METHODS OF RISK ANALYSIS OF TELEMATIC OBJECTS

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Summary: The paper focuses on basic description of the tunnel as a telematic object and its architecture. Conventional methods of risk analysis of telematic objects are introduced in relation to their safety. New approaches of risk quantification are shown in connection to existing legislation and directives of European Commission.

1. TELEMATICS AND INTELLIGENT TRAFFIC SYSTEMS

Telematics is a systematic engineering field, dealing with creation and purpose-made utilization of information environments for homeostatic processes of territorial complexes, up to global field network.
Telematics results from convergence and subsequent combination of telecommunication technologies and informatics with support of management economy and mathematical methods for creation and control of complex systems. The effects of telematics is shown in wide spectrum of user area, from multimedia communication of individuals up to intelligent application and control of global network fields such as transport, connections and public administration.
Intelligent traffic system integrates information and telecommunication technologies into traffic engineering with support of other related subject fields (economics, traffic theory, etc.) so that increases traffic performance, safety and comfort of transport.
Practically traffic telematics represents information and telecommunication support of traffic process. Detailed explanation can be found e.g. in [1].

2. THEORETICAL PART

Tunnel as a telematic system

Tunnel is a traffic system which works with large amount of data. In the system there are measured:

- Traffic data,
- Technological data,
- Weather conditions,
- Ecological conditions.

Besides it is necessary to reliably transfer verbal information from SOS boxes and television surveillance is of high significance level too. Large amount of data is related to use of security system (emergency push button, automatic call point) and more over data from own technology is joined to ensure ventilation, illumination, etc. In case of the tunnels it is necessary not just to communicate reciprocally with gateways, police dispatching, but also to ensure relations from control point of view.
The tunnel equipped with relevant technologies is one of the fundamental telematic subsystems and has to be integrated into the central traffic control centre of the telematic system.

Tunnel system architecture

Traffic telematics point of view describes tunnel architecture on the base of user's requirements. According to [2], the architecture is split into the following parts:
Functional – forms and defines individual element, module and subsystem functions including relations between them and thereby allows forming applications;
Informational – defines principles of creation the structure of relevant informational subsystem including requirements for allocation, coding and transfer of information;
Physical – defines physical equipments which perform single functions to ensure functionality of applications hence assigning individual elements, modules and subsystems defined in functional architecture to relevant physical equipment;
Communicational – describes system information transport in relation to the physical architecture.

Graphical interpretation of this classification is shown in figure 1. The tunnel system at the bottom layer is represented by physical reality: actual tunnel, interactions, buildings, equipment…
Second layer represents detailed subdivision to physical systems and devices. On the base of this division it is possible to visualize physical model which should not be connected with concrete elements or suppliers but should be as general as possible.
The abstract description takes place in the top layer where functions are assigned to the physical entities, relations between functions are defined and information flows help to define communication architecture. Whole activity is ensured by organizational configuration which the organization architecture is created by.

The tunnel technology consists of hierarchical subsystems: safety, ventilation, lighting, traffic, control system, operation. Each of those subsystems has its own architecture.

The source of information is technological equipment of tunnel. It is a regulated system consisting of individual functional complex sensors and acceptors – the output elements intermediating contact with drivers. The basic functional complexes of tunnel are traffic subsystem, safety and technical subsystems ensuring tunnel functionality. System behaviour is determined by the central control system according to predetermined models.

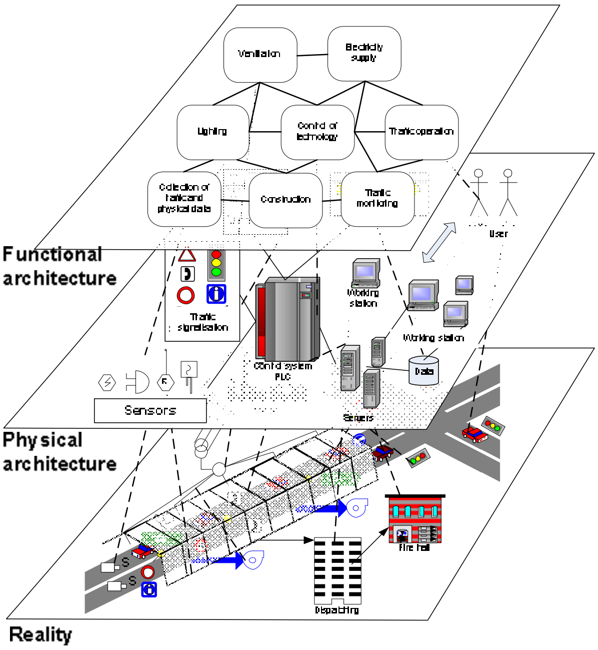

Fig. 1. Tunnel system architecture

For proposing of functional complexes there are used exact procedures (calculation, simulation, modelling) or expert methods (use of statistical methods for analysis of historical events, assessment carried out by experts, fuzzy rules implementation into decision processes). The advantages of this group of methods are proved by solving extraordinary situations (fire, accident).

The most important factors participating on total risk level which are endangering traffic participants using the highway tunnel are [2]: traffic participants discipline, reliable and safe function of tunnel technology, correct and coordinated dispatching activity, regular accountable prophylaxis, diagnostics and maintenance of tunnel subsystem components, quality of technical personnel operation, immediate traffic state (density and composition), weather conditions and finally the safe condition of technologies in extraordinary situations, circumspectly behaviour of participants, fast and organized intervention of integrated rescue services.

Concept of the risk

Systems in which failure can cause dangerous or hazardous state are usually termed as safety-critical systems (SCSs) or safety-related systems (SRSs). SRSs come under the group of critical processes. Control of critical processes is set apart from control of conventional (non-critical) processes by selection of assortment of resources that enables to predetermine behaviour of the system when the specific group of failures occurs. SRSs claim extraordinary consistency in stage of their specification and design to prevent errors in its realization. Hazard is a source of jeopardy (harm) and risk is the measure of this jeopardy. Situation or state of the system in which some predictable possibility of harming of persons or physical elements of the system exist is mostly considered as hazard. It is impossible to speak about harming in the system where no hazard is. Also it is not possible to evaluate risk which is represented by harm if there is no harm. The term risk *R* is used for quantitative or qualitative evaluation of possibility of harming. It is usually defined as affect or consequence of undesirable event occurrence per time unit [3]. These are basic values which are standardized (e.g. passenger per kilometre etc.) and simple mathematical model (1) can be deduced out of them. The model is common in risk analysis and it is used for systematic and objective expression of quantitative intensity of risk.

$$R = HR \times V \qquad (1)$$

The risk arising from i-th event occurrence U_i can be expressed:

$$R_{Ui} = HR_i \times V_i \qquad (2)$$

Total risk which represents event occurrence is:

$$R = \sum(HR_i \times V_i) \quad ! \leq R_{accept} \qquad (3)$$

The acceptable risk (R_{accept}) of the system is represented as multiplication of intensities HR_i and consequences V_i. It has to be less or equal to risk which is admissible in the analyzed system.

3. GENERAL PRINCIPLES OF RISK DEFINITION

In technical and scientific literature the risk itself is informally expressed by many manners. Most frequently as probability of undesirable event occurrence, subsequence of undesirable event occurrence and probability of undesirable event occurrence multiplied by its consequence. The third one is most used, because in practice it takes in consideration both probability of occurrence and the consequences.

Safety chain

Integrated safety for tunnels is often presented as a so-called 'safety chain' – figure 2. It is considered inefficient to focus on the improvement of the safety performance of only one link, without consulting the safety performance of the other links.
The safety chain consists of the following links:
- *Pro-action:* avoids unsafe situations in a tunnel by the elimination of all root causes. This includes the structural and operational safety measures during the planning phase before construction of new tunnels or refurbishment of in-service tunnels;
- *Prevention:* reduces tunnel accident probabilities;
- *Mitigation:* mitigates the consequences of a tunnel accident as much as possible. This includes taking measures in the case of an accident, enabling the tunnel users to rescue themselves (*self-rescue*) before the rescue teams arrive;
- *Preparation:* represents the emergency preparedness (such as the training of rescue personnel);
- *Repression:* makes sure that adequate support by public rescue teams will be provided in the case of serious consequences after an accident;
- *After-care:* does all that is needed to return to 'normal' (e.g. assistance to victims and settlement of damage).

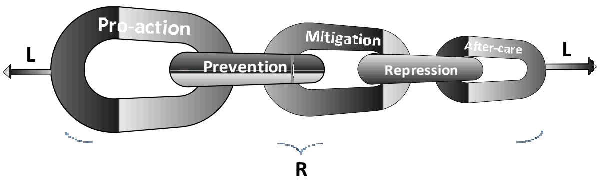

Fig. 2. Safety chain

Shape of the chain has to adapt to requests of safety measures of the actual risk. Prevention is of course of primary importance, and therefore this link is bigger than the others. In practice it is not always possible to prevent all events, therefore when an accident or fire has occurred, the most effective response is self-rescue (mitigation) of users inside the tunnel. Hereby the consequences of an accident will be reduced because the rapid development of a fire can make any intervention ineffective after e.g. ten minutes, and emergency services cannot generally reach the fireplace in such a short time. Hence, it is inefficient to focus on improvement of the safety performance of only one link, without consulting the safety performance of the other links. It is obvious that such a narrow focus will not enhance the strength of the total chain. An acceptable resistance of the chain to "unsafety loads (L)" (tunnel system safety demand) can only be created by enhancing the "unsafety resistance (R)" (tunnel system safety performance) of each link of the chain and therefore the emphasis is put on strength of the total chain.

Causal chain

Another graphic form used to express the tunnel safety aspects is the causal chain. In most cases, accidents are determined by certain pre-conditions (causes) and the accident development processes determine the seriousness of the accident effects. This can be expressed graphically by regarding the accident as a nodal point between the pre-conditions (causes) and the effects (consequences) by the chain with Causes–Accident–Effects, called the Bow Tie Model.

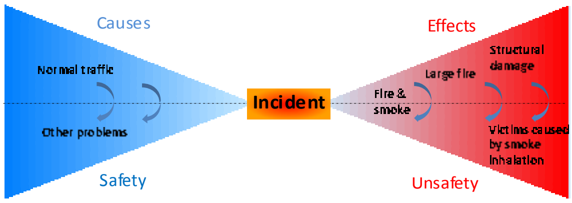

Fig. 3. Bow Tie Model

Both tie sides contain the points of action to influence the events before or after the incident. On the left side, attention should be given to accident prevention (for instance brake overheating of trucks). On the other side, the mitigation (for instance of a small fire turning into a large fire) and suppression of accident effects (such as smoke or toxic gasses) is of crucial importance.

An integrated approach for road tunnel safety

An integrated approach to tunnel safety means taking into consideration at what point in the safety chain the necessary activities take a start and which parties and departments should be involved during the life of a tunnel.

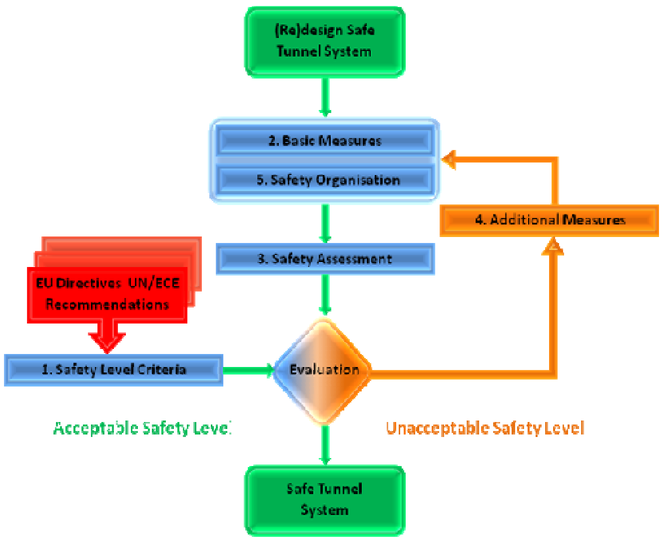

Fig. 4. Schematic representation of integrated safety system

Figure 4 shows a schematic representation of the integrated approach to tunnel safety as developed by the Centre for Tunnel Safety of the Dutch Ministry of Transport, Public Works and Water Management. This approach takes in consideration not just the technical measures and security management but also possibilities to self rescue of the tunnel users and response to situations of emergency and collision. Created computing model allows realizing quantitative risk analysis of tunnels including car fires, leakage of dangerous goods, traffic congestions, timely detection effects, various ventilation strategies, manual or automatic action of operator or control system and man escape strategy.

4. DISCUSSION

In general for risk assessments there are used quantitative and qualitative methods.
For quantitative (numeration) risk assessment tree diagrams are used in world scale. These diagrams are relatively complicated and their limit lies in subsuming a large set of variables influencing the safety in to the risk assessment. It makes the diagrams very chaotic. This type of analysis is very detailed and therefore requires most of the time which makes the research very expensive.
The other method (qualitative) is pretty original and heretofore it was not published in world scale. The core of the method is that it utilizes tree diagrams for the qualitative assessment but it significantly reduces the problem dimension which makes the method very transparent and easy to repeat. The problem reduction lies in the use of expert method based on fuzzy approach.
For qualitative risk assessment the unified modeling language (UML) can be used. UML is a graphic representation of the common safety concept which is applicable for any of road tunnels. It allows to research situations of type of a fire or accident with injuries by object oriented approaches based on state models and models representing system dynamics. These are basis for risk analysis in the form of scenario analyses or analyses based on probabilistic trees.

5. CONCLUSION

The safety of traffic and traffic systems is expressed as condition when the risk of harming of human health or the material damage is eliminated to the acceptable level. Safety has become one of the crucial criterions in traffic quality assessment. System of traffic quality assessment uses whole series of indicators which are mostly reciprocally conditioned or supported by each other.
The paper is introductory paper to dissertation thesis of the first author which engages with creation of new theoretical apparatus for analysis and assessment of road tunnels risk. Present contribution lies in analysis of present approaches to definition, quantification and assessment of risks. Further process is to deal with question of assessing of approaches, description and modelling of the system from process dynamics perspective and developing of theoretical apparatus for reduction of problem dimension. Last steps should be the quantitative risk analysis and formulation of the risk assessment methodology.

Acknowledgement

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