Advanced methodology of Risk breakdown structure developing for risk management of tunneling and construction projects

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RÉSUMÉ. Les projets de construction, et a fortiori ceux de tunnels sont des processus complexes ; ils impliquent un grand nombre d'acteurs et sont sources de risques de nature variée. Nous proposons une méthodologie pour développer des RBS (Risk Breakdown Structure) en nous basant sur plusieurs contraintes : une adaptation à l'avancement et au degré de développement du projet, une modélisation offrant des vues adaptées aux différents acteurs. Un soin particulier a été apporté au développement d'une base de connaissances assurant la cohérence des données. Le processus de reconstruction des RBS permet la comparaison des différents RBS par le recours à plusieurs critères : l'avancement du projet, la satisfaction des utilisateurs et le contraste entre les différents risques. Le mode de construction de la base de données garantit que celle-ci pourra aisément être mise à jour ou faire l'objet de développements ultérieurs.

ABSTRACT. Tunneling and construction projects are complex processes, which concern many stakeholders and for which, risk factors have many origins. We propose a methodology to develop RBS that are adapted to several constraints: being fitted to the stage and degree of development of the project, being able to offer different views for the different partners. A specific care is given to the development of the knowledge database, in order to ensure consistency of the data. The RBS rebuilding process is driven so as to make possible the comparison between RBS according to several criteria: degree of development, satisfaction of user, highlighting the contrast between risks. The way the database is built also ensures that further developments and updating will be easy.

MOTS-CLÉS : gestion des risques, tunnel, construction, risk breakdown structure, méthodologie

KEYWORDS: risk management, tunnel, construction, risk breakdown structure, methodology

1. Introduction

In recent years, intensive research and development has been done in the area of construction and projects risk management (Klemetti, 2006). Failures in risk management in construction and tunnels are often seen as spectacular structural collapses or serious accidents, however the project risk management covers a wider field than that of human and structural safety.

Tunneling is increasingly being used worldwide to provide the infrastructure required for sustainable urban communities. The majority of these works are completed safely and satisfactorily (Atkins, 2006) but tunnel construction is one of the riskiest insurance fields. When an accident occurs, it often reaches catastrophic proportions (Gallagher, 2005). Tunnel accidents can cause loss of live, equipment damage, damage to tunnel structure and loss of third parties. The consequences of such accidents in urban projects introduce additional risks to tunneling work due to the density of the existing infrastructures and the spread of the population. However, tunneling risks are not limited to the constructional accidents and collapses but can also include the over cost, delay, environmental pollution, safety of workers, etc.

In theory, by applying a proper risk management process (RMP), the negative outcomes of risks events can be minimized. One difficulty is that the tunneling and construction project management involves many participants. The variety of views on project risks makes the RMP modeling difficult, since it is often considered privileging one specific point of view (Klemetti, 2006; Zeng et al, 2007). These different perspectives explain the reason why the same project can be considered a success by one party and unsuccessful by another (Din et al., 2010).

This research aims to develop a general method to develop Risk Breakdown Structure (RBS) in an efficient way to identify and organize risks in construction and especially in tunneling projects. One objective is that, for each new project, different partners, by following a general guideline, will have the possibility of building their own RBS according to their objectives and their special view on project risks, while a common view on risks will also remain possible. This will make possible a “multi-scale approach”, in which each partner can focus on some special risks and develop the RBS for his own purposes by some more subcategories in special fields. Of course RBS will remain a tool used in the frame of a more general RMP.

2. Risk Breakdown Structures: a helpful representation of risks

Project Risk Management is a dynamic process following the project life. It contains the usual stages of risk identification, risk assessment and analysis (qualitative or quantitative), response definition and risk mitigation (Breysse, 2009). This process is iterative, since in each phase of the project, new information is available and new events can happen, which require an updating of the strategy.

There is a variety of tools that can be used to communicate identified risks to project stakeholders such as risk registers, risk matrix and risk maps (Patterson and Neailey, 2002, Holzmann and Spiegler, 2010). The hierarchical description of risks is a very practical tool, which makes risk management easier. It can be based on the risk breakdown structure – RBS, which offers a global view on the risks (Chapman, 2001).

The RBS is a hierarchical structure that represents the overall project and organizational risk factors and events organized by group and category (Holzmann and Spiegler, 2010). Figure 1 illustrates an example of a RBS. This type of representation has many advantages:

- It offers a synthetic view on risks, which can be grouped in a number of risk categories, each of them covering a series of risk events. This synthetic view is helpful when the project stakeholders must discuss risks.
- It can be reduced or broadened, in depth or in breadth, to meet varying needs (Holzmann and Spiegler, 2010) according to the level of information available and to the focus the user requires.
- It enables the propagation of information along its branches, from the bottom to the top, once rules have been defined for this propagation (for instance how risk event consequences or severity are aggregated on various levels of the tree).
- The RBS can be complemented with a second representation, that of the project tasks (WBS, work breakdown structure) and the two pictures can be combined so as to offer a “hierarchical matrix” (Aleshin, 2001; Hillson and al, 2006).

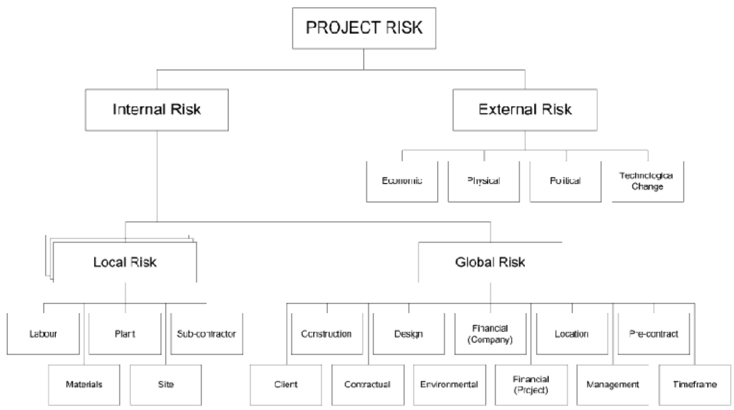

Figure 1. *Example of a Risk Breakdown Structure (Tah and Carr, 2001)*

However, RBS suffers several drawbacks, the main one being that there is no consensus on how to develop a RBS. In fact, each user develops its own RBS, without following any guidelines. The result is that it is impossible to identify “good practices” for developing RBS and a detailed study has shown (Mehdizadeh et al., 2010) that lack of clarity and inconsistencies are not uncommon. There is in general no clear definition of the meaning of risk categories, and the same words can cover different items. Another difficulty comes from the definition of the rules enabling the transfer of qualitative/quantitative information on risks across the tree. The sensitivity of the results to the rules deserves a careful study.

Our aim is to develop a methodology which takes profit of all advantages of RBS, without suffering its usual drawbacks. We, however, need to initially detail some additional requirements.

3. Methodology

3.1. Objectives

The methodology is based on:

(a) Establishing a taxonomy of risk events (RE) and risk categories (RC), based on an extensive review of existing literature.

(b) Identifying a database of elementary trees, or micro-trees (MT), which highlight how each risk category can be subdivided into subcategories. Each micro-tree is defined by:

- a “father node” RC,
- possible subcategories at the immediate lower level,
- relations with other micro-trees in order to ensure compatibility and avoid redundancy and/or confusion when the RBS will be built.

(c) Synthesizing the knowledge base, which includes the risk events, the risk categories and the micro-trees, by building a set of relationships which formalizes all possible hierarchical links.

(d) Defining a series of criteria which makes it possible to quantify the “quality” of a RBS. The issue of quality is central, since there is no “optimal RBS” but RBSs which are more or less adapted to a given situation and a given objective.

(e) Elaborating a strategy for building a RBS which satisfies the main requirements, which are expressed in a given situation. This strategy is based on the hierarchical nature of the RBS and on the fact that it is scalable and must therefore be adapted “in real time” to the context.

(f) The last step is the definition of the rules enabling the transfer of information (frequencies/ probabilities and magnitude/impact) from the bottom to the top of the RBS.

3.2. Knowledge base

This work is based on a thorough analysis and literature review of more than 90 scientific papers and risk management cases for which RBS is the main method used for risk identification (Mehdizadeh et al., 2010). About 90 RBS have been analyzed, so as:

- to identify, for each RBS, its general typology, and to which objectives the decomposition answers,
- to identify the logical relations between RC in each RBS: how the categories are decomposed? What RE do they cover? What RE do they exclude?
- to identify the set of more usual risk events at a given level of detail, and how they can be grouped into categories.

The aim was not to reach exhaustivity, which is obviously a mirage, but to homogeneously cover the main areas of risk in construction projects.

This analysis enabled us to identify many confusions and inconsistencies (typically the case for a RE which can belong to two RCs in the same RBS) or gaps (typically the case for a RE which is not covered by any RC in a given RBS). It was based on the combination of a bottom-up approach (from basic RE to global Project Risk) and of a top-down approach, where the global project risk is decomposed into several RCs, each of them being further decomposed until the required level, at which RE can be attached to RCs.

The synthesis of all these data aimed at building a knowledge base containing three interactive components (Figure 2):

- a library of Risk events (RE),
- a library of Risk categories (RC),
- a library of Micro-trees (MT).

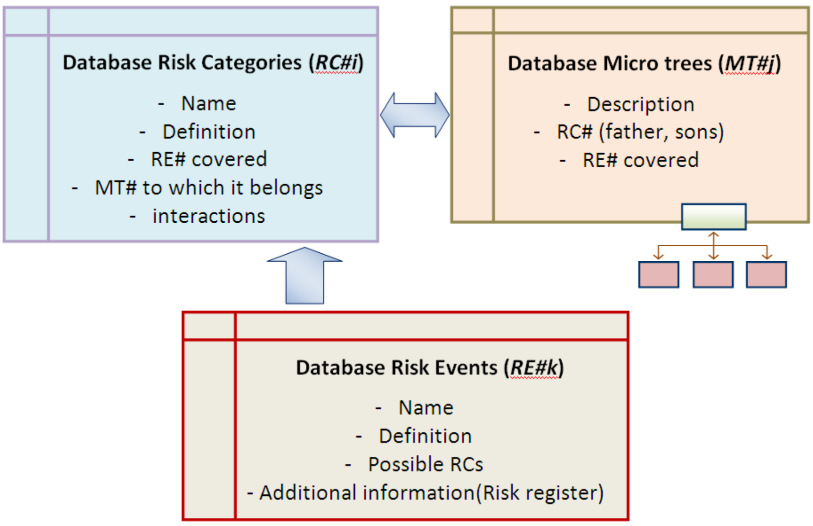

Figure 2. *Relations between the three components of the database.*

3.2.1. Risk events

The RE database must answer two questions: that of the identification of RE, that must be consistent in terms of level of detail and that of their classification. It is clear that such a list cannot be exhaustive. The issue is therefore to build a first version of the database, allowing evolutions in further stages of development of this work. This version must contain a series of "common" risk events, covering the more important ones, because of their frequency in construction and especially in tunneling projects or because of their possible impact. The bibliographical analysis has led to more than 320 general REs for construction field and 150 REs by focusing on tunneling projects, which had then to be classified.

The classification stage consists in defining all RCs to which the RE can belong. One practical difficulty is that the RC database is developed in parallel, thus requiring iterative checking. Table 1 represents a small part of tunneling risk events available in RE database.

Table 1. *A partial list of tunneling risk events*

- Poor project feasibility study
- Poor Preliminary assessment and evaluation of tunneling methodologies
- Inappropriate form or type of the contract
- No proper design review and checking by consultant
- Poor traffic management in tunnel during construction phase
- Failure of equipments and mechanical systems during construction
- Damage to installed lining during the work

3.2.2. Risk categories and micro trees

The development of the RC database raises the same type of questions than that of the RE database. The bibliographical analysis has lead to more than 270 RC, but they have been reviewed in detail, in order to ensure consistency. The knowledge modeling process is mostly empirical and iterative, since the risk categories and their relative organization within micro-trees are identified together. In fact, it is during this stage that the name of the categories has also been fixed, so as to reduce their overall number, while covering a wide variety of risk factors/events.

The main constraint is that, if a RC#i "father node" and a series of RE#j that belong to this RC#i are given, any possible decomposition of the father (RC#i) into subcategories has to be consistent. Then it must be carefully checked that for each MT#k whose father node is RC#i, all RE#j events can be attached to one (and only one) of the subcategories (sons of the father node) in that tree. Any impossibility to attach or any possible double attachment reveals some inconsistency, which must be corrected. Regarding the micro trees with the same father node, the consistency constraint is that if several MTs are considered corresponding to different decomposition of a category, if a risk event can be attached to the first MT, it should also be (necessarily) attached to the other MTs. An automatic process has been developed so as to proceed to automatic checking of these constraints, and to clearly explain where conflicts are located, making the progressive development of the databases easier.

To understand how the MT database has been developed, the simplest way is to look at the top level ("level 0"), where three logics prevail for decomposing the global risks of a project, which are more often broken down according to:

- Internal and external risks, related to source of the risks,
- Risks associated with the phases of the project, and risks of interfaces between phases ("project risks" category is decomposed into "feasibility", "contract", "design", "implementation", "operation" and "management" subcategories),
- Risks associated with the project stakeholders, and risks of interfaces between them ("project risks" category is decomposed into "project stakeholders", "external risks" and "management" subcategories).

Once the question has been treated at the top level, it remains open at lower levels, here "level 1", where the three above possibilities introduce a large number of new categories (respectively 2, 6 and 3 for the three variants), even if management appears twice. For each of these categories the process of identification of relevant subcategories and alternative ways of grouping them is repeated. At the end of the process, the database contains a list of MTs and a list of RCs, with all belonging relations between RCs and MTs.

These rules ensure the propagation of belonging properties from the bottom level to the top level in the RBS. For the existing database, it also appears that some of the RCs are not further decomposed (they never appear as a "father node" of any MT). These RCs are "bottom categories" to which RE can be directly attached. For all others RCs, it is only through propagation that REs are attached.

The authors are fully aware that the solution for covering a large amount of existing RBSs is not unique and these choices have been somehow subjective. They result from a long maturation process, during which the criteria for decisions were: elimination of useless solutions, reduction of the possibilities, consistency checking.

4. RBS Building process – a multiscale and dynamic view

The issue is now to define a process enabling the building and the selection of a "convenient" RBS to be used in RMP process. Any RBS is viewed as a set of MTs, in which each "son" RC can be further decomposed, as long as it is a father node in another MT. The database presently contains 72 micro-trees which correspond to a very large number of possible RBS (several billions). This number reduces to few thousands if one adds the constraint of developing the RBS homogeneously at the same level on all branches. Since such a number is not a problem for automatic computations, the choice has been made, in a first stage, to automatically build all "possible" homogeneous RBSs and to consider them as candidates as the "best ones". These RBSs will be ranked regarding the main criteria of quality of the RBSs and considering the general requirements and objectives of user and selected REs which have to be propagated through the RBS. The most convenient RBS is selected regarding the global notes of the RBSs, the one with the highest ranking. In the last step, the quality of this RBS can be improved by extending more the risky categories and by deleting negligible and unimportant branches regarding the level of details and criticality. The main steps of generation, ranking and selection of the most convenient RBS are schematically illustrated in Figure 3.

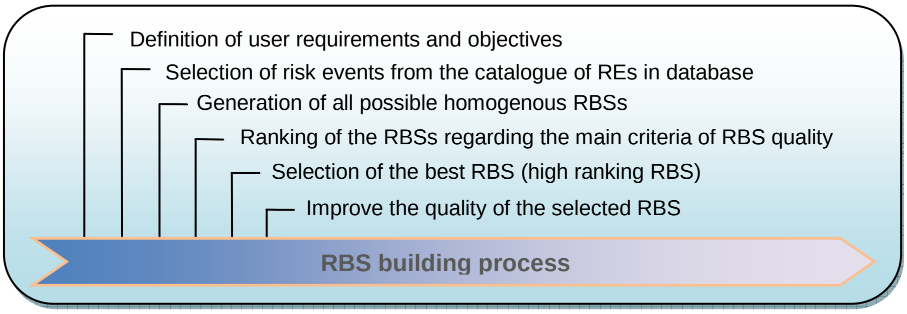

Figure 3. *RBS building process*

4.1. Criteria for selecting a convenient RBS

Thus one must define on what criteria the RBS can be ranked and selected. The criteria defining what is a "good" RBS are the following ones:

(a) a RBS must cover all considered REs in a given project, but this is not discriminant, since it is obviously satisfied with the consistent database. If it was not, the solution would be to broaden or to deepen the database by adding new REs, new RCs and new MTs.

(b) a RBS must be developed at a "convenient" level (neither too much nor too little). This criterion evaluates the adequacy of the level of detail of the RBS. A quantitative note (N_{conv}) is calculated regarding the number of risk events attached to each "bottom RC". The higher N_{conv}, the more equilibrated is the number of REs in each "bottom RC" of the RBS.

(c) a RBS must decompose the risks in agreement with the user view: what are his objectives? On what performance does he want to focus? This criterion corresponds to the ability of the RBS to fully show what is important for the user. Depending on the context, the user may prefer to focus on project phases, on a given stakeholder (e.g. himself !) or on some components of the project performances (cost, delay, quality). Three notes (N_{phases}, $N_{stakeholder}$, $N_{performances}$) are calculated for each RBS, considering the local notes of its

MTs. These local notes are corresponding to the adequacy of the MT with such requirements (phase, stakeholder, RM objective).

(d) a RBS must decompose the risks such as to highlight the more important ones. Applying this criterion needs to know the risk value of REs and RCs. The idea is to favour RBSs having the higher contrast between risky domains and non-risky domains and is quantitatively represented by a $N_{contrast}$ note for each RBS.

It is on the basis of the set of five notes (N_{conv}, N_{phases}, $N_{stakeholder}$, $N_{performances}$, $N_{contrast}$) that all RBSs can be compared and the best ones selected, using a final multicriteria decision process. At the present stage of development of this work, the propagation rules have not yet been fixed, but they will be implemented in order to make possible the propagation of quantitative information, as well as that of qualitative information, like that of a Likert scale.

4. Conclusion

We have explained the reasons why and the methodology for developing a formal and synthetic approach for building Risk Breakdown Structures for a better management of risks in construction projects. This work has consisted in identifying relevant risk categories and hierarchical relations between these categories such as to identify and define elementary micro-trees. The database is constructed so as to ensure consistency between all basic information, and to make easy any further developments and updating.

In parallel, efforts have been devoted to the automatic rebuilding of RBS that must be scalable, adaptable to the project development and allow multi-view from each of the stakeholders. The building process combines: a top-down approach in which risk categories are progressively subdivided, and a bottom-up approach in which risk events are progressively grouped. The rebuilt RBS are compared with regards to a set of five notes, enabling to have, at the same time, different “best RBS” for different project partners and making communication between partners easier.

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6. References

Aleshin A., «Risk management of international projects in Russia», *Int. J. of Project Management*, vol. 19, 2001, p. 207-222.

Atkins W.S., The risk to third parties from bored tunneling in soft ground, research report 453, HSE, 2006.

Breysse D., *Maîtrise des risques de projet, Vol. 2: Maîtrise et gestion des risques dans l'aménagement et la construction*, Hermès-Lavoisier, 2009.

Chapman R.J., «The controlling influences on effective risk identification and assessment for construction design management», *Int. J. of Project Management*, vol. 19, 2001, p. 147-160.

Din S., Abd-Hamid Z., Bryde D.J., «ISO 9000 certification and construction project performance: The Malaysian experience», *Int. J. of project management*, In press, doi:10.1016/j.ijproman.2010.11.001.

Gallagher , http://www.agcs.allianz.com/sharing-knowledge/risk-features/tunneling-code-of-practice/, 2005.

Hillson D., Grimaldi S., Rafele, C., «Managing project risks using cross risk breakdown matrix», *Risk Management*, vol. 8, 2006, p. 61-76, Palgrave Macmillan Ltd.

Holzmann V., Spiegler I., «Developing risk breakdown structure for information technology organizations», *Int. J. of project management*, In press, doi:10.1016/j.ijproman.2010.05.002.

Holzmann V., Spiegler I., 2010 . «Developing risk breakdown structure for information technology organizations», *Int. J. of project management*, In press, doi:10.1016/j.ijproman.2010.05.002.

Klemetti A., Risk management in construction project networks. Ph. D., Helsinki Univ. of technology, Espoo, 2006.

Mehdizadeh R., Breysse D., Chaplain M., Niandou H., «A methodology for building taylor's made RBS for project risks management in construction», *5th Asranet conf.*, Edimburgh, 14-16 june 2010.

Patterson F.D., Neailey K., «A Risk Register Database System to aid the management of project risk», *Int. J. of Project Management*, vol. 20, 2002, p. 365-374.

Tah J.H.M., Carr V., «Towards a framework for project risk knowledge management in the construction supply chain», *Advances in Engineering Software*, vol. 32, 2001, p. 835-846.

Zeng J., An M., Smith N.J., «Application of a fuzzy based decision making methodology to construction project risk assessment», Int. J. of Project Management, vol. 25, 2007, p. 589-600.