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AN INNOVATIVE EXPERT SYSTEM FOR REAL TIME SAFETY MANAGEMENT OF ROAD TUNNELS (ESIMAS)

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Domain:
Transport safety

1. INTRODUCTION

Effective and safe transport infrastructure is essential to guarantee the mobility and supply of the population. Road tunnels have here a special meaning, as compared to the open road, where even smaller incidents such as overheated vehicle part (for example overheated brakes) can cause major impacts, such as devastating fires with many casualties. Several fires in the Alpine tunnels have indicated this fact.

The number and length of road tunnels are significantly increasing both domestically and internationally. To ensure the safety of road tunnels in Germany, tunnels with a certain length have to be monitored permanently by a tunnel control center (RABT 2006[I] & Directive 2004/54/EG). The personal of the tunnel control center must permanently analyze the incoming flood of information, such as camera images and numerous single sensor data, and directly evaluate the safety situation inside the tunnel.

The demand for the tunnel operators is continuously growing. Decisive reasons for this are:

- The increase of traffic density
- The rising number of tunnels that have to be monitored
- The demand of higher safety levels

An extensive infrastructure monitoring and influencing both traffic and prevailing atmospheric conditions inside the tunnel, during normal operation and in the case of an incident, is achieved by the existing technical facilities inside the tunnels. A large number of installed sensors and detectors are used, which deliver on their limited monitoring range, corresponding individual messages and data. A holistic view of the information received is not currently taking place.

In order to process the increasing flood of information, expert systems that provide support are primarily required in the future, which by means of data fusion, supply improved information content, largely automatically evaluate the system and can specify the measures or combination of measures that have to be initiated for successful incident management.

In this present study, the research field and the first results of the project ESIMAS are presented. The abbreviation ESIMAS stands for the German project title “Echtzeit Sicherheits-Management System für Straßentunnel” which means “Real time management system for road tunnels”.

[II] RABT: Richtlinien für die Ausstattung und den Betrieb von Straßentunneln (Guidelines for the equipment and operation of road tunnels)

2. Development of an Innovative Expert System for Real Time Safety Management of Road Tunnels

2.1 Objective and Goals

Aim of this research is to develop an expert system providing an online safety management for road tunnels, which supports the tunnel operators in order to manage properly emergency situations and to enable preventive and reactive measures. In this way, ESIMAS will increase the performance, safety and availability of transport infrastructure, due to the faster and more efficient reaction of the tunnel operators, particularly with regard to the increasing number of monitored tunnels in one control center. The innovative approach of ESIMAS is the holistic view of all individual information and its online risk analysis and evaluation of the safety situation.

ESIMAS is a flexible, modular and innovative system that consists of two major components: the detection system and the expert system. Innovative data fusion and risk assessment tools are the core elements of ESIMAS. These tools help to pool the data as well as perform real-time analysis, plausibility checks and evaluation of safety-relevant data from various detection systems. Common traffic information and innovative detection data will be combined, merged and prioritized in real time. Through the integration of conventional and new detection technologies, such as infrared technology, Automatic Incident Detection (AID) , or video detection, into the existing monitoring system of road tunnels, an optimization can be achieved, especially in the field of prevention.

The main goals of ESIMAS are:

- Faster and more efficient reaction of the tunnel operators by reducing the information burden of them with a primarily automated system.
- Holistic overview instead of individual information.
- Automatic analysis and assessment of the increasing information density.
- Data fusion and plausibilization.
- Continuous risk and safety status evaluation in real-time.
- Automatically generated recommendations.
- Integration of innovative measures for incident management.

2.2 WORK PACKAGES

In order to achieve the above mentioned goals, an amount of eight work packages (WP) are planned to be fulfilled during the project time of 3 years. These WP are divided into several related tasks which are presented in Figure 1.

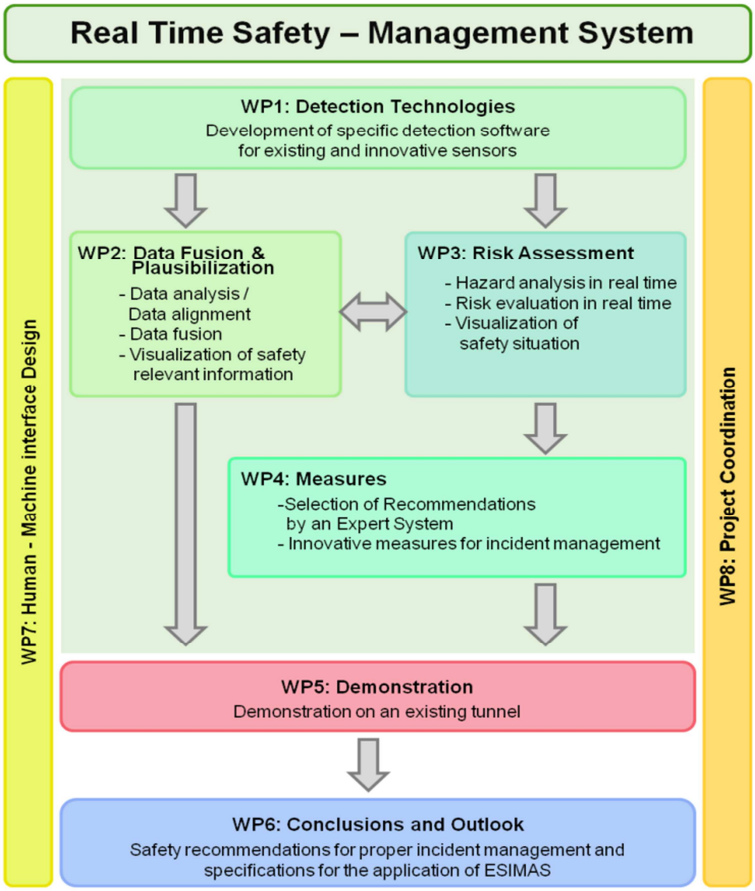


Figure 1: Work packages of the project

In WP-1 new software solutions for the detection systems used in ESIMAS are further developed. The combination of several detection systems is planned in order to achieve redundancy and better detection rates (faster detection and reduction of false alarms). In WP 2 appropriate methods are developed for the analysis, the preparation and the correlation of several sensor data coming from the conventional and innovative detection systems used in Tunnels. In WP 3 methods for detecting and displaying the safety situation inside the tunnel in real time are investigated, based on the results of WP 2 concerning the collection of data and it's fusion. In WP 4, alternate measures and recommendations in order to minimize the potential safety risk in the tunnels are developed. In this way ESIMAS will support tunnel operators in order to manage properly emergency situations and to facilitate preventive and

reactive measures. In WP 5, all developed subcomponents of ESIMAS are combined and integrated in a real tunnel structure during a demonstration phase. Further formulation of the final recommendations based on the results of the project will be carried out in WP 6. WP 7 deals with the analysis of requirements, design, prototype development and evaluation of the human-machine interface of ESIMAS. Parallel to the other WPs, WP 8 focused on the project coordination and quality control.

2.3 Detection Technologies

A variety of sensors and detection systems are currently used for tunnel monitoring. Unfortunately, the conventional detection systems usually work independent of each other, providing an amount of information and sensor data to the operator without evaluating of the occurring incident. This is a major disadvantage for incident management because the operator has to interpret and to merge different values and information in order make a judgment about the safety situation in the tunnel. As mentioned before the development of new detection technologies is one of the two major components of ESIMAS. Aim is also to combine the advantages of the conventional techniques used with new detection technologies in order to increase the incident detection reliability. This fact will be conducted in a next step by fusion and plausibilization of the sensor data. New detection systems, which will be further developed and used in ESIMAS, are presented in the following paragraphs (Figure 2).



Figure 2: Conventional tunnel detection systems and Detection systems in ESIMAS

Table 1 presents the incidents which should be detected with ESIMAS using conventional and new detection systems.

Table 1. Detectable Incidents

Nr.	Detectable incidents	Conventional detection systems					New detection systems			
		Visibility measurement	CO-Measurement	Fire detection cable	Induction loop	Luminance camera	Video detection	Automatic Incident Detection	Laserscanner	Thermal imaging camera
1	Fire of a vehicle	S	S	M		S	M		M	M

2	Too low / too high speed				M		M	M		
3	Traffic jam				M		M	M		
4	Congested traffic				M		M	M		
5	Accident / collision				M		M	M		
6	Too low safety distance				M		M	M		
7	Reversing, turning				M		M	M		
8	Wrong-way driving				M		M	M		
9	Objects on the road						M			
10	Persons on the road						M			
11	Smoke development at a vehicle	S	S			S	M		S	S
12	Vehicle break-down / stop of a vehicle				M		M	M		
13	Overheating (vehicle parts, cargo)								M	M

M=Main information

S= Sub-information

Certain incidents can be detected by several detection systems (for example the development of smoke can be detected by visibility and CO measurement, luminance camera, video detection and thermal imaging camera, except the situation of “cold smoke”). The detection system that can detect the specific incident early and true fully should be determined by the expert system as the main information. The sub detections systems (sub-information) are used to confirm the specific incident by decreasing the failure rate.

2.3.1 INFRARED TECHNOLOGY AND LASER SCANNING (VEHICLE HOTSPOT DETECTOR)

By using infrared line cameras, a non-contact temperature measurement and classification of vehicles in different temperature ranges from about 50 to 300°degrees for the detection of hot spots (e.g. overheating brakes, turbochargers or cargo) is possible. By installing the detector on an overhead gantry sign in front of the tunnel, a timely detection of the vehicles with elevated temperatures can be ensured. The problems in the detection of overheated vehicle parts include the setting of limits and difficult weather conditions. This technology holds great potential for synergy effects in incident prevention intervention.

A similar construction of this detection system is currently being used with great success in Austria. An amount of 60 trucks per month (average value) are detected and banned out of the traffic circulation in order to cool down before passing through a tunnel. All trucks have to pass with very low speed through an old toll station, where the vehicle hotspot detector is installed, before entering the tunnel. The in ESIMAS developed vehicle hotspot detector will be able to measure the vehicle temperatures under normal traffic conditions with a vehicle speed up to 100 km/h.

2.3.2 Automatic Incident Detection- AID (Combination of Induction loops with Weigh-in-Motion

When driving over an AID-measuring point – with an induction loop and a WIM sensor - each vehicle produces a unique electromagnetic fingerprint. By dividing a tunnel into separate tunnel sections using several AID-measuring points, the travel time of each vehicle can be calculated, together with indicators of potential abnormal conditions. Deviations of the expected travel time could indicate a slow or stopping driver due to an accident or a technical defect. The additional information about the vehicle's weight should help the operators to assess the risk situation faster and more accurate especially in case of involvement of hazardous materials. Hence, the initiation of the appropriate assistance for each situation can be improved.

2.3.3 Video detection

Video detection is the computational analysis of video sequences of image contents provided by existing surveillance cameras. By using pattern recognition and tracking algorithms for determining image contents or motion paths, incidents like congestion, slow traffic flow, vehicle on the hard shoulder, accidents, fire or pedestrians on the roadway can be detected (Rios-Cabrera et al., 2012). Major advantages are the possible combination with many other detection systems for validation as well as the possibility of direct control of the relevant sequence. Disadvantages are the still high rate of false alarms in case of some incidents (such as cargo lost or obstacles on the road) and the dependency of the existing video equipment in the tunnel, which partly provides a low-resolution (Haack et al., 2008). During the research project this technique will be further developed, e.g. new shadow algorithms will help to reduce the false alarms caused by changing light conditions.

Video detection can be combined with other detection technologies increasing the traffic safety by recognizing not only incidents what have already happened, but also risk situation before they even occur. The tunnel operator can react faster and more efficient. In this way traffic jams and accidents can be avoided. Positive effect of this detection system is the use of an image method, which provides a high transparency to the operators regarding their acceptance.

2.4 Data Processing &Risk Evaluation & Visualization of an Expert System

Data from the detection systems must be continuously collected via defined interfaces. For the risk assessment in real time, these data are fused and evaluated through a plausibilization process. Sensor data from conventional sensors (e.g. visibility measurement) and tunnel specific values (e.g. statistical accident rates) will be taken into account and certificated through the plausibility control whether the information provided can be associated to a specific incident or not. This procedure last only some milliseconds. If an incident occurs, the associated information is passed to the control system and it appears immediately on the monitor of the operator's interface (Figure 3). In this way, the operator gets a concrete picture of the situation. In addition, ESIMAS should also provide specific instructions for already occurred incidents and recommendations for risk situations.

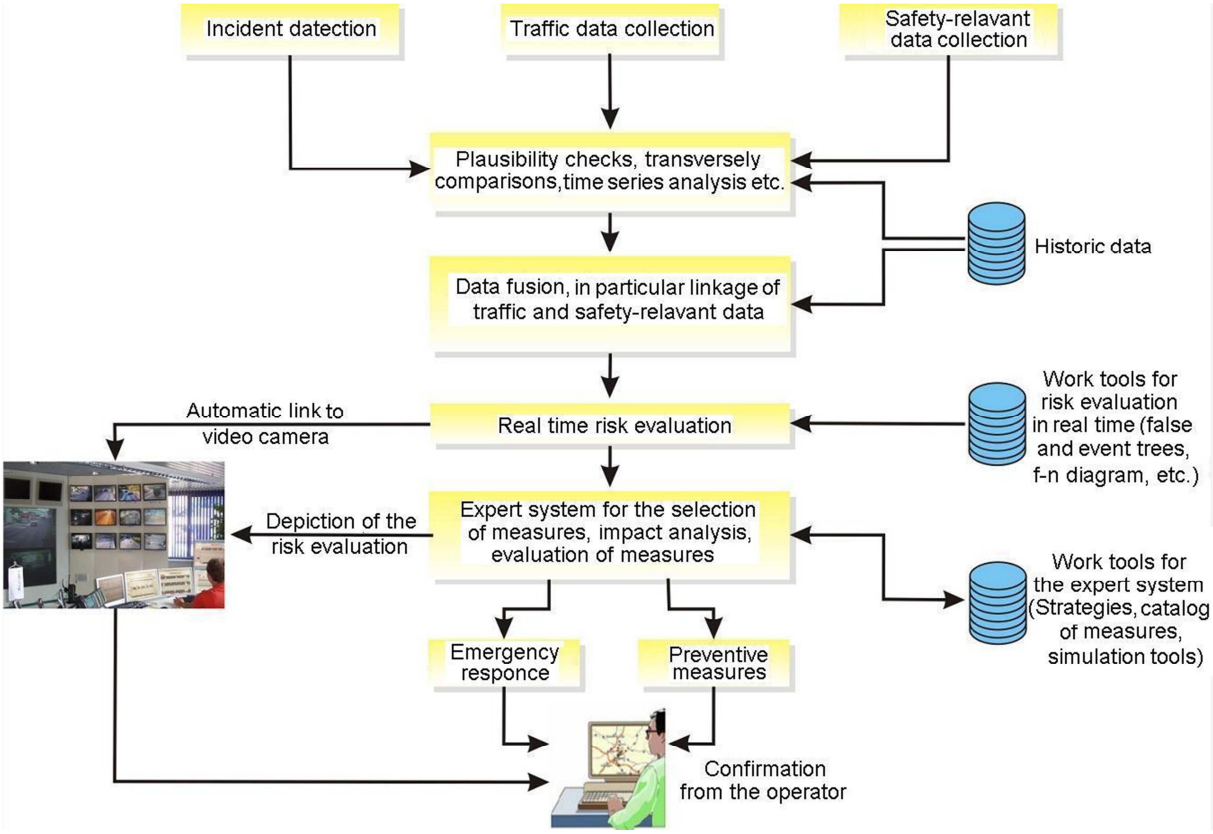


Figure 3: Data flow and the sequence of processing in ESIMAS

The visualization of high risk situations is still under development. Previous similar principles used (Kaundinya et al., 2012) a simple light system to meet the condition of the tunnel statements. Whether this is sufficient for the purposes of ESIMAS will be revealed later in the project.

The major challenge for the research project is the presentation of the entire safety situation of every tunnel monitored and controlled by the tunnel control center. It must be possible for the operator to identify the tunnel that requires increased attention by using ESIMAS. This aspect is particularly relevant if several incidents occur simultaneously in several tunnels. The Expert system will evaluate the present situation in addition to the prioritizing of which incident must be managed first, not according to the “First In - First Out” principle, but taken into account the expected impact of the incidents, the possibility to avoid subsequent incidents and the relevance of the tunnel for the traffic network.

Nowadays, incident management and recommendations regarding measures for specific incidents are defined by the General emergency plans (AGAP) of each German state. These emergency plans are available for each tunnel and usually exist only in paper form. One approach in ESIMAS is to integrate the AGAPs into the expert system. For this purpose, a collection of all measures for each incident and combinations of them, from a representative amount of AGAP must be made, in order to classify and select the appropriate measures which will be used in ESIMAS. Innovative measures and recommendations will be developed for both already occurred incidents and risk situations, where no incident has happened, improving the safety of tunnels. Again the occurring of several incidents in the same time must be considered.

Currently, conceptions are being made of how the expert system can be integrated into the existing users interface. In this framework, the identification of the user requirements of various types of control centers is analyzed. For this reason, a workshop for tunnel operators was organized. Several results were obtained about what the users consider to be particularly important in terms of detectable conditions, preventive action and visualization of information.

Request of the operators was to get merged and clean messages, to know as closely as possible what an incident can possible occur, where it happens and which is the overall safety situation at that moment in this tunnel (entrance of dangerous truck, construction, etc.) and at the entire infrastructure. The operators don’t want any measures to being taken automatic by the system. They want to make their own decisions and to be supported by the system. Measures from the AGAP should always be displayed in form of a checklist. ESIMAS should prioritize the appropriate measures and recommendations, as well as propose necessary combinations of measures from AGAP and recommendations.

Another important issue for users represents the aspect of transparency, especially with regard to the traceability of the message provided by the expert system. Currently, it is checked whether these requests of the users are technically feasible.

2.5 DEMONSTRATION

A prototype of ESIMAS is going to be integrated at a German road tunnel in North Bavaria. Each subsystem of methods, procedures and system components developed in the several WPs of the project will be installed in the demonstrator tunnel, commissioned, operated and optimized for testing purposes. The demonstration phase has a duration time of 30 months and is divided into the following tasks:

- Planning
- Installation of innovative detection systems
- Test phase
- Operational phase
- Analyze of the operational phase

2.5.1 PLANNING

Before planning started, an appropriate tunnel which qualifies as a representative demonstrator had to be found. The overhead noise barrier Goldbach-Hoesbach (Figure 4) in North Bavaria fulfilled this requirement and represents an interesting case due to its traffic relevance (such as high traffic density) and its specific construction characteristics (such as the box cross section in case of a fuming exposure). The noise barrier Goldbach-Hoesbach has two tubes, one for each direction. Each tube is split into two sections due to an entrance and exit cross in the center. The north tube towards Frankfurt exists of two parts with different lengths. The tunnel sector of the north tube towards Frankfurt with a total length of over 1.3 Km was chosen as demonstrator in order to proper simulate different incident situations (such as the outbreak of fire). In this direction the chance of having vehicles' passing with overheated brakes, especially trucks, is relative high due to a steep road slope just before the entrance of the overhead noise barrier Goldbach-Hoesbach. In order to detect these vehicles coming not only from the main highway, but also from sideways, the vehicle hotspot detector will be installed on an existing overhead gantry sign before the smaller part of the north tube.



Figure 4: Overhead noise barrier Goldbach-Hoesbach in North Bavaria

Planning a demonstration system for the detection of vehicles using optical sensor, infrared and laser technology includes first of all the conceptual design and configuration. All technical requirements for the implementation in the existing technology of the tunnel must be clarified. In this step, communication forms and data transfer between the single components of each subsystem (detection systems) need to be clarified in order to complete successfully the integration of the expert system into the tunnel control center. All necessary interfaces and protocols have to be defined. Investigations have been conducted in order to determinate the best installation locations for the additional sensor which will be used in the ESIMAS project and have to be installed in the existing tunnel structure.

2.5.2 INSTALLATION OF INNOVATIVE DETECTION SYSTEMS

After the documentation of the boundary conditions the installation of all components into the tunnel structure and into the tunnel control center can begin. All the required installation and integration works must not affect the normal operation of the tunnel and the tunnel control center. For this reason, the installation of the required sensors for the AID (induction loops + WIM) and the vehicle hotspot detector (laser scanner and thermal imaging camera) will be installed during two planned semi- blocking phases of the demonstration tunnel. During these phases the traffic will be redirect and the sector where the sensor are planned to be installed is free of traffic. For the video detection system no new cameras will be installed and the existing cameras for video surveillance will be used.

2.5.3 TEST PHASE

At the test phase each installed subsystem will be setup, tested on general function and finally taken into operation. Initial data and results from the developed analysis software from WP 1 will be demonstrated at the tunnel structure. The ESIMAS project partner will complete the necessary test runs in order to develop a full functional prototype of ESIMAS. In order to improve the accuracy and reliability of the detection systems, several scenarios, which due to safety reason cannot be tested on a tunnel under operation, should be tested during a planned semi-blocking of the tunnel (Table 2).

Table 2. Test scenarios at non working tunnel

Nr.	Test Scenario	Conventional detection systems					New detection systems			
		Visibility measurement	CO-Measurement	Fire detection cable	Induction loop	Luminance camera	Video detection	Automatic Incident Detection	Laserscanner	Thermal imaging camera
1	Objects on the road						M			
2	Persons on the road						M			
3	Smoke development at a vehicle	S	S			S	M		S	S
4	Vehicle break-down / stop of a vehicle				M		M	M		
5	Overheating (vehicle parts, cargo)								M	M
6	Reversing, turning				M		M	M		
7	Wrong-way driving				M		M	M		

M=Main information

S= Sub-information

The entire test procedure requires a very close cooperation between the project partners and the tunnel owner.

2.5.4 OPERATIONAL PHASE

In the operational phase each Project partner has to perform final parameterizations of his subsystems. The prototype of ESIMAS is going to run in an evaluation mode, which will be

continuously monitored and optimized online (update of developed software). The test operation includes all traffic and operating conditions, such as may occur in a later control mode.

In order to manage properly emergency situations and to facilitate preventive and reactive measures the expert system has to recognize and distinguish high from low risks. Table 1 presents risk situations which are suggested to be detected in ESIMAS. Accuracy and early stage of incident detection is achieved again through fusion and plausibilization of the several sensor data.

2.5.5 ANALYZE OF THE OPERATIONAL PHASE

An analysis and assessment of the achieved results is going to be conducted during the entire test operation of ESIMAS due to further improvement of the safety management system. It will determine whether the collected data for risk assessment in the tunnel is sufficient and whether the underlying decision of the expert system algorithms reflect a proper risk assessment. The analysis of the results will determine whether and in which level it is possible to distinguish during the detection between situations of high and low risk. After evaluating the results proposals for optimizing the system will be generated.

3. CONCLUSION AND OUTLOOK

The essential scope of ESIMAS is to increase safety in road tunnel by minimizing significantly the work load of the operators in the tunnel control centers, especially taking into account the growing number of monitored tunnels in one tunnel control center. Through the use of new and improved detection systems and integrated risk assessment in real time, the operator shall be provided with a tool to gain an overview of the entire safety situation of all monitored tunnels. In this process, the combination of the individual subsystems and integration of ESIMAS into the tunnel control center must be accomplished without the occurring of incorrect transmit of relevant information and an overflow of irrelevant information. Significant attention has to be given to the minimization of false alarms, as it is expected with any other acceptance of the operators of the system. However, they are closely involved since the project began at the same time to ensure the development of a user-based system. However, especially in the first test phase where the system will be set with a very sensitive mode, it is to be expected that in particular for the detection of risk situations a continuous calibration and parameterization must be performed. Definition of alarm thresholds will be also focused on in the first test phase. Hopefully after a successful testing

and operational phase at the demonstration tunnel, the developed expert system will be modified and used for other tunnels.

4. Acknowledgements

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