Determination and analysis of tunnel safety requirements from a functional point of view

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INTRODUCTION

As stated in the presentation 'Magic Numbers in Tunnel Fire Safety' [1] during the ISTSS2008, there is a need for another approach for determining safety requirements and designing safety systems for tunnels. In this article an approach is presented to determine the main safety functions and requirements for a tunnel, in order to analyse and to verify from a functional point of view whether the tunnel can be regarded as safe; both in the design phase and during operation.
This approach was used in 2009 to determine a set of high level safety requirements for the development of the N201Waterwolf Road tunnel in the Netherlands. This tunnel is presently under construction and due to open in 2011. These high level requirements were utilised to validate the safety level for this tunnel.

FROM MAGIC NUMBERS TO PERFORMANCE BASED DESIGN

In the past most tunnel designs in the Netherlands were made with use of prescriptive guidelines only, containing many so called 'Magic Numbers'. However, in recent years there has been a change in contracting and design. More tunnels are assigned by Design, Build, Maintain & Operate (or similar) contracts in combination with the use of Systems Engineering (SE). This opened the way for designs based on more performance based functional requirements. A tunnel is then considered as a fulfiller of a set of functional requirements, as opposed to the product of an application of prescriptive standards.

RISK ANALYSIS

For the safety analysis of a tunnel an obligatory quantitative risk analysis and a scenario analysis are both applied in the Netherlands. For a scenario analysis there is a limited set of four top safety objectives available to use.
A safety design based on these objectives had not been applied until recently as the use of SE in Dutch tunnel design had not been developed to use functional requirements. The designs and requirements were largely based on existing prescriptive guidelines, i.e. the requirements were made by changing the guideline's style of language without changing its contents.

STRUCTURE OF SAFETY OBJECTIVES, FUNCTIONS AND REQUIREMENTS

The four top safety objectives laid down in the handbook 'Handreiking Risicoanalyse Tunnelveiligheid' [2] are related to the main processes in the safety chain: traffic management, incident control, self rescue and emergency assistance (refer to Table 1). These objectives however, are formulated in a generic manner and are not applicable for design or validation purposes.

Table 1 Top safety objectives

Process	Objective
Traffic management	The safety provisions are aimed at a safe and steady flow of traffic and a 'as good as reasonably possible' prevention of incidents and response to disruptions in traffic.
Incident control	The tunnel system has educated and trained personnel and adequate, reliable (technical and organisational) facilities to minimise the consequences of incidents.

Process	Objective
Self rescue	The available safe egress time (ASET) is sufficient for people who are able to get themselves to safety.
Emergency assistance	Emergency assistance can be given effectively.

For the verification of the Waterwolf tunnel safety level, these generic objectives have been expanded into sub-objectives, functions and requirements, as seen in Figure 1. These functions can ultimately, be effectuated by a combination of measures (or facilities) that can be both technical and organisational. To determine a proper set of objectives and functions it is important is to get a complete set, without going into too much detail or determining solutions prematurely. In the Waterwolf project this was done by a 'soft and global' formulation of functions and requirements, using definitions such as 'big', 'much' etc. showing the line of thought. This made it easier for non-experts e.g. decision makers to understand. A clear visible line of thought and global values also make backtracking and adaptations easier and it leads to better integration of the technical and organisational measures.

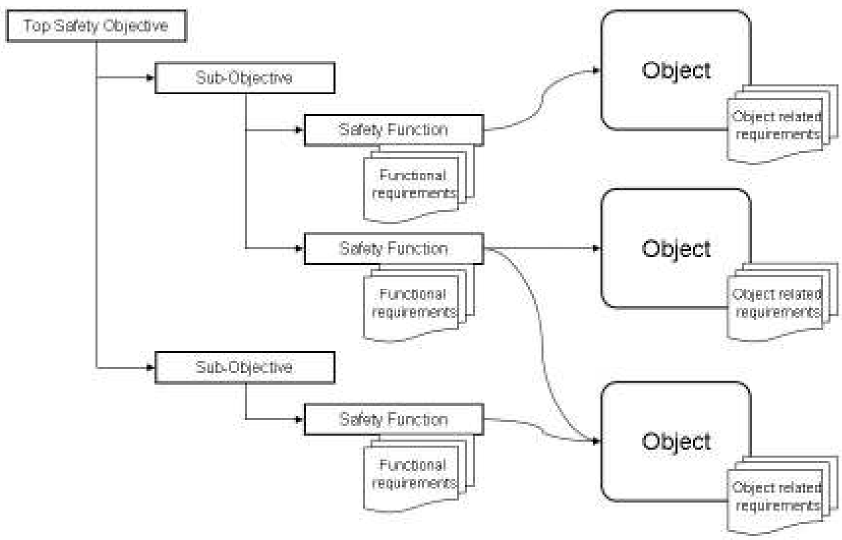

Figure 1 Structure breakdown of functional safety objectives

However, further down the chart, more structured detailed SMART requirements (numbers) are added. The SMART requirements can be obtained using legislation, standards, risk analysis and 'good engineering discipline', but they must also match with the ambitions of the stakeholders involved. That ambition can, for various reasons, be different than the legal minimum or the practical average.

EXAMPLES

From the top safety objective 'Self rescue' (see Table 1) the sub-safety objective 'Minimisation of the consequences' can be derived. One of the sub-objectives will be 'To provide a physical safety escape route'. The associated safety functions are for example 'Providing sufficient orientation possibilities' (installations such as tunnel lighting and escape route lighting fit in here), 'Guidance for people' (installation solutions can be escape route lighting, signs and audio guidance) and 'To control the en-route conditions' (to be fulfilled with ventilation and overpressure but also maintenance procedures to keep routes free of obstacles). These safety functions are described more specifically (SMART) in a next level, for example 'The escape route should be at least 1.2 metres in width'. Remark: the magic number 1.2 can originate from a legal standard or an intermediate functional requirement. On the other hand, when more escape routes are implemented the tenability control en-route can be defined less

strictly, as evacuees can reach a safe area earlier and easier.
In Figure 2 another example is shown for an expansion of top objective 'Incident Control'.

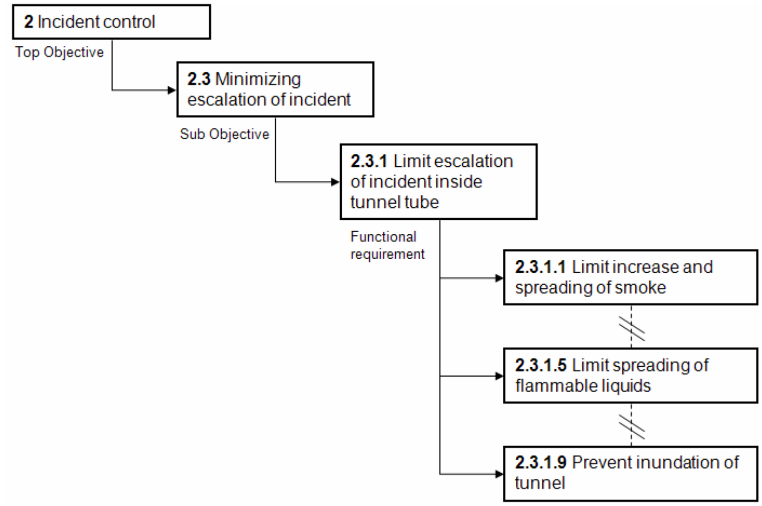

Figure 2 Example of safety structure

SCENARIOS AND RELIABILITY

Also, a link can be made between the objects, the tunnel safety systems, including organisation, and scenarios described in the scenario analysis. This helps to identify and define the critical and supportive installations of several project specific incidents or scenarios, as shown in Figure 3. As (sub)systems fulfil functional requirements, system failure can lead to loss of a specific safety function. Insight into the contribution of each safety system gives a better idea of which installations, will compensate and support the function failure to retain an acceptable safety level. This helps the tunnel management in adaptive decision making with additional measures such as temporarily exclusion of certain traffic, lower speed limits, lane closure etc. to reduce risk and exclude scenario's than cannot be controlled. This may lead to less tunnel closures.

FUNCTIONAL SAFETY REQUIREMENTS / INSTALLATIONS AND MEASURES	10 Power supply	20 emergency lighting	30 pump installations	35 ventilation-system	35 visibility detection	35 a longitudinal ventilation	35 b pressure ventilation	40 trafficinstallations	41 traffic management installation	42 traffic speed detection	50 fire suppression installation	51a hydrant outlets	51b water supply pumps	51c fire detection	60 communication	61 CCTV	62a HF-installation	62b Intercom	62c C-2000 radio communication
2. Incident control																			
2.1 Limit risk of disruption causing incident																			
2.1.1. quick detection to operator	C				C									C		C			
2.1.2. quick information and instruction to drivers	C															S	C	C	
……..																			
2.2. Limit effects of incident																			
2.2.2. Minimize number of casualties																			
2.2.2.3. Fysical protection	C								C	C									
……..																			
Scenarios																			
1. Fire in passenger car	C	C				C	S		C	S		S	S	S		C	C	C	S
2. Fire in HGV	C	C			S	C	C		C	C		C	C	S		C	C	C	S
3 . …….																			

Figure 3 Example, functional verification of critical(C) and supportive(S) safety installations

The safety level and handling of scenarios can also be validated by this functional breakdown structure. For each scenario adequate safety measures should be present. The reliability and redundancy related to safety can be analysed against the background of the RAM-criteria.

For the Waterwolf tunnel this exercise showed that the design contains enough technical facilities to cover the functions and scenarios, but that attention need to be given to organisational procedures.

This functional approach, whereby the tunnel safety -installations are classified in safety-critical or supported installations (per typical scenario and function), is also currently in development for the Dutch rail tunnels. An automatic closure of the tunnel at every false-alarm or sub-installation failure can be prevented leading to a higher availability.

INSIGHT IN SPECIFIC SITUATIONS

The functional approach will give a better insight into the specific circumstances or use of 'city'- or 'non trans-European' road tunnels. Functional analysis decisions can be made on basis of the safety contribution of each individual safety measure, or combination of measures.

The Waterwolf tunnel is a regional road tunnel. This means that the regular prescriptive Dutch standards, which are mainly developed for tunnels in highways, will not lead to a tailor-made safety concept. For example, the traffic management system of the Waterwolf tunnel will be of a 'high standard' and incorporate the nearby local road junctions, as discontinuities in traffic are a major project specific risk. Another example for this tunnel is the specific high level of emergency response available. As the tunnel is located in the Schiphol Firefighting region, emergency assistance can be dispatched within minutes. So compared to other tunnels the functional requirement of incident control and repression of a large HGV-fire will be dealt with more adequately.

The same functional approach has been followed for planned maintenance works in one of the Botlek road tunnel tubes (Rotterdam Harbour). Based on the functional analysis two-way traffic in one tube was accepted, although this solution seems to be in contradiction to the prescriptive Dutch tunnel regulations. In the event of fire, the risks of the jeopardized ventilation strategy (and so limited fulfilment of the function 'control of fire and smoke' through this installation) were mitigated by the imposed limited speed and the 24-hour presence of a quick response fire fighting team.

DISCUSSION AND CONCLUSION

In the case presented the functional method worked well and further development of this approach, the safety functions and global requirements is needed. For detailed design and verification purposes it is important to add SMART criteria. A well structured combination of performance based requirements (safety functions) and (not so) magic numbers, opens a new way to safe design that can be more easily validated. This approach is more flexible and applicable for D&C contracts and all types of tunnels and road, rail, size, configuration complexity, traffic type and volume. This method provides space for the introduction of innovative cost effective solutions for unconventional situations. It offers better tuning between technical and organisational measures as a safe tunnel (design and operation) remains the ultimate 'top' requirement.
The spell around the 'magic numbers' will be broken largely when the line of thought from top requirements, soft functions to SMART criteria can be clearly identified.

REFERENCE LIST

Symposium proceedings:

1. Ingason, H. "Magic numbers in tunnel fire safety", Proceedings from the Third International Symposium on Tunnel Safety and Security, Stockholm, Sweden, 21-27, 2008

Handbooks:

2. Projectbureau Tunnelveiligheid, "Veiligheidscriteria voor de SceA". In the *Handreiking Risicoanalyse Tunnelveiligheid* (Arie-Jan Arbouw et. al.), The Hague, 2006