Supporting Tunnel Safety Assessment with an Information Model

N. Vossebeld[1] and T. Hartmann[1]

[1]VISICO Center, Department of Construction Engineering and Management, Twente University, P.O. Box 217, 7500AE Enschede, The Netherlands; PH (+31)53 489 4254. E-mail: n.vossebeld@utwente.nl

ABSTRACT

Building information models (BIMs) promise to support information provisioning over the entire lifecycle of infrastructure assets. However, currently, few integrated BIM decision support systems exist. Therefore, many modeling efforts are being undertaken across the world to gradually support more and more key processes through the application of BIMs. The safety assessment of infrastructure is a key process that can potentially be effectively supported by applying integrated BIM tools. For the Netherlands highways agency the safety assessment of road tunnels provides an important challenge. Many technical complexities and domain-specific laws and regulations impact safety assessment. Safety assessment is determinative for success: for example, every road tunnel must be checked for compliance with laws and regulations before it can open.

This paper proposes an information model that can support the safety assessment task in the context of the Netherlands highway agency. It departs from requirement analysis efforts conducted within the organization and provides use cases and a description of the information model developed. The paper concludes with a description on how we plan to integrate and test the model on the ability to support tunnel projects.

INTRODUCTION

Worldwide many information modeling efforts are undertaken to gradually support more and more key processes with BIM. Lucas et al. (2013) have developed an object-oriented model to help healthcare facility managers to better respond to patient safety events and make facility operation and maintenance more efficient. Zhang et al. (2013) have developed a model for the automated checking of construction models and schedules to prevent fall incidents on construction sites. Bulbul et al. (2006) proposed a model for embedded building commissioning in which to make architectural evaluation a persistent part of the building lifecycle. The Netherlands highway agency is also conducting efforts for BIM and is developing a comprehensive object type library to enable data-exchange between specialized BIM tools and distributed databases.

Within the agency's efforts road tunnels provide a particular challenge, because of the systems complexity and many domain-specific laws and regulations. System complexity of the road tunnel results from multiple facets, such as the required technical safety installations to allow safe use of the tunnel, complexities related to underground construction methods, and the number of parties heavily involved in the systems' operational phase, such as the emergency services. Furthermore, strict laws and regulations state that every road tunnel must at a minimum be evaluated on the following views to be able to open and to stay open: road user safety in case of fire incidents; maintenance of safety-critical parts; traffic management procedures; incident control procedures; and the education and training of personnel. For each view insight in specific technical, organizational and process/procedural aspects of the tunnel system are required. Therefore, in current practice, a comprehensive dossier is kept along the tunnels lifecycle that contains safety-critical information on all these views. For each milestone, many safety documents are created by project managers to provide insight into the characteristics of the tunnel system in relation to each view as, jointly, these documents allow to pass the milestones in the product process.

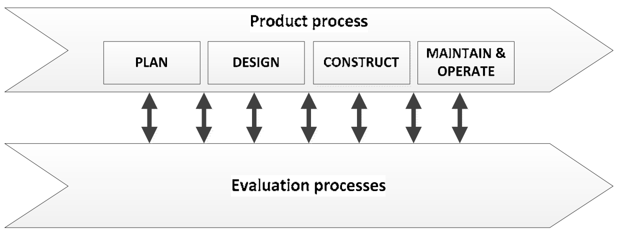

Figure 1. Information exchange between the product and evaluation processes, after Bulbul et al. (2006)

Current, document-based practice, however makes it very difficult for practitioners that assess the tunnels' safety and obtain sufficient insight in the dossiers completeness and consistency. Furthermore, the high amount of information recreation can introduce human error especially if dossiers are built last minute before a safety evaluation milestone. Additionally, documents do not allow effective reuse in later phases. An integrated BIM decision support system must be able to, as a minimum, generate these required views of the tunnel as a product. See figure 3.

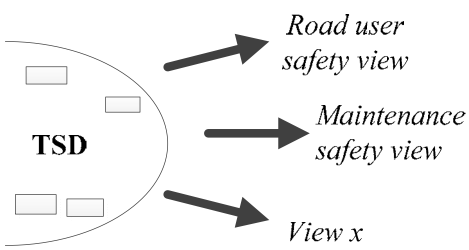

Figure 2. Support of safety evaluation for each view in the safety dossier (TSD)

This paper proposes an information model that can support a part of the road tunnel safety assessment task, taking into account the real-life context of the Netherlands highways agency. First, this paper provides a brief insight into the use case oriented development approach as followed. Second via an use case narrative the necessary insight into the context of use is provided. Third, two use cases as developed within a larger requirements analysis effort are described. Fourth, the information model itself is described in detail. Finally, the ongoing development plans are discussed, showing the next steps towards actual support of practitioners working on projects in the road tunnel domain.

DEVELOPMENT APPROACH

Currently, no object type library (OTL) specification of sufficient quality exists to specifically support the tunnel safety evaluation process. Such a library must – in time – provide a description of functional types, data attributes and relations between objects as required to assess safety. Eastman et al. (2010) suggest that perfectly complete and successful exchange between BIM-tools can only be achieved when the exchange incorporates the semantically required subset of the following classes of description for each object in the exchange: functional type (e.g. column, door, siren); data attributes (e.g. length, color); relations between objects, the relevant set of topological relations to define operations on the configurations of shapes (e.g. proximity, connectivity, adjacency, membership, orientation); geometry, suited for the intended purpose; and behavior rules to determine how the shape and related properties of the object adjust within an assembly when edited, based on context. Eastman et al. (2010) suggest almost all of these classes can in time be supported by standards, but it has taken many years for AEC researchers and the industry to reach the recognition that without careful definition of all aspects of each task-specific exchange beforehand, transactions will inevitably continue to be unreliable and faulty. Therefore, a use case approach is applied.

The information model is developed as part of a project aimed at allowing the first author to gain the required knowledge about how to design a database to support a specific organizational process. The development process took place in line with Muller, Robert J. (1999), a book that focusses at the application of UML modelling techniques. First, an use case narrative for the to be developed system is made in order to identify end-users and explain the context of future use of the model in depth. The first author has already conducted various smaller research efforts within the highway agency and the tunnel domain for a year. Following initial drafts of the narrative a study of specific company guidelines and policy documents is conducted to improve the use case narrative and information model development. Second, specific insights in requirements is obtained by use case development. For each distinct sub-domain a set of use cases is made. As each safety view differs strongly per subdomain, but mainly because each domain has its own dynamics in information transactions, roles and organizations involved. Although ongoing efforts also provide insight in other use cases, in this paper only one set is explained in detail. Fourth, the use cases modelled have been validated based on interviews with intended users. Last, a class model is developed to support the use cases sketched. This class model provides insight in the information to be provided to support safety assessment.

USE CASE NARRATIVE

The safety of road users in tunnels is strongly related to the occurrence of fire or explosion events. Therefore, Dutch law prescribes both an approach and the application of a software tool to assess road user safety in case of occurrence of such an event. This assessment is conducted at the planning phase and updated in every successive phase over the tunnels lifecycle shown in figure 1, but only if required.

Road user risk is expressed as the probability of a group of lethal fatalities within the tunnel per km of tunnel tube per year due to fire and explosion events.

Risks related to external causes such as earthquakes or anchors of ships falling on top of the tunnel are not included in this specific analysis. However, it does take into account key characteristics of the tunnel and the characteristics of traffic passing through the tunnel. The prescribed Quantitative Risk Analysis (QRA) approach is systematic, quantitative, probabilistic and user-scenario based. As BIM is to be the single version of the truth, the QRA input data used must always be consistent with the BIM of a specific tunnel.

The QRA-analysis requires specific input values regarding the tunnel product, traffic characteristics and accident probabilities. Tunnel configuration characteristics are provided directly from the BIM database. Traffic figures are provided by an expert. Incident probabilities are estimated, again by an expert, but based upon both the traffic figures and characteristics of the tunnel configuration. The analysis itself is conducted by an independent QRA-analyst using the prescribed stand-alone software tool. The analyst will always need to interpret the input values provided to fit the specific tunnel to the tools model. The analyst makes assumptions during this process which are recorded. Thereafter, a sensitivity analysis is conducted on the input parameters to test the robustness of the evaluation results. The robustness is expressed separately for each of the tested input parameters. Finally, an evaluation report is generated and distributed to the tunnel safety officer and the tunnel manager for review and acceptance. Successive QRA-analyses can in some cases years later – especially in the operations & management phase – making it important to record assumptions made and sources used for later recollection and to be able to understand the robustness of the previous evaluation. Table 1 summarizes the future users identified within this specific subdomain.

Table 1: users within the road user safety subdomain

User	Role	Description
Tunnel Manager	Decision maker	End-responsible for consistent safety evaluation. Decides on the necessity to update the QRA.
QRA-analyst	Safety Expert	Independent expert that conducts road user safety evaluation of the tunnel system.
Tunnel Safety Officer	Safety Expert	Evaluates the integrated tunnel safety dossier and coordinates dossier building.
Highway Agency Project Manager	Information provider	Provides information from the product process towards the safety evaluation process.
Traffic Expert	Information provider	Provides traffic data as required to evaluate road user safety.

USE CASE DIAGRAMS

Muller (1999) describes use case diagrams must model at a high level for what the system should do from a user's perspective and represent the transactions between the actors and the software system. An actor element characterizes the role played by professionals and existing database systems outside the system under development. As an update of the QRA is only conducted if required, the information model must support two use cases: conducting a QRA for a specific tunnel, and assessing the necessity to update the QRA based upon insight into the validity of the previous evaluation. The use cases shown in figure 4 follow the narrative as described earlier. Note the Tunnel Manager and the safety officer are represented as one in this diagram, as the safety officer always conduct his efforts for the Tunnel Manager.

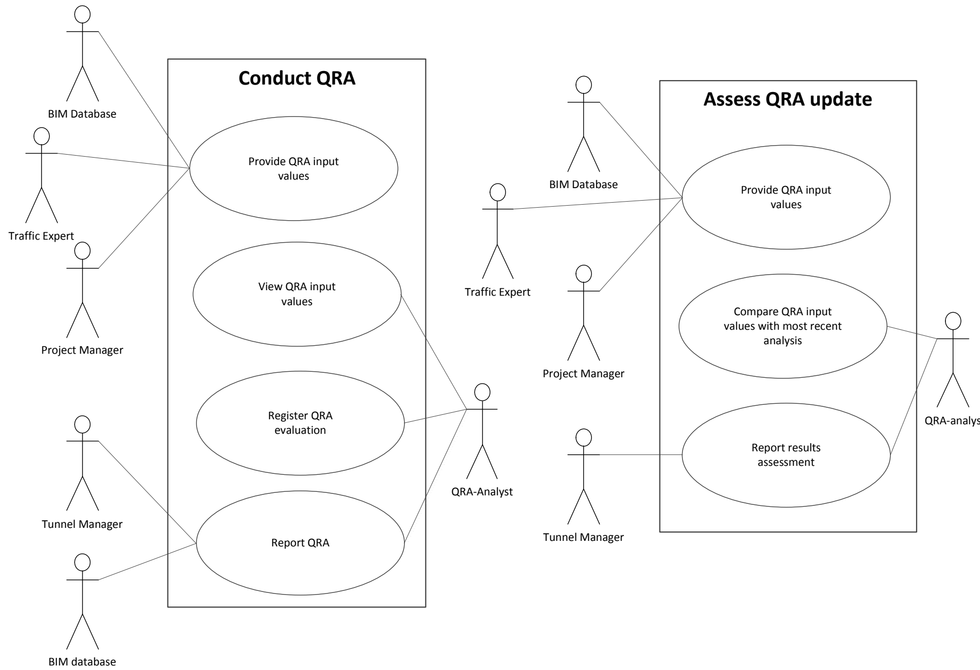

Figure 3: Road User Safety Evaluation Use Cases

INFORMATION MODEL

Since the development of the information model is still ongoing, we report on the status of the existing design.

Figure 5 shows interfaces between subsystems as expected. The BIM database is 'the single version of the truth' and storage of for tunnel specific reports and data as required for different views, among which, the road user safety evaluation. In its turn, the Road User Safety sub-system provides insight in the stage of the evaluation as conducted via the 'state' interface. This allows insight in Tunnel Safety Dossier building on top level.

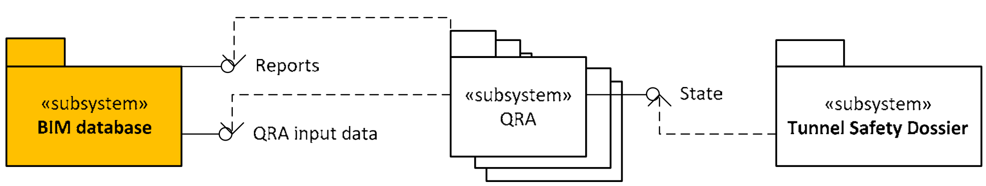

Figure 4: interfaces between sub-systems at the safety dossier-wide level

Figure 6 shows different parts of the information model as will be spread over the packages. Part I is oriented at managing the overall tunnel safety dossier building process along the road tunnel products lifecycle. It shows that each view – such as road user safety – is associated with one-to-many lifecycle stages such as the design phase. The model can be extended by including other subtypes of views on the tunnel.

Part II shows the model to support road user safety evaluation. At its core is the QRA-analysis class. Each QRA-analysis has a specific set of input values as provided to the analyst. The QRA-analysis can have different statuses. Examples are: not started, draft, ready for review by safety officer, reviewed by safety officer, approved by Tunnel Manager, released to the BIM database, or update needed. Stages show state information at a global level and is meaningful for insight in the status of safety dossier development. Stages can also allow for the proper access rights for each user as each plays a different role in the process. Three subtypes of input values are specified: (1) tunnel configuration; (2) traffic figures estimates; and (3) incident probability figures necessary for the probabilistic assessment. Input values can partly be obtained from the BIM database and standard values for incident probabilities are used in the QRA-tool. These standard values can be provided in the model. Traffic figures should, however, still be provided by traffic experts as they are not included in the intended BIM database.

Part III and IV specify the specific attributes that need to be queried from the BIM database to obtain insight in the tunnel configuration. Geometric characteristics of 4 classes of tunnel configuration items and characteristics of 16 installations are specified. Examples of tunnel configuration characteristics with an impact on the road user safety are the type of fire-detection system and wither or not subsystems are related to an operators emergency button for automatically controlled start-up. Note that the provisioning of a safety installation is currently limited to wither or not [yes/no] the installation is part of the specific tunnels configuration. Current practice seems best supported with a link towards design documentation and test reports that support the reliability claimed, a traceable storage of documentation as provided. Although, ongoing modelling attention is focused on providing a more comprehensive representation of the provisioning of safety installations as can be obtained from the maintenance systems. Given the prescribed generic tool, analyst deviations will always be required to fit specific tunnels to the analysis model available. For example, if regarding geometry the BIM database does not allow a direct mapping. The model has an analyst deviation class that allows the storage of any motivated deviation from the input values as provided. The class includes: a motivation (string), author, date, new value, and a reference to source documents used such as a design drawing. In this manner the QRA analyst can explicitly register assumptions and the difference between values provided and used. Storing this kind of information will allow the QRA-analyst to compare successive QRA's more easily as different persons can conduct successive analyses which can, in some cases, be years apart. The robustness class allows storage of a the evaluations robustness as assessed for some input values in a sensitivity analysis. A factor represents the robustness relative to the legal safety norm. New input values can be compared to this factor to determine wither or not a new situation complies to the safety norm. Last, the ReportFigures class can store QRA-tool output figures as necessary for human-readable QRA-report generation that can be stored in the BIM database. Figure 6 shows the class diagram described.

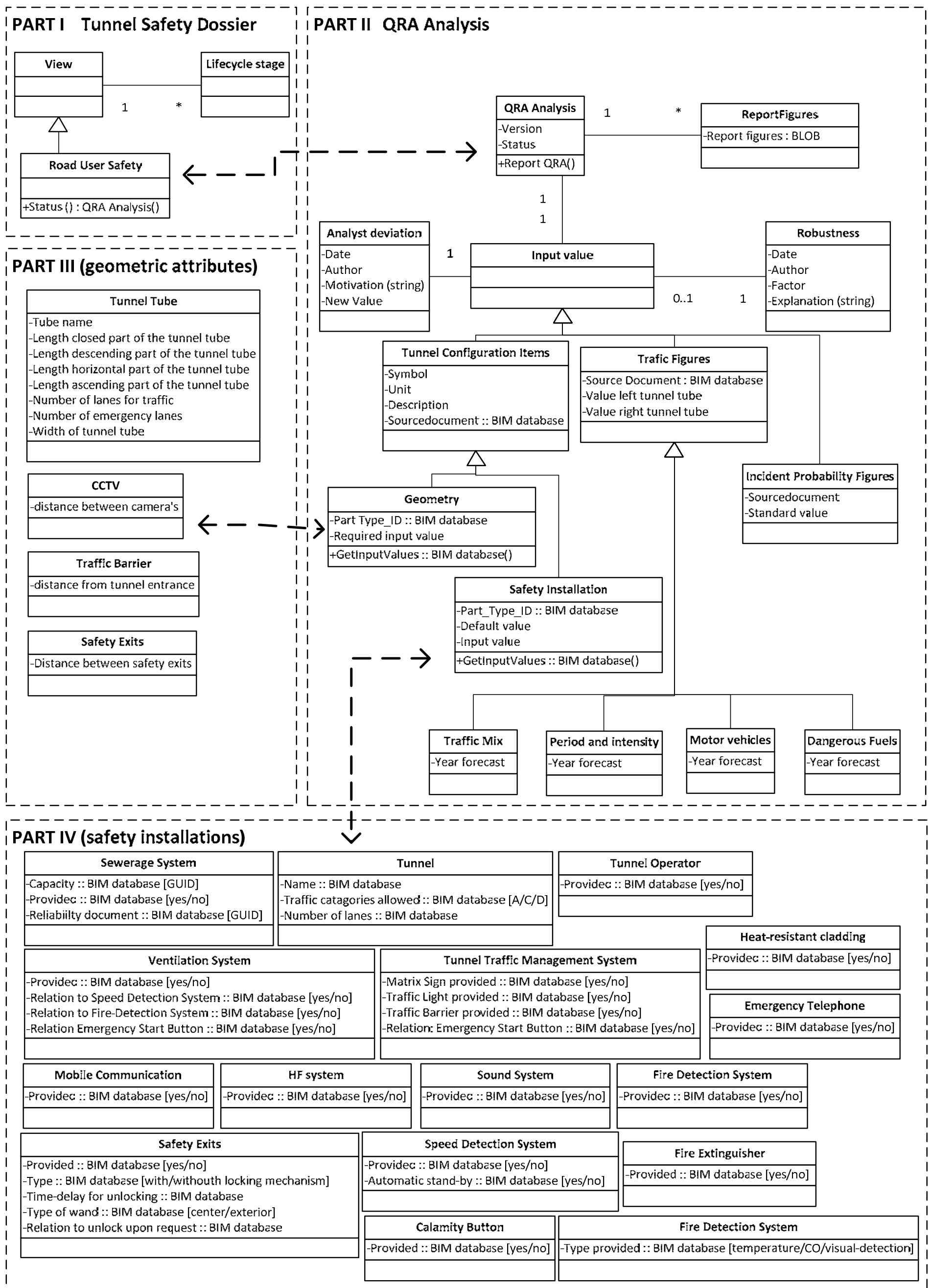

Figure 5: UML classes as required for road user safety evaluation

DISCUSSION & OUTLOOK

This paper has presented an information model that can support the road tunnels safety assessment. It has elaborated on one safety view in detail, as it is key for the Netherlands highway agency. Figure 6 (part III & IV) shows specific attributes of classes that should be included in the BIM database and object type library in order to evaluate road user safety using the QRA-analysis tool.

Furthermore, the information model proposed takes into account the need for local – motivated – deviation from provided input values as human expert interpretation is still required to fit a tunnel to the prescribed tool and interpret data provided. Additionally, some interfaces have been proposed between sub-systems to focus on both process control and specific views on the tunnel.

The model discussed is part of an ongoing effort to develop a comprehensive and integrated information model that supports the safety assessment of road tunnels from many more views as discussed. First attention will be given to the upkeep of insight in the performance of safety installations during the operating stage. This is an important insight needed for the Highway Agency. As maintenance is usually outsourced, obtaining the required information is no matter of course. One other aspect that will need further study is the required representation of geometric aspects as the intended model is to be used by many different end-users for different purposes, while the description of geometric relations must be closely aligned with the intended purpose for successful exchange (Eastman, 2010).

Currently, class models are developed for some key maintenance focused safety evaluation processes as relevant within the Highway agency. Future steps include the integration of the different classifications in a proof-of-concept prototype. The proof-of-concept will be based upon the existing functionalities of a PLM tool which is often used in the automotive and aerospace industry. This tool supports a rich visual representation of the tunnels geometry and role based user access to information to the different classifications developed. This will help to demonstrate how users can meaningfully interact with the data model and retrieve relevant information. The prototype will demonstrate that safety assessment of the tunnel can be supported.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the practitioners at Rijkswaterstaat, the Netherlands highway agency for their time and cooperation. The first author’s 2-year post-master educational program is funded by the Netherlands highway agency.

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