DEVELOPMENT AND IMPLEMENTATION OF AN INTEGRATED TUNNEL SAFETY MANAGEMENT SYSTEM

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ABSTRACT

The objective of this paper is to provide a generic framework for developing and implementing a Tunnel Safety Management System (TSMS). The development of the content and structure of the proposed TSMS was based on: i) the plan, do, check, act management cycle, ii) the tunnel lifecycle elements (i.e. design, construction, operation, maintenance, and refurbishment), and iii) the prevailing legal, institutional, organizational, operational and technological environment. The implementation of the proposed approach led to the identification of a set of guidelines for developing a TSMS.

1. INTRODUCTION

Tunnel safety constitutes an essential element of transportation system safety. The importance of tunnel safety led national governments and international organizations to develop guidelines for improving the safety performance of tunnels (UNECE[1], EU[2], Hale[3], SAFE-T[4]). Tunnel safety management constitutes a complex process that involves the planning, implementation, and monitoring of a set of measures that aim to prevent tunnel incidents and/or reduce the associated potential consequences. A critical success factor in improving tunnel safety performance relates to the development of an overall safety management system for: i) monitoring the performance of the existing tunnel facilities, services, and operations, ii) identifying potential sources of intolerable risk, and iii) coordinating a process for establishing additional safety measures and appropriate interventions (i.e. political, institutional, organizational, technological).
The objective of this paper is to propose a generic framework for developing and implementing integrated tunnel safety management systems (TSMS).
The remainder of this paper consists of three sections. Section two presents the methodological framework used to determine the proposed TSMS structure and content while section three describes the constituent elements of the system. Section four provides the guidelines for implementing the proposed TSMS.

2. METHODOLOGICAL APPROACH

Tunnel safety management system (TSMS) is defined as a set of integrated management processes that aim to improve the safety level throughout the whole lifecycle of the tunnel (SAFE-T[4]).

The content and structure of a TSMS can be defined by considering the following three dimensions (see Figure 1): the tunnel lifecycle, ii) the management stages applied at each phase of the tunnel lifecycle, and iii) the prevailing legal, institutional, organizational, operational, and technological environment.

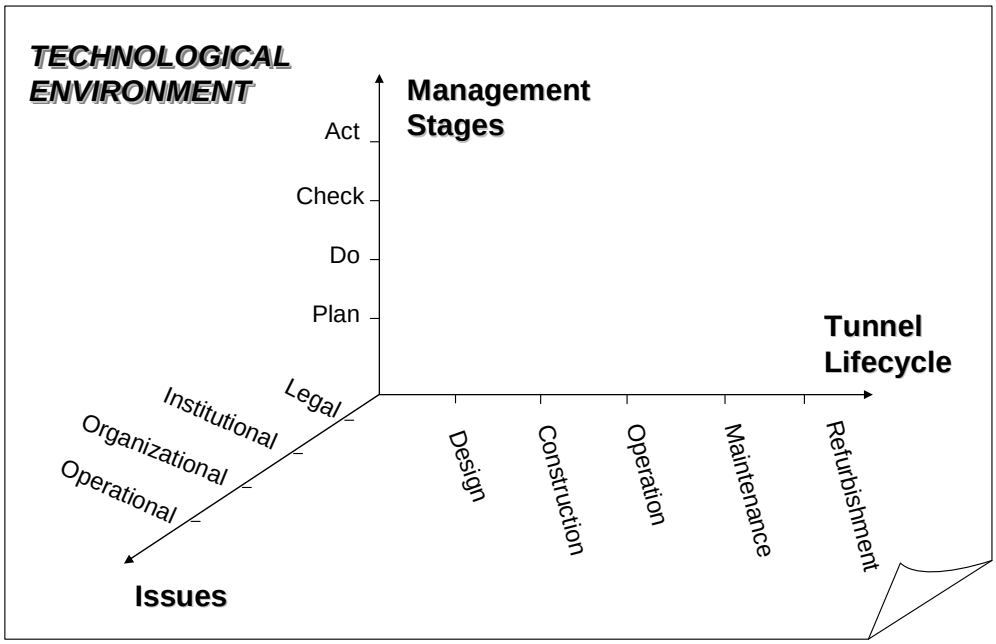

Figure 1. The integrated view of the Tunnel Safety Management System

The scope of the TSMS covers the entire tunnel lifecycle including the following phases: i) design, ii) construction, iii) operation, iv) maintenance, and v) refurbishment.
In each phase of the tunnel lifecycle, safety should be considered at all four management stages i.e. “Plan”, “Do”, “Check”, “Act”. “Plan” refers to the determination of the major safety planning processes and their interrelationships. “Do” involves the safety processes that refer to the implementation of the safety plans. “Check” refers to the assessment of the tunnel safety performance and “Act” covers the legal, organizational, operational, and technological interventions needed to improve tunnel safety. Figure 2 illustrates the four safety management stages. The concept presented in the graph implies that the sequential repetition of the four management stages leads to tunnel safety improvement (Ross[5]).

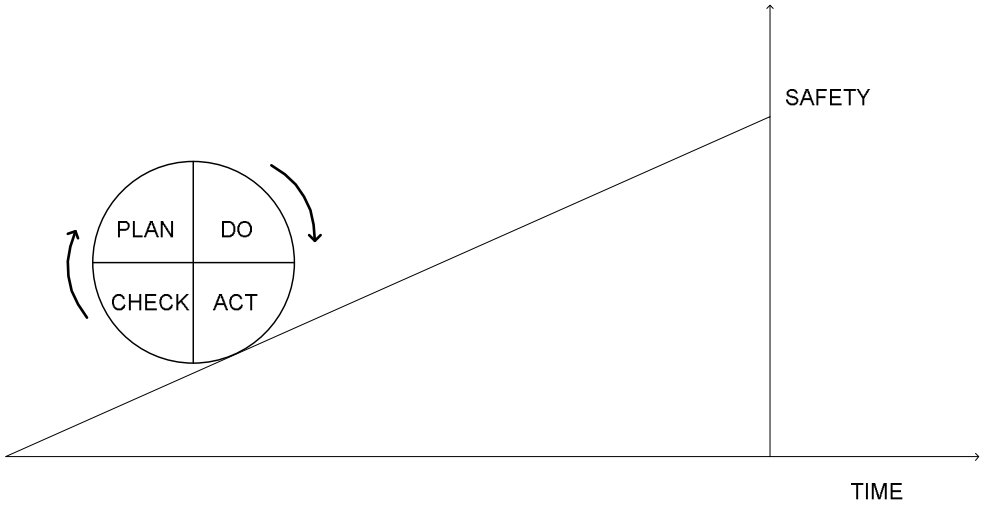

Figure 2. Tunnel Safety Management Stages

The development of an integrated TSMS should consider: (i) the legal and institutional environment, (ii) organizational issues, and (iii) the operational and technological requirements of the tunnel. The legal issues on tunnel safety refer to the regulations on tunnel infrastructure management and operation that are established and enforced by law. The institutional framework of the TSMS refers to the set of policies and basic regulations on tunnel safety management and organization that emerge from the associated legislation. The organizational and operational issues of a TSMS are specified by the relevant national or/and international legislative and institutional framework. Thus, TSMS encompasses all safety activities that should be taken into account in each management stage and phase of the tunnel lifecycle. These safety related activities should also comply with the prevailing legal, institutional, organizational, operational, and technological environment.

The identification of the constituent elements and structure of a TSMS was based on the methodological framework illustrated in Figure 3. The objective of the proposed approach is to determine the legal and institutional framework, the organizational structure of the tunnel management system, and the operational and technological requirements for the tunnel operation. The specification of the legal and institutional environment at each management stage (i.e. Plan, Do, Check, Act) was achieved through the collection and analysis of the relevant national and European (EU) legislation on tunnel design, construction, operation, maintenance and refurbishment. The organizational structure of the tunnel system was determined through the specification of the role of the major stakeholders involved in or affected by each management stage and tunnel lifecycle phase. Finally, the constituent operational and technological issues emerged from the national and European legislation and the best practices across the seven member states that participated in the SAFE-T project (SAFE-T[4]) i.e. Spain, Italy, Norway, Austria, Germany, Netherlands, and Greece. The analysis of the collected information on the aforementioned issues led to the development of an integrated view of the TSMS and the specification of the major safety activities within each management stage.

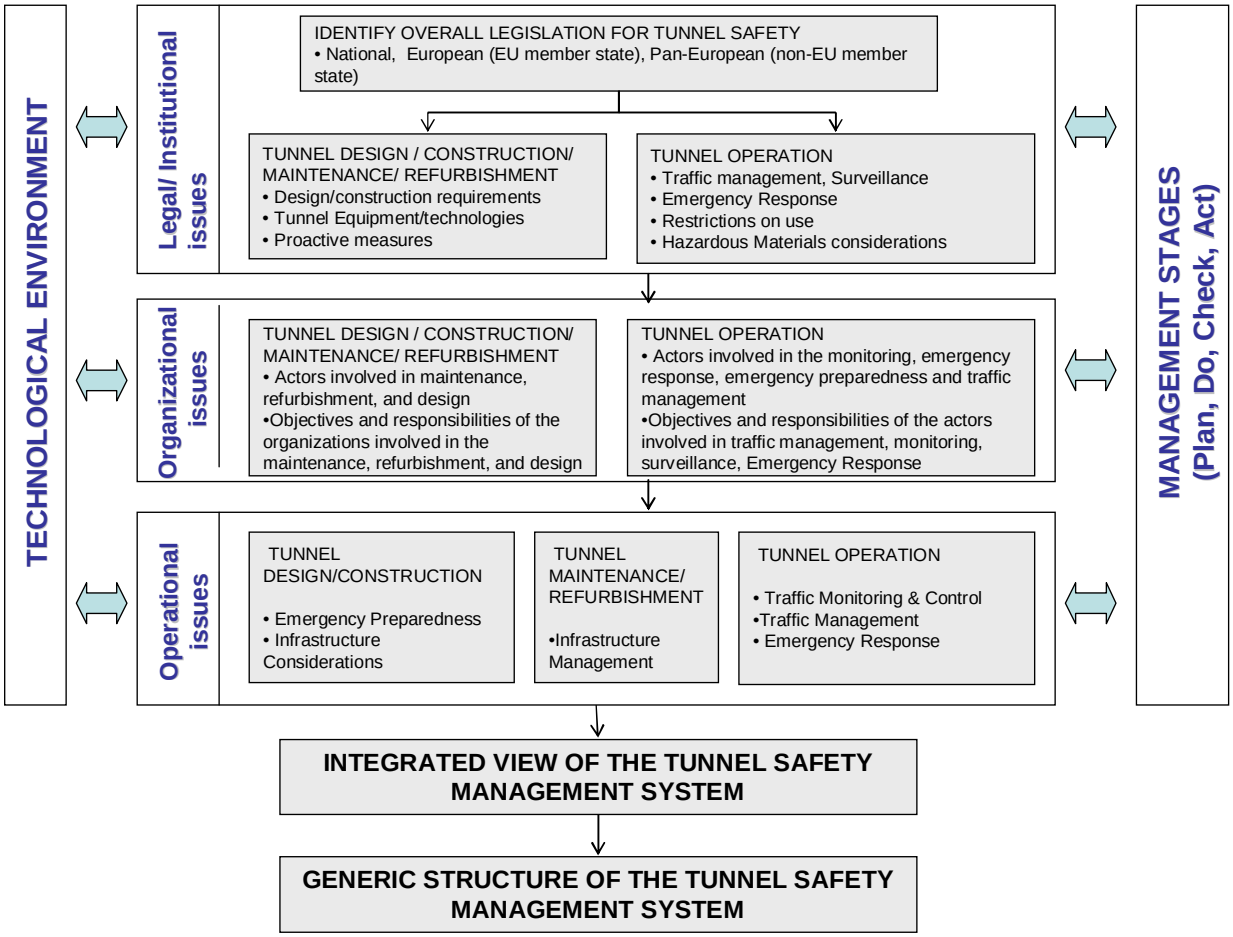

Figure 3. Methodological approach for developing an integrated Tunnel Safety Management System

3. THE PROPOSED TUNNEL SAFETY MANAGEMENT SYSTEM

The analysis performed on the basis of the framework presented in the previous section led to the development of a generic Tunnel Safety Management System (TSMS) that takes into account the following objectives:

- Provision of the necessary structural and operational safety considerations during the design/planning phase (before tunnel construction or refurbishment).
- Identification and implementation of processes and precaution measures for avoiding tunnel incidents (e.g. traffic management measures to avoid accidents or the establishment of monitoring process of the incoming and outgoing traffic).
- Provision of emergency preparedness measures and processes for establishing efficient emergency response services and operations.
- Provision of all necessary incident/accident repression measures for mitigating the incident/accident consequences.
- Provision of measures for post-incident services i.e. operations performed after the repression stage in order to restore the normal conditions of the tunnel operation
- Evaluation of the incident/accident features, impacts, and the response of the emergency response system (e.g. accident investigation).

- Management of the archival information for future planning and monitoring of the compliance of regulations and laws
- Human Resources training and skills development

Figure 4 presents the major components of a TSMS and their interrelationships. In particular, the proposed TSMS is defined as a continuous process that involves the following repetitive sequential components that span the entire tunnel lifecycle: i) Plan, ii) Do ,iii) Check, and iv) Act.

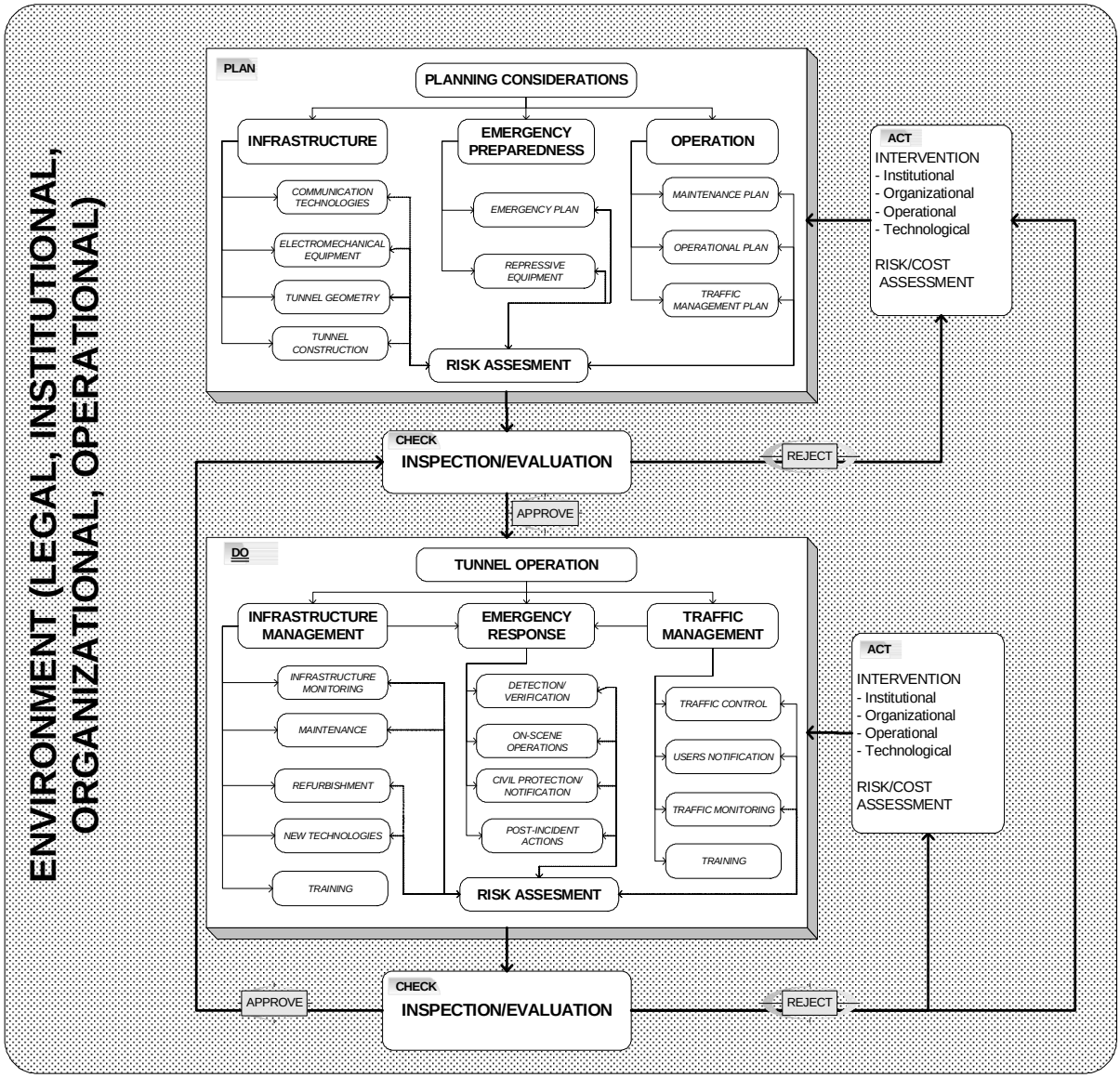

Figure 4. The content and structure of the proposed Tunnel Safety Management System

The "Plan" stage of the proposed TSMS involves the following considerations: (i) determination of the design standards of the tunnel infrastructure, (ii) planning of the tunnel operation, and (iii) organization of the emergency response process. In establishing tunnel design standards it is necessary to set minimum equipment requirements covering communication technologies, electromechanical equipment (ventilation system, detection system etc.), and tunnel geometry and design specifications (e.g. tunnel height, width, emergency exits).

The planning element of TSMS addresses safety issues related to maintenance, traffic management, and emergency response. The content of these plans stems from best practices across Europe and the minimum requirements implied in the EU Directive. Enhancements or modifications to the aforementioned plans may be induced by legal, institutional, organizational, and operational changes. Risk Assessment constitutes a central process in the "Plan" component of the TSMS.

The "Do" component of the TSMS involves a set of processes that contribute to the safety objective and relate to infrastructure management, emergency response and traffic management. The infrastructure management involves the following activities:

- Infrastructure Monitoring: this process involves the procedures established within the tunnel control/management that aim to check, record and assess the technical conditions of the tunnel equipment and the physical conditions of the tunnel structure.
- Maintenance and Refurbishment, which refer to the operations for regular or unplanned (due to technical failure) maintenance of tunnel equipment.
- Introduction of New Technologies: this process involves the identification of new technological improvements that should be embedded in the tunnel infrastructure in order to improve the tunnel safety.
- Training: a basic prerequisite for the efficient and safe operation of a tunnel is the training of the tunnel personnel in order to achieve a high security level during the maintenance and tunnel monitoring operations.

Emergency response involves the operations that contribute to the mitigation of the incident consequences and aim to restore normal operating conditions for the tunnel. The objective of the tunnel emergency response system is to provide all necessary incident repressive measures required to: (i) safeguard the health protection of the users and the tunnel operation personnel, (ii) control promptly the incident consequences and restrain them from producing potential hazards, (iii) protect the tunnel structure and equipment from damage, and (iv) restore the normal conditions of tunnel operation. A typical emergency response system consists of the following stages: (i) incident detection, (ii) incident verification, (iii) dispatching of emergency response units, (iv) on-scene emergency response actions (e.g. consequences repression, evacuation of tunnel etc.), (v) post-incident actions (e.g. traffic conditions restoration, incident investigation etc.). The effectiveness of the emergency response process depends on: (i) the prompt and accurate incident notification provided by the monitoring processes of the TSMS, (ii) the degree of training of the responders, (iii) the level of emergency preparedness in terms of emergency response planning and repressive measures. Finally, traffic management involves a set of operations that aim to manage incoming and outgoing tunnel traffic flow in order to prevent incidents or notify in real time the users (drivers) about the occurrence of an incident. Traffic Management includes: (i) traffic control, (ii) user notification, (iii) traffic monitoring and (iv) training. Typical traffic management measures are the road signing, traffic signal setting, tunnel closure, and traffic redirection. The safety performance of these processes within the "Do" component of the TSMS are evaluated through risk assessment. The risk assessment objective is to verify the safety level within the tunnel given the existing tunnel safety procedures and measures.

The monitoring of the risk level during the tunnel operation constitutes the "Check" component. The information collected through the inspection process is evaluated in order to identify the type(s) of intervention required for improving the safety level of the tunnel operation. The objective of the "Check" component is to enable the TSMS to continuously evolve towards improved levels of safety taking into account the: (i) current performance, (ii) technological progress, and (iii) expected operational conditions of the tunnel (e.g. expected demand).

The implementation of the proposed interventions constitutes the "Act" component of the TSMS. These interventions may be institutional, organizational, or operational.

4. CONCLUSIONS AND RECOMMENDATIONS

The analysis performed for the development of the proposed TSMS led to the formulation of the following guidelines that are suggested to be taken into account in organizing and structuring a TSMS:

- Risk assessment should be performed in the "plan", "do", "check", and "act" stages of a TSMS throughout the entire tunnel lifecycle. The risk assessment methodology used may vary according to the phase of the tunnel lifecycle and the management stage. Therefore, depending on the management stage and the phase of the tunnel lifecycle, appropriate risk assessment methods should be proposed.
- The selection of the most appropriate interventions (institutional, organizational or operational) for improving tunnel safety should be based on Cost-Risk Assessment. The objective of this type of assessment is to determine the cost-effectiveness of each alternative intervention in terms of risk mitigation.
- The TSMS should be continuously tested by an inspection and evaluation system that monitors and assesses the tunnel operation conditions in terms of safety.
- The actors performing tunnel safety inspections should be certified. The certification should ensure the competence of the inspectors.
- Coordination and cooperation of the involved tunnel actors throughout the entire tunnel lifecycle is a key success factor. The roles and responsibilities of all actors should be carefully identified in order to eliminate overlapping and gaps of responsibility.
- The integration of the tunnel safety management technologies should allow the efficient flow of information among all actors involved in any of the management stages throughout the tunnel lifecycle.
- The tunnel safety management technologies should facilitate collaborative decision making. The flow of information through integrated tunnel safety management technologies, is expected to facilitate the collaborative decision making process.
- A critical issue in establishing the proposed structure of the TSMS refers to the training of the staff of the tunnel. The provision of training should aim at improving the safety culture of the staff of the tunnel operators and administrators.

The content and structure of the proposed TSMS led to a set of recommendations regarding the essential characteristics of the TSMS. Thus a TSMS should be:

i) Integrated: including the tunnel safety processes that refer to each phase of the tunnel lifecycle (design, construction, operation, maintenance, and refurbishment) and the operational components (i.e. tunnel structure, tunnel manager, tunnel operator, and users) of a tunnel system. Furthermore, it considers all types of intervention (legal, institutional, organizational, technological, and operational) throughout the tunnel lifecycle.

ii) Dynamic: implying that the operation of the system should be based on the continuous evaluation of tunnel safety. The evaluation process should take into account changes that occur over time on the tunnel system and its environment and should provide feedback by specifying the necessary interventions for enhancing tunnel safety.

iii) Holistic: enabling the coordinated and central monitoring and control of the tunnel safety level.

iv) Coordinative: in terms of minimizing the gaps and overlapping of responsibility among the stakeholders.

5. ACKNOWLEDGEMENTS

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