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RiskSOAP: Introducing and applying a methodology of risk self-awareness in road tunnel safety

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A B S T R A C T

Complex socio-technical systems, such as road tunnels, can be designed and developed with more or less elements that can either positively or negatively affect the capability of their agents to recognise imminent threats or vulnerabilities that possibly lead to accidents. This capability is called risk Situation Awareness (SA) provision. Having as a motive the introduction of better tools for designing and developing systems that are self-aware of their vulnerabilities and react to prevent accidents and losses, this paper introduces the Risk Situation Awareness Provision (RiskSOAP) methodology to the field of road tunnel safety, as a means to measure this capability in this kind of systems. The main objective is to test the soundness and the applicability of RiskSOAP to infrastructure, which is advanced in terms of technology, human integration, and minimum number of safety requirements imposed by international bodies. RiskSOAP is applied to a specific road tunnel in Greece and the accompanying indicator is calculated twice, once for the tunnel design as defined by updated European safety standards and once for the 'as-is' tunnel composition, which complies with the necessary safety requirements, but calls for enhancing safety according to what EU and PIARC further suggest. The derived values indicate the extent to which each tunnel version is capable of comprehending its threats and vulnerabilities based on its elements. The former tunnel version seems to be more enhanced both in terms of it risk awareness capability and safety as well. Another interesting finding is that despite the advanced tunnel safety specifications, there is still room for enriching the safe design and maintenance of the road tunnel.

1. Introduction

Many civil engineering systems combine both "socio", i.e. people and society, and "technical", i.e. machines and technology, components (Walker et al., 2008) working together and interacting in order to achieve the purpose of the system. On that account, many civil engineering systems may be considered as complex socio-technical systems. Road tunnels, for instance, consist of many parts, controlled by human or automated agents being in constant interaction and close cooperation with each other, though usually located in different hierarchical levels and at distant regions. Communication and control among the system agents are critical attributes of a tunnel in order to make itself aware of possible threats and vulnerabilities and, therefore, to enhance its resilience and safety. Ideally, such attributes should be originally embedded into systems, so that they can meet their utmost purpose to be in service for people and apply a variety of traffic conditions for ensuring the safety of people that use the infrastructure.

Being aware of a system's threats and vulnerabilities is a prerequisite for its safety, so it is generally accepted that safety and awareness are positively correlated (Chatzimichailidou and Dokas, 2015). Building upon this relationship, the Risk Situation Awareness Provision (RiskSOAP) methodology is introduced for the first time to the field of road tunnel safety. The risk SA provision reflects the inherent, according to the system design and development, capability of each system part to provide its agent with Situation Awareness (SA) about the presence of system threats and vulnerabilities, possibly leading to accidents (Chatzimichailidou et al., 2015). The underlying idea is that all, or some, parts of a complex socio-technical system, such as a road tunnel, can be designed and developed with more or less enhanced risk SA provision capabilities. Systems, for instance, can integrate or leave out elements, like sensors capable of detecting more threats and vulnerabilities or agents whose mental or process models sufficiently represent possible accident scenarios etc. (Chatzimichailidou et al., 2015).

The motivation of this work is to introduce better tools for the purpose of designing and developing systems that are self-aware

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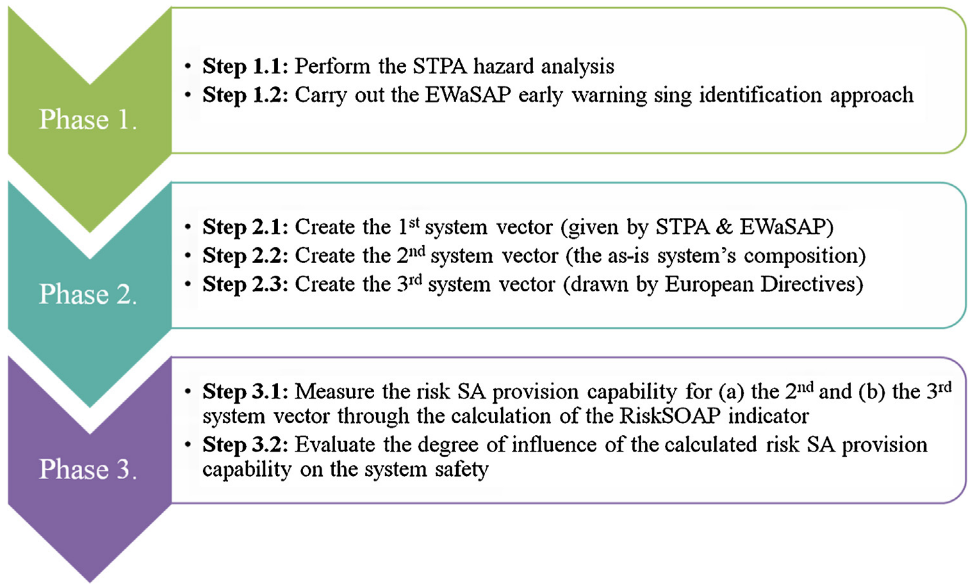

Fig. 1. The phases of RiskSOAP methodology.

of their vulnerabilities and they will ideally react to prevent accidents and losses. This also indicates the need for appropriate tools to support safety-driven system design and operations, as well as for accident prevention mechanisms to give critical engineering infrastructure freedom from accidents (Leveson 2011). RiskSOAP is such a tool, which is intended to measure the risk SA provision capability in terms of system's threats and vulnerabilities that may endanger safety.

Regarding the previous work on SA measurement techniques, the difference between the proposed RiskSOAP methodology and the existing SA measurement techniques is that the latter (a) embark on a direct measurement of SA, which is not the question asked here at all, (b) appreciate a small portion of system elements, mainly human ones, but neglect others, mainly technical ones. On the other hand, RiskSOAP is grounded on a comparison between, at least, two design versions of a complex socio-technical system that differ in the elements and characteristics that affect the risk SA provision capabilities of its parts (Chatzimichailidou and Dokas, 2015). This discussion was done in detail by Chatzimichailidou et al. (2015), who introduced the concept of the risk SA provision capability. In this manner, the development of the RiskSOAP methodology was encouraged by the lack of a proper measurement technique for this capability.

By using RiskSOAP, engineers can measure the risk SA provision capability beforehand, even from the early stages of design, based on tangible system elements, such as the number, type, and characteristics of each one of the system elements that together shape the different parts of it. Hazard analysis techniques such as FTA, HAZOP, STPA (Leveson 2011) etc. can be used, among others, as a basis for the selection of the above system elements and their characteristics that should ideally be included in the system design specifications (Chatzimichailidou et al., 2015). This practically means that with a hazard analysis, one can detect the system elements that are likely to contribute to the enhancement of the system's risk SA provision capability.

Furthermore, RiskSOAP, being a systems-based tool, can support safety-driven road tunnel design and operations, enable tunnel engineers and designers to choose the tunnel or the tunnel's alternative design requirements that maximise the awareness of safety-related issues, and give critical engineering infrastructure freedom from accidents. Overall, a structured and proactive tool can further facilitate engineers, designers, and safety professionals in general, tracking the level of safety that fluctuates in response to changes in the system's composition through time, and different phases as well. Appropriate tools can raise, at the same time, their awareness of whether the technology and the human operators are adequate in quality and quantity to detect the threats and the vulnerabilities of the system before the infrastructure, the public, the engineers and all other stakeholders involved in the system suffer from the corresponding consequences. The RiskSOAP methodology is therefore applied to a specific road tunnel, which is going to be presented later in this paper.

The main objective is to test the soundness and the applicability of the newly introduced methodology in road tunnel safety. As indicated previously, road tunnels in Europe, which came into operation a long time ago, were designed at a time when technical possibilities and transport conditions were very different from those of today. Thus, there are still tunnels that meet only the minimum safety standards. Recent accidents, however, emphasise the importance of adopting harmonised safety measures (European Commission 2004). European Directives for road tunnel safety in the trans-European road network (e.g. Directive 2004/54/EC) lay down a set of harmonised minimum safety standards dealing with the various organisational, structural, technical and operational aspects. Hence, there are currently two types of road tunnels: (a) those which adhere to updated safety regulations and (b) those which are about to be maintained so as to meet the recent European Directives for safety. Especially in the second type of tunnel composition, RiskSOAP is introduced as a tool for the representation of the current tunnel status in terms of its self-awareness about its own vulnerabilities and threats. Furthermore, as a decision making tool, RiskSOAP can support designers and engineers to plan and equip tunnel upgrades on the basis of enhancing the risk SA provision capability.

In this paper, the RiskSOAP indicator is calculated twice; once for the road tunnel design as defined by the EU Directive 2004/54/EC and PIARC (2007, 2008a,b), and once for the composition of the examined 'as-is' tunnel being considered for renovation in compliance with updated safety requirements. It is expected that the lowest value for the risk SA provision capability will be returned for the system version that is proclaimed as less vulnerable, and vice versa. This will also draw an implication of the positive relationship between safety and awareness. This research effort will, therefore, show to what extent European Directives have a