnel wall which creates a light beam every
time a vehicle is approaching the entrance in the tunnel. The driver sees the light beam and try to follow it.

This light beam will move along the tunnel with a speed needed for the vehicle to achieve (with comfort acceleration or deceleration) the desired distance from vehicle ahead respecting the maximum speed allowed.

**Fig. 4 : telecontrol application diagram**

**The dissemination of information**

The problem of the dissemination of the information to the driver in case of accident in the tunnel is very important as underlined in previous paper.

The application is devoted to the vehicle equipped with a suitable Human Machine Interface (HMI) and in communication with the Traffic Management Center of the road operators.

The objective of the application is to send on-board vehicle a set of information calibrated according to:

- The accident type (Vehicle breakdown, collision, fire)
- The accident severity
- The position of the vehicle in the tunnel

In case of accident the Control Centre receives from the vehicle its position and the identification parameters (a set of information regarding the vehicle type and the transported goods). As consequences the emergency information (instructions like “please leave your vehicle”, “please U turn in the next stop place”, “go to the next refuge – direction north”, …) are selected and sent to the vehicle. These emergency information will depend on the distance from and severity of the accident. SAFE TUNNEL, in this case, could take benefits from the cooperation with other EU research projects like SIRTAKI.

Messages will use the TMC protocol (Traffic Message Channel), with some integration when needed.
Conclusions

The SAFE TUNNEL concept has the clear objective to reduce the number of accidents in the road tunnels: both primary and secondary accidents.

The approach is based on the basic consideration that the vehicle can provide valuable information that infrastructured systems are not capable to detect with the needed level of precision using external equipments.

On the other hand, the most important tunnels, and in particular the alpine monotube tunnels are already equipped with many ITS that properly adapted are able to provide driving aids in normal conditions and relevant information to the driver in emergency situations.

The step forward, which is the main objective of SAFE TUNNEL, is to “create a link” between these two “different” worlds.
The user need analysis has confirmed a good level of interest of different stakeholders towards the proposed applications.

Concurrently an effort to contain costs is a mandatory condition to achieve a reasonable diffusion of the applications. From this point of view the increasing initiatives of vehicle makers in order to develop open and modular telematic platforms able to host several applications is a valuable point for the gradual diffusion of SAFE TUNNEL concepts related to access control and emergency information distribution.

Also for prognostic applications it is forecasted a gradual transition from current situation, where already a sophisticated diagnosis is available on board, to a situation where most of on board systems will be able to predict failures.

Telecontrol current technologies are mature to demonstrate a great part of this approach still with some technological limitations (for example the radar technology today does not allow a reliable measurement of the distance at 150m (presently the distance required in long monotube tunnels) in open space, and further analysis is needed for the specific tunnel environment).

The possibility to realize telecontrol as a mass production application is linked to the diffusion of Adaptive Cruise Control of which, the distance and speed control defined in our project, is a specific mode of operation. As intermediate bridge solution for non equipped vehicle, the MSLS could be a good alternative.

Taking into account user needs and future exploitation plan the SAFE TUNNEL architecture has been defined and here presented.

Demonstrator have been defined and, currently, design and implementation are on going.

In the first half of next year, validation, user evaluation and result analysis, will be performed.

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References

(1) – SAFE TUNNEL , R. Brignolo, P. Carrea, F Esposito, G. Sala presented at e-Safety ITS congress , Lyon (F) , Sep. 2002

The following SAFE TUNNEL (IST–2000-28099) deliverables *:

(2) - **D02.01** - User Needs Analysis (Tunnel operators) – final version
(3) - **D02.02**  User Needs Analysis (Drivers and Fleet Managers) – final version
(4) - **D02.03**  Tunnel Control and Enforcement Strategy – final version
(5) - **D02.04**  Functional description of SAFE TUNNEL concept – final version
(6) - **D03.01**  System Architecture description – final version

* all these documents together with presentation and the 1st SAFE TUNNEL workshop presentations are available on the SAFE TUNNEL website : www.crfproject-eu.org