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Dynamic and multi-perspective risk management of construction projects using tailor-made Risk Breakdown Structures

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*Dynamic and multi-perspective
risk management of construction projects
using tailor-made Risk Breakdown Structures*

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Abstract

In recent years, intensive research and development have been done in the area of construction projects risk management. The construction projects involve numerous participants whose interests and demands need to be considered in the managerial decision-making to ensure the success of the project.

Risk Breakdown Structure is a hierarchically organized depiction of the identified project risks arranged by risk categories and subcategories that identifies the various areas and causes of potential risks. This type of representation has many advantages and is a suitable tool especially for risk management of construction projects since: it offers a synthetic view on risks, each stakeholder can have his own view on the project and it is compatible with evolutionary and dynamic nature of project risks. However, RBS suffers several drawbacks such as lack of consensus on how to develop an RBS for a new project, lack of clarity and inconsistencies in definition of risk categories and lack of rules enabling transfer of qualitative/quantitative information of risks across the tree.

In this PhD thesis, we propose a methodology for the development of tailor-made RBS's which 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. This makes it possible to establish a dynamic, multi-scale and multi-perspective approach in which each partner, at each desired stage, can focus on selected specific risks and divide the RBS's up into a greater number of subcategories in specific fields. It allows to identify and manage the construction project risks in a more formal, efficient and systematic way.

In parallel, efforts have been devoted to the development of an advanced method for analysis and aggregation of risk values through RBS. The aim was to develop a more coherent approach in order to get more realistic results without suffering from the usual weaknesses of available methods in literature to calculate the risk value of categories in RBS. The method combines consistently the quantitative and qualitative approaches, allowing the user to choose the best one for risk assessment at any level based on the available information and required accuracy.

Special care was taken in the development of the risk knowledge database in order to ensure the data's consistency. A database which has three interactive components of risk events, risk categories and micro trees, and have been developed based on a thorough analysis of literature. This knowledge base is general enough to cover all construction projects but at the same time, specific enough to be adapted to a given particular project. This database provides a common language within which the project risks can be described and discussed. The RBS rebuilding process is driven in such a way as to make it possible to compare different possible RBS's according to several criteria (degree of development, user satisfaction and highlighting the contrast of risk values). The database is constructed in such a way as to facilitate further developments and updating.

Key words: *Risk Breakdown Structure, Risk management, Construction, Methodology, Database.*

Résumé

Depuis quelques années, de nombreux travaux de recherche se sont portés sur le domaine de la gestion des risques pour les projets de construction. Les projets de construction font intervenir de nombreux acteurs dont les intérêts et les besoins doivent être pris en compte dans le système décisionnel afin d'assurer le succès du projet.

Une RBS (Risk Breakdown Structure) est une représentation hiérarchisée des risques d'un projet. Elle est composée de catégories de risque qui explicitent les différents domaines pouvant être source de risque. Ce type de représentation présente de nombreux avantages, la rendant ainsi adaptée à la gestion des risques dans les projets de construction : elle offre une vision synthétique des risques, elle est compatible avec la nature dynamique et évolutive des risques et elle permet à chaque acteur du projet d'avoir sa propre vision des risques. Cependant les RBS présentent aussi des inconvénients : il n'existe pas de consensus sur la façon de les construire, la définition des catégories de risque est souvent floue et non partagée, enfin il n'y a pas de règles permettant de propager les évaluations (qualitatives ou quantitatives) dans les branches de la structure.

Dans cette thèse, nous proposons une méthodologie pour le développement de RBS sur mesure, c'est à dire adaptées à l'étape et au niveau de développement du projet et permettant d'offrir un point de vue adapté aux différents acteurs. Cela permet de poser les bases d'une approche dynamique, multi-échelle, multi-perspective dans laquelle chaque acteur, peut, dans chacune des phases, se concentrer sur certains risques par une décomposition adaptée de sa RBS. Cela permet d'identifier et de gérer les risques liés au projet de construction d'une façon plus formelle, plus efficace et plus systématique.

En parallèle, des efforts ont porté sur le développement d'une méthode avancée pour l'analyse et l'agrégation des valeurs de risque par les RBS. Le but était de développer une approche cohérente afin d'obtenir des résultats réalistes sans souffrir des faiblesses habituelles des méthodes disponibles dans la littérature. La méthode combine les approches quantitatives et qualitatives, permettant ainsi à l'utilisateur de choisir, selon l'information disponible et la précision souhaitée le choix du type d'évaluation le plus adapté.

Une attention particulière a été portée quant au développement de la base de connaissances, afin d'assurer la cohérence des données. La base de connaissance est composée de trois types d'objets principaux : les événements risqués, les catégories de risque et les arbres élémentaires. Elle a été alimentée par une analyse approfondie de la littérature. Cette base de connaissances est suffisamment générale pour couvrir tous les projets de construction et suffisamment précise pour être adaptée à un projet particulier. Elle fournit un langage commun avec lequel les risques liés au projet peuvent être décrits et discutés. Le processus de construction des RBS est basé sur une logique multicritère (degré de développement, satisfaction des utilisateurs, contraste des valeurs de risque) permettant de comparer les différentes RBS entre elles. La structure de la base de connaissance est conçue de façon à faciliter sa mise à jour et ses développements ultérieurs.

MOTS-CLÉS: *hiérarchie des risques, gestion des risques, construction, méthodologie, bases de données.*

چکیده پایان نامه

در طی سال‌های اخیر، تحقیقات گسترده‌ای در زمینه مدیریت ریسک پروژه‌های ساخت و ساز و زیربنایی انجام گرفته است. غالباً این نوع از پروژه‌ها در برگیرنده تعداد زیادی ذینفع (مالک، پیمانکاران، طراحان فنی و معماری، سرمایه‌گذار، بیمه‌گر و ...) می‌باشند که مدنظر قرار دادن منافع، اهداف و مطالبات آن‌ها در اتخاذ تصمیم‌ها یکی از موارد لازم برای اطمینان از موفقیت پروژه می‌باشد.

ساختار درختی ریسک (Risk Breakdown Structure) که بازنمودی طبقه‌بندی شده از ریسک‌های پروژه ارائه می‌نماید، متشکل از گروه‌ها و زیرگروه‌های سازمان یافته ریسک بوده و ابزاری بسیار موثر در شناسایی منابع و آثار محتمل ریسک‌ها می‌باشد. این نوع بازنمود ریسک‌ها دارای مزایای فراوانی می‌باشد به خصوص در مدیریت ریسک پروژه‌های عمرانی و زیربنایی. بخشی از دلایل این مدعا عبارتند از: توانایی RBS در تجزیه و تحلیل ریسک‌های پروژه و اینکه با استفاده از RBS هر یک از اعضای ذینفع پروژه می‌تواند دیدگاه خاص خود را نسبت به ریسک‌های پروژه داشته باشد که این قضیه با ماهیت دینامیک و تکاملی پروژه‌ها به خوبی سازگار می‌باشد. با این حال، علیرغم قابلیت‌های فوق العاده این ابزار، RBS دارای چندین ضعف اساسی می‌باشد از قبیل: عدم وجود راهنما، روش و اجماع در چگونگی طراحی RBS جدید برای یک پروژه جدید با ویژه‌گی‌های خاص خود، وجود تعاریف مبهم و بعضاً متناقض ریسک‌ها و گروه‌های ریسک در RBS‌های موجود، عدم وجود روشی مشترک و موثر برای انتقال اطلاعات کمی و کیفی وقایع ریسک بر روی ساختار درختی RBS به منظور محاسبه مقادیر ریسک هر گروه ریسک.

در این رساله دکتری، روشی نوین برای طراحی RBS‌های سازگار برای هر پروژه یا شرایط خاص ارائه می‌گردد. این RBS‌ها با مقطع زمانی و میزان پیشرفت پروژه و همچنین دیدگاه‌های متفاوت ذینفعان پروژه نسبت به ریسک‌ها سازگار می‌باشند. این روش متضمن اعمال مدیریت ریسک پویا و دینامیک، چند مقیاسی و چند بعدی در پروژه‌ها بوده و هر یک از اعضای پروژه در هر مقطع زمانی خاص قادر خواهد بود بر ریسک‌های مورد نظر خود تمرکز نموده و برای کسب اطلاعات جامعتر، هر گروه ریسک در RBS را به تعداد بیشتری زیر گروه تجزیه نماید. چنین رویه‌ای ابزار و روش لازم برای شناسایی و مدیریت سیستماتیک، موثرتر و رسمی‌تر ریسک‌های پروژه را فراهم می‌نماید.

همزمان با توسعه روش مذکور برای طراحی RBS‌های سفارشی برای هر مورد خاص، تلاش ویژه‌ای برای ابداع روشی نوین به منظور کسب نتایج واقع‌بینانه‌تر در آنالیز و توزیع مقادیر ریسک بر روی شاخه‌های RBS اعمال گردید. روش پیشنهادی، ترکیبی سازگار از رویکردهای کمی و کیفی ارائه نموده و کاربر قادر خواهد بود بر اساس میزان اطلاعات موجود و دقت مورد نیاز بهترین گزینه را انتخاب نماید.

برای اطمینان از سازگاری اطلاعات مورد استفاده در روش‌های فوق‌الذکر و ایجاد ادبیاتی مشترک و استاندارد برای توصیف و بحث پیرامون ریسک‌های پروژه، دقت خاصی در توسعه دیتابیس (بانک اطلاعات) ریسک اتخاذ گردید. این پایگاه داده که بر اساس مطالعه و تجزیه و تحلیل دقیق متون موجود، استانداردها و گزارشات فنی پیرامون مدیریت ریسک پروژه‌های عمرانی تهیه گردیده است متشکل از سه بخش اساسی پویا و توسعه پذیر می‌باشد: وقایع ریسک، گروه‌های ریسک و میکرو درخت‌ها. در عین جامعیت این دیتابیس برای تحت پوشش قرار دادن انواع پروژه‌های عمرانی، ساختار اطلاعات به گونه‌ای طراحی گردیده که توسعه آن برای تمرکز بر نوع خاصی از پروژه (تونل، سازه‌های موقت، ...) امکان‌پذیر می‌باشد.

فرایند طراحی RBS‌های سفارشی با بازسازی تمامی RBS‌های ممکن از طریق ترکیب میکرو درخت‌های موجود در دیتابیس آغاز گردیده و سپس برای انتخاب بهترین درخت ریسک، تمامی گزینه‌های ممکن به واسطه معیارهای کیفیت تعریف شده RBS (میزان توسعه ساختار درخت ریسک، تناسب ساختار RBS با مطالبات و اهداف کاربر و کنتراست مقادیر ریسک بر روی شاخه‌های RBS) مقایسه می‌گردند.

برای تسهیل کاربرد عملی روش‌های ارائه شده در پروژه‌های واقعی، نرم افزار خاصی بر اساس تمامی مفاهیم و الگوریتم‌های موجود در روش‌های توسعه داده شده تهیه گردیده است. این نرم افزار با واسط کاربر پسند، ابتدا تمامی RBS‌های ممکن را تولید نموده، مقادیر ریسک گروه‌های ریسک را محاسبه کرده و به طور اتوماتیک برای هر RBS پنج فاکتور کیفیت محاسبه می‌نماید. در گام دوم، تمامی RBS‌های ایجاد شده با استفاده از یکی از روش‌های تصمیم‌گیری چندمعیاری رتبه‌بندی شده، کاربر قادر خواهد بود بهترین RBS را انتخاب نماید. نرم افزار قادر است به طور گرافیکی ساختار درختی تمامی RBS‌های طراحی شده را به همراه مقادیر ریسک محاسبه شده و توزیع وقایع ریسک بر روی شاخه‌های RBS نمایش دهد.

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Abbreviation

ABI - Association of British Insurers

AHP - Analytic Hierarchy Process

APM - Association for Project Management

BTS - British Tunneling Society

CEVP - Cost Estimation Validation Process

DAT - Decision Aids for Tunneling

GERMA - Gestion des Risques liés au Management des projets complexes de Génie Civil

HSE - Health and Safety Executive

IPA - Independent Project Analysis

ITA - International Tunneling Association

MT - Micro Tree

NATM – New Austrian Tunneling Method

PMBOK - Project Management Body of Knowledge

PMI - Project Management Institute

PPP - Public-Private Partnership

PRM - Project Risk Management

RBS - Risk Breakdown Structure

RC - Risk Category

RE - Risk Event

RMP – Risk Management Process

TBM – Tunnel Boring Machine

WBS - Work Breakdown Structure

WSDOT - Washington State Department of Transportation

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Chapter 1

INTRODUCTION

1. Introduction

1.1. Problem definition

Project Risk Management (PRM) is a systematic process of identifying, assessing and responding to project risk. The overall goal of the risk management process is to maximize the opportunities and minimize the negative consequences of risk threats.

Construction projects are usually considered as long time projects which during their life cycle are affected by variety of risk categories such as economic, environmental, political, financial, geological, technical, etc. By the progress of the project the level of available information about risks usually increases. Some predicted risks events occur while others will not, new unpredicted risk events may occur or may be identified, and the characteristics of those already identified may change. As a consequence, an iterative risk management should be carried out at all stages of the project life cycle, considering variety of risks which may appear in certain circumstances and for a period of time. Furthermore, project success should be viewed from the different perspectives of the individual owner, developer, contractor, user, the general public, and so on. These different perspectives explain the reason why the same project can be considered a success by one party and unsuccessful by another.

Many tools can be used to communicate identified risks to project stakeholders such as risk registers, risk matrix and risk map. Among them, the hierarchical description of risks using the Risk Breakdown Structure (RBS) is a very practical tool, which makes risk management easier. It can be used in risk identification stage and it can provide a support in the later stages (risk assessment and risk response), since it offers an overview on the risks which affect the project.

Hillson (2002) believes that RBS is a powerful aid to risk identification, assessment and reporting, and that its ability to roll-up or drill-down to the appropriate level provides new insights into overall risk exposure on the project. A common language and terminology facilitates cross-project reporting and lesson learning. The RBS has the potential to become a valuable tool in assisting the project manager to understand and manage risks. However, RBS suffers several drawbacks such as lack of consensus on how to develop RBS for a new project, lack of clarity and inconsistencies in definition of risk categories and lack of rules enabling transfer of qualitative/quantitative information about risks across the structure. In fact, each user develops his own RBS, without following any guidelines. The result is that it is impossible to identify “good practices” for developing RBS. Another criticism against RBS is that they have difficulties in accounting for (existing) interactions between risks, because of their hierarchical structure when the underlying processes of a real project are more complex.

1.2. Research objectives

This research aims at developing a more formal and synthetic approach for building tailored-Risk Breakdown Structures to identify and organize risks in construction projects. This method can provide the essential information to take a reasonable decision to carry on the effective response actions (avoid, transfer, share, etc.). 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 dynamic, multi-scale and multi-perspective approach in which each partner can focus on some special risks and develop the RBS by some more subcategories in special fields. Of course, the methodology must be both general enough to cover all construction projects and specific enough to be adapted to a given particular project. Thus the specific objectives of our research are as follows:

- The development of a risk knowledge database, including three interactive components of risk events, risk categories and micro trees, in order to ensure the data's consistency. This knowledge base should be general enough to cover all construction projects and specific enough to be adapted to a given particular project. This database must provide a common language with which the project risks can be described and discussed.
- Generation of tailor-made RBS's which are adapted to several criteria: being fitted to the stage and degree of development of the project, being able to offer different views for the different partners, highlighting the contrast between risks.
- The development of a more consistent approach for analysis and aggregation of risk values through RBS to get more realistic results without suffering the usual weaknesses of available methods in literature.
- The development of a software with a user friendly interface for an easy application of the proposed methodology in real projects.
- Application of the proposed method in a real case to show how this method can be useful in identification and analysis of the project risks and how different perspectives of the project partners can be considered in this process. Furthermore, it should be discussed how the project risk management is dynamic and how risk interactions can be considered to get more realistic results.

This thesis is based on some of the works performed in a national research project in France, named GERMA. In this project, engineering companies and contractors have worked with academic researchers, with the aim of a better management of risks in complex construction projects.

1.3. Thesis outline

This thesis is organized as follows:

Chapter 2 provides a general introduction to the risk management in construction projects. In this chapter the main concepts of risk and project risk management, different steps of this process and available tools and techniques are discussed. Risk Breakdown Structure (RBS) as a practical tool in project risk management is introduced and available methods of risk analysis are evaluated. It is explained how the project risk management is a dynamic practice and how risk identification and analysis process is affected by risk interactions. This chapter presents the main theoretical framework for the research. It provides the background and all needed information to discuss the issues and proposed solutions in this research.

In Chapter 3, the methodology of generation of tailored-Risk Breakdown Structures is explained in detail. The chapter begins explaining how the three iterative components of the risk knowledge base (risk events, risk categories and micro trees) are developed based on a thorough analysis of literature, and how the consistency and extensibility of the database is controlled. The chapter continues with generation process of the tailored RBS's, providing the general algorithm and definition of the RBS quality criteria.

To aggregate the risk values through the RBS branches, a method is explained in detail. The method combines consistently the quantitative and qualitative approaches, allowing the user to choose the best one for risk assessment at any level, based on the available information and required accuracy.

In Chapter 4, after a brief introduction of the software which has been developed for an easy application of the proposed methodology, a practical application of the proposed method in real projects is provided. The focus is on a dynamic and multi-perspective risk management of the project. The chapter also discusses the sensitivity of generation process of tailored RBS's and risk analysis results to the user requirements, applied parameters and different perspectives of stakeholders to project risks.

General conclusion and recommendations for future works are provided in Chapter 5.

Appendix 1 provides the content of the database, including REs, RCs and MTs. Appendix 2 provides the results of synthesis of some RBS's available in literature. Their drawbacks are highlighted and their structure is compared with the proposed MTs in our consistent database. Appendix 3 provides a comprehensive introduction of the software. Different parts of the software are introduced in detail and it is explained how to manage the information in database, how to control the consistency of data, how to solve the errors and how to interpret the results of generation and ranking of RBS's. Furthermore, some applicable examples are presented at the end of Appendix 3 to show how this software can be used in practice.



1.4. Introduction to GERMA project

GERMA¹ project, the French acronym for “managing risks related to management of complex civil engineering projects” was supported by a set of engineering companies (COTEBA, EGIS, IOSIS, Coyne & Bellier), a general contractor (Vinci), linked to research laboratories: University of Marne-la-vallée, Bordeaux, GRID (research group involving ENSAM and ESTP). This project was certified by the “Pôles de compétitivité” Advancity and GIS-MRGenCi and has received funding from the National Agency of Research for a period of 3 years. This project aimed to develop and broadcast tailored methods for project risk management, and to raise awareness of project stakeholders to the importance of these approaches.

The evolution of regulatory and legislative context (public-private partnerships, extension of project management activities to regional communities...), involvement of local politics which can constrain or modify projects, together with increasing number of involved project partners have contributed to make project and risk management more complex. Furthermore, these projects sometimes led to serious failures (technical, financial or commercial), considering the usual project objectives (cost, time and performance) or specifically related to environment, sustainable development, work accidents, etc. These are the reason why the project management and management of risks have become a major issue for many organizations. On the other hand, between all partners involved during the life cycle of a project, the knowledge bases and practices (methods and tools) in project risk management are quite fragmented and compartmentalized. Studies related to project risk management in construction are still rare and main stakeholders in civil engineering domain are not effectively involved in development of risk management approaches.

The project objectives and adopted approach

The objective is to enable different project partners (owner, contractor, consultants...) to better understand and integrate risks associated with their project, and also to consider how they can be anticipated, analyzed or even be better modeled. It is no longer conceivable today that the project management can ensure the success of project without taking risks into consideration.

This research project aims to generally and specifically address the risk management in management of project (project leadership and decision support). The objective was to amplify development of:

- new approaches and methods of project management for better integrating the increasing complexity of projects,

¹ . Gestion des Risques liés au Management des projets complexes de Génie Civil

- the reliability approach but also the explicit integration of other methods, such as risk analysis and its enrichment via decision models,
- tools and methods of assessment for better management of risks,
- tools and methods to monitor risks in real time.

In this context, the consortium decided to create, for the first time in France, a reference guide and more relevant practical tools based on review of good practices and current researches, through collaboration and dialogue between all project partners. In this collaborative project, several meetings were held to compare and discuss different ideas and points of view of all project partners. The work was accompanied with many discussions and interviews with more than twenty large complex projects (buildings, infrastructure, transport systems, urban development) of the organizations which were involved in this process (EDF, Vinci, Bouygues, RFF, Alstom, ADP, AREVA, Ville de Paris,...).



Chapter 2

RISK MANAGEMENT IN CONSTRUCTION

STATE-OF-THE-ART

2. Risk management in construction, state-of-the-art

2.1. Introduction

In recent years, intensive research and development has been done in the area of construction projects risk management. It is widely recognized as one of the most critical procedures and capability areas in the field of project management (Klemetti, 2006). Failures in risk management in construction 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. A project is defined (ISO, 2003) as “*A unique process consisting of a set of coordinated and controlled activities with start and finish dates, undertaken to achieve an objective conforming to specific requirements including constraints of time, cost and resources*”. Thus Project Risk Management (PRM) is aimed at reducing the probability of failure to reach the project objective at a residual, identified and acceptable level. It is intended to maximize the beneficial outcome of the opportunities and minimize or eliminate the consequences of adverse risk events.

A significant number of construction failures and collapses occur during the construction phase and in most of the cases these failures involve the temporary structures and equipment which are used during the construction process (Mehdizadeh et al., 2012). However, failure of projects is not limited to these kinds of accidents and collapses. Cost overruns are not uncommon, especially in complex projects. Also the problem of delay is a global phenomenon (Sambasivan and Soon, 2007) and a project is considered 'successful' if it is completed on time, within budget and to the specified quality standards (Chan and Kumaraswamy, 1997). The major factors causing delays on construction projects have been reviewed and critically appraised in many scientific journals and reports (Luu et al, 2009). After examining more than 1,000 site-based projects from over 100 different manufacturing sites around the world by IPA (© Independent Project Analysis), the study found that, on average, only 37 percent of the projects at a site meet the success criteria, including schedule, safety, operability and final cost of the project (IPA, 2011).

An analysis of projects supported by the World Bank (1974-1988) has shown that 63% of 1178 projects have known a significant overrun (Baloi and Price, 2003). For the same period, Pipattanapiwong (2004) found delays between 50 and 809 %. Flyvbjerg et al. (2002) published an extensive statistical analysis of big projects covering 70 years of experience. They found overruns on 9 transportation projects out of 10, ranging from 20% (road projects) to 45% (railway projects). Morris and Hough (1991) found that cost overruns in a large sample of projects (3500 projects of different countries) were typically between 40 and 200 per cent. Odeck (2004) reports from a study of 620 public road projects in Norway completed during 1992-1995 that in more than half of the projects the total cost exceeded the budget. Lam (1999) quoted the « Second Stage Expressway », suspended after a 3.1 billion dollars investment.

The construction project management involves numerous participants: end users, promoters, construction companies, project designers, government/public bodies as well as a large number of sub-contractors, suppliers and other entities (Pérez et al., 2010) whose interests and demands need to be considered in the managerial decision-making, to ensure the success of the project (Aaltonen, 2010). In practice, the objectives of PRM can vary according to whom is concerned:

- the client (owner) focuses on the final quality of the project product (building, infrastructure, etc.), on final cost and delay,
- the contractor is interested in its proper financial result, but also in safety of workers, in the possibility of future projects with the same client, in its image in the society...
- Other stakeholders (consultants, insurers, final users, third parties, etc.) can have their own objectives on the same project. This variety of views make the PRM modeling difficult, since it is often considered privileging one specific point of view (Klemetti, 2006; Zeng et al, 2007).

Furthermore, PRM is a scalable activity and should be commensurate with the size and complexity of the project under consideration. As result, the project risk management process has to be tailored for each particular case and project (Mehdizadeh et al, 2010).

A renewed interest in PRM comes from the development of new modes of contract, like public-private partnership, where the contractor may need to manage risks well after the end of construction. In such a case, PRM really becomes a shared objective for all project partners although they may have different perceptions of proper risk allocation. Consequently, disputes may arise between those parties thus creating new sources of risk for the project (Abednego and Ogunlana, 2006).

Apart from contracts, studies show that construction risks are mainly handled with experience, assumption and human judgment (Baloi and Price, 2003). Since risks are highly situation-specific, expert judgment provides sufficient means of risk management. Problems occur when this expert knowledge isn't documented (which is common in the construction industry) and knowledge is not transferable. Lack of an industry accepted model of risk analysis forces every construction company to form and test its own risk management models (Hartman, 2000; Baloi and Price, 2003). Other risks relate to possibly biased decision making, when personal background and assumptions inevitably reflect on the person's evaluation (Klemetti, 2006).

2.2. Objectives and practices of project risk management

Project success should be viewed from the different perspectives of the individual owner, developer, contractor, user, the general public, and so on (Lim and Mohamed, 1999). 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). Usually the main objectives of the project are cost, time and quality (Swan and Khalfan, 2007). Although, Eriksson and Westerberg (2010) believe that this “iron triangle” focuses on short-term aspects of performance crucial for clients’ immediate project success. Hence, they have identified three additional performance aspects vital for sustainable success of the project: environmental impact, work environment, and innovation. So, “Quality” can cover the functionality of the product, but also other dimensions like the workers’ safety or environmental impacts.

PRM has been the topic of many studies since the beginning of the 1990s (Simon et al, 1997; Chapman and Ward, 1997; Tah and Carr, 2001; APM, 2004). In a bibliographical synthesis, Williams (1995) identified main stakes and difficulties in this domain. It is, however, only recently that first guidelines have been published for construction projects, in the field of urban tunnels (ITIG, 2006) and that innovative professional practices have appeared for a better PRM (WSDOT, 2008).

The improvement of practices is mainly based on the diffusion of guidelines for good practices, which detail what all project stakeholders must do, at each stage of the project, for a better PRM. The contrast is high between these very general texts on one hand and academic studies on the other hand, where the purpose is to develop an in-depth analysis of risks, trying to qualify/quantify them at any stage of the project. It will be shown here how this gap can be filled, by developing modeling tools, adapted to the real project context and to the need of driving factors.

France has known only a few catastrophic structural failures, even if the Malpasset dam collapse is known worldwide (Breyse and Elachachi, 2012). The poor development of the culture of risk management, together with the small number of academic studies of economics/construction management, have restrained the development of PRM in France. However, the collapse of the Roissy Terminal 2E in May 2004, whatever its causes (technical, organizational...) may have been, was the signal for a need for change. It was only in 2008 that the first research project was created, under the auspices of the National Agency for Research. In this project, referred to as GERMA, engineering companies and contractors have worked with academic researchers, with the aim of improving the management of risks in complex construction projects.

This chapter aims to set the background of the research area and discusses the problems the study deals with. In the following the main concepts of risk and project risk management, different steps of this process and available tools and techniques will be discussed. Risk Breakdown Structure (RBS) as a practical tool in project risk management will be introduced and available methods of risk analysis will be evaluated. It will be explained how the project risk management is a dynamic practice and how risk identification and analysis process is affected by risk interactions. This chapter presents the main theoretical framework for the

research. It provides the background and all needed information to discuss the problems and proposed solutions as the results of this research.

2.3. Definition of project RISK

It is important to understand exactly what is meant by risk before it can be managed (Chapman, 2001). In literature, the word “Risk” is used in many different meanings with different words such as hazard or uncertainty. It is found that there is no uniform or consistent usage of the word risk in the literature. In addition, most definitions of risk have focused only on the downside associated with risks such as losses or damages, and neglected the upside or opportunity such as profit or gains (Al-Bahar and Crandall, 1990). This word has different meaning to different people; that is, the concept of risk varies according to viewpoint, attitudes and experience (Baloi and Price, 2003).

The review of scientific literature on project risk management led to find variety of “Risk” definition (PMI, 2008; WSDOT, 2010; Baloi and Price, 2003; Barber, 2005; Chapman and Ward, 2002; Flanagan and Norman, 1993; IEC, 2001; Jaafari, 2001; Smith et al., 2006). Several of these definitions have a common feature: they define risk in terms of uncertain events and their impact on project objectives. The international standard “Project risk management–Application guidelines” uses the terms probability and consequence and defines risk as a combination of the occurrence probability of an event and its consequences on project objectives (IEC, 2001). According to PMI (2008), risk is defined as “an uncertain event or condition that, if it occurs, has a positive or negative effect on one of project objectives”. Ward and Chapman (2003) discuss the concept of risk in greater detail and suggest using a more general concept of uncertainty. They argue that the term “risk” is often associated with adversity and focus on threats, not opportunities. The questionnaire survey conducted by Akintoye and MacLeod (1997) strengthens the argument, showing that the majority of respondents perceive risk as a negative event.

The many inconsistent and ambiguous meanings attached to “risk” lead to widespread confusion and also mean that very different approaches to risk management are taken in different fields. As an example, in a research by Zhi (1995), the major risk factors of the overseas construction projects have been identified and the risks are classified in terms of their initial sources: the external and internal aspects of an overseas construction project. Some of the identified risks are: defective physical works, schedule delay, cost overrun, social environment, market fluctuation, etc. The problem is that, all the items are ambiguously called RISK, while schedule delay and cost overrun are the “consequence” on the project objectives and the other items are the “source” of difficulties. Such a list is the mixture of different risk definitions and can make lots of difficulties in project risk management process.

A synthetic analysis of literature shows that two mutually exclusive definitions of “risk” are used. Table 2.1 lists some examples in literature. This confusion is probably due to different views of industrial risk experts (the risk is the phenomenon or process due to...) and specialists in natural hazards (the risk is the potential outcome of a hazard). This difference was pointed out by Breysse (2009a).

It is important to ensure that the participants in the risk identification process remain focused on the distinction between risks and their potential effect or outcome (Chapman, 2001). Perry (1986) and the HM Treasury Procurement Guidance note No. 2 (1997) refer to the importance of the distinction between risks and their effects without stating why it is important. In simple terms, the distinction is important as it prevents the risk list becoming a confused mixture of risks and effects, making the response process particularly difficult, if not impossible.

Table 2.1. Two different definitions of “Risk” in literature

Risk : the measure of consequences	Risk: the source event
ISO guide draft 73 (2009) Effect of uncertainty on project objectives. An effect is a deviation from the expected positive and/or negative objectives.	Chapman (2001) an event, which should it occur, would have a positive or negative effect on the achievement of a project's objectives
WSDOT (2010) The combination of the probability of an uncertain event and its consequences. A positive consequence presents an opportunity; a negative consequence poses a threat.	PMI (2008) (PMBOK) project risk is an uncertain event or condition that, if it occurs, has a positive or negative effect on a project's objectives.
ITIG (2006) Risk is a function of the consequence/severity of a hazard and the likelihood of occurrence of the hazard.	Del Cano and Cruz (2002) an uncertain event that, if it occurs, has a positive (opportunities) or negative (threats) on a project objective.
Bourdeau et al. (2003) Expectancy of undesirable results (but the occurrence of positive results can be integrated).	Baloi and Price (2003) The likelihood of a detrimental event occurring to the project.
Raferly (1999) Exposure to the possibility of economic and financial loss or gain, physical damage or injury, or delay as a consequence of the uncertainty associated with pursuing a particular course of action.	Al-bahar and Crandall (1990) The exposure to the chance of occurrences of events adversely or favorably affecting project objectives as a consequence of uncertainty.

In this research, the definition proposed by ISO 31000 was adopted and thus the “Risk” is considered as the effect of uncertainties on project objectives (ISO guide draft 73, 2009). Based on this definition, which was discussed and adopted by the GERMA project members, risk is the measure (the mathematical sense) of consequences resulting from the occurrence of

undesirable events or distance between objectives and results. The consequences are related to one or more of the project objectives.

2.3.1. Risk versus opportunity

The traditional view of risk is negative, representing loss, hazard, harm and adverse consequences. But some current risk guidelines and standards include the possibility of „upside risk” or opportunity, i.e. uncertainties that could have a beneficial effect on achieving objectives (Hillson, 2002).

Following the proposed definition in the last section, project risk encompasses uncertain events which could have a negative effect on project objectives, as well as those which could have a positive effect. These two types of risk are called, respectively, threats and opportunities. It is important to address both threats and opportunities within a unified Project Risk Management process.

In the following sections, our focus will be more on threats than on opportunities, but the proposed methods and approaches can be easily expanded to cover the opportunities as well.

2.4. Project risk management process

Risk management is a systematic process of identifying, assessing and responding to project risk (PMI 2008). The overall goal of the risk management process is to maximize the opportunities and minimize the negative consequences of risk threats. A variety of risk management models with different number of stages can be found in the literature.

Berkeley et al. (1991) and Flanagan and Norman (1993) divided the systematic process of risk management into: risk classification, risk identification, risk analysis and risk response, where risk response has been further divided into four actions, i.e. retention, reduction, transfer and avoidance. The international standard “Project risk management – Application guidelines” (IEC, 2001) has offered a model with four steps: risk identification, risk assessment, risk treatment, and risk review and monitoring. According Practice Standard for Project Risk Management (PMI, 2008), PRM includes the processes of conducting risk management planning, identification, analysis (quantitative, qualitative), response planning, monitoring and control on a project (see Figure 2-2). WSDOT (2010) and Office of Project Management Process Improvement (2003) have suggested the same process of project risk management as PMBOK. But Baloi and Price (2003), include an additional step of risk communication. The five key phases of the Risk Management Process (RMP) proposed by Tah and Carr (2001) are represented in Figure 2-1. In each step of this dynamic process the input data, tools, methods and expected outputs have been provided.

The Association of Project Managers (APM) have developed Project Risk Analysis and Management (PRAM), as described by Chapman (1997). In this case, nine phases have been considered: define, focus, identify, structure, ownership, estimate, evaluate, plan, and manage. In another research, Hertz and Thomas (1983) proposed this process as a logical sequence of steps consisting of risk identification, risk measurement, and risk evaluation and re-evaluation. Furthermore, they linked risk management with strategic planning and management. Chapman and Ward (2003) presented the SHAMPU (Shape, Harness, and Manage Project Uncertainty) framework which involves nine stages: define the project, focus the project, identify the issues, structure the issues, clarify ownership, estimate variability, evaluate implication, harness the plans, and manage implementation. Del Cano and de la Cruz (2002) propose an integrated methodology for project risk management in large and complex construction projects. The model is divided into four process phases: initiation, balancing, maintenance and learning. Each phase consists of several stages, which, in turn, are divided into different activities.

Despite the variety of existing models in the literature, they all share a common goal and have similar characteristics. The aim is to provide a systematic approach to risk management involving: the identification of risk sources; the quantification of their effects (qualitative and quantitative risk analysis); the development of responses to risks; and the control and monitoring of risks and risk responses. In the following parts of this chapter, these main steps will be further explained.

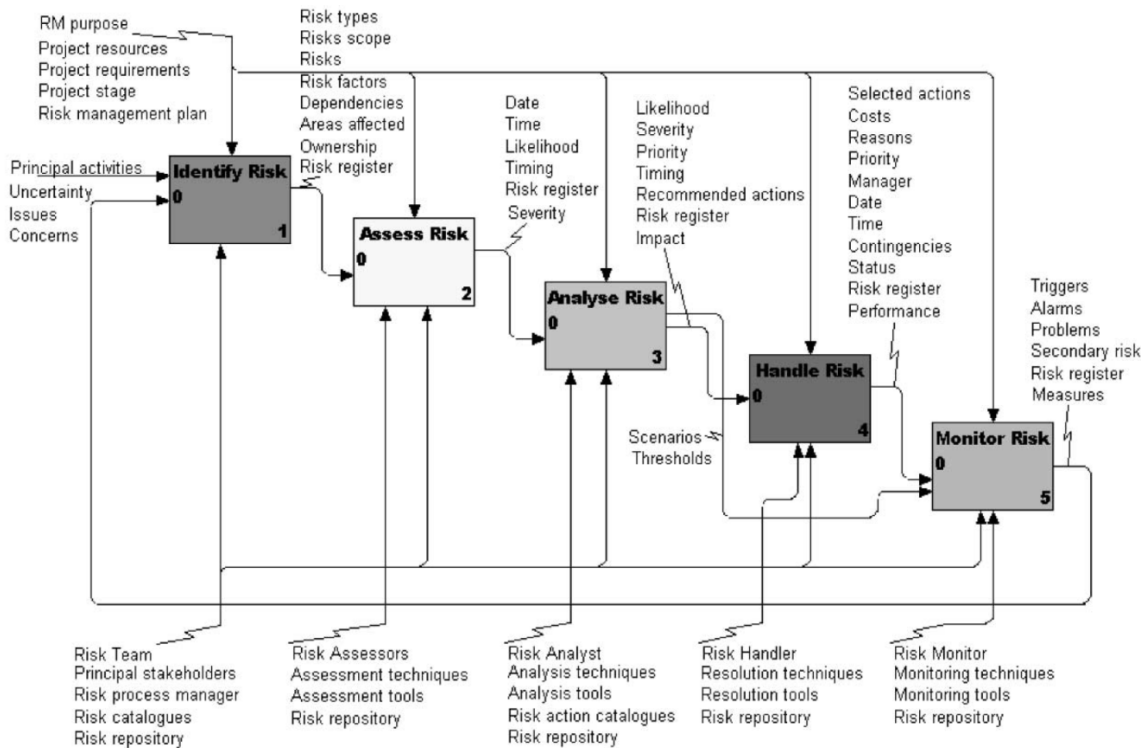


Figure 2-1. The Risk Management Process (RMP)(Tah and Carr, 2001)

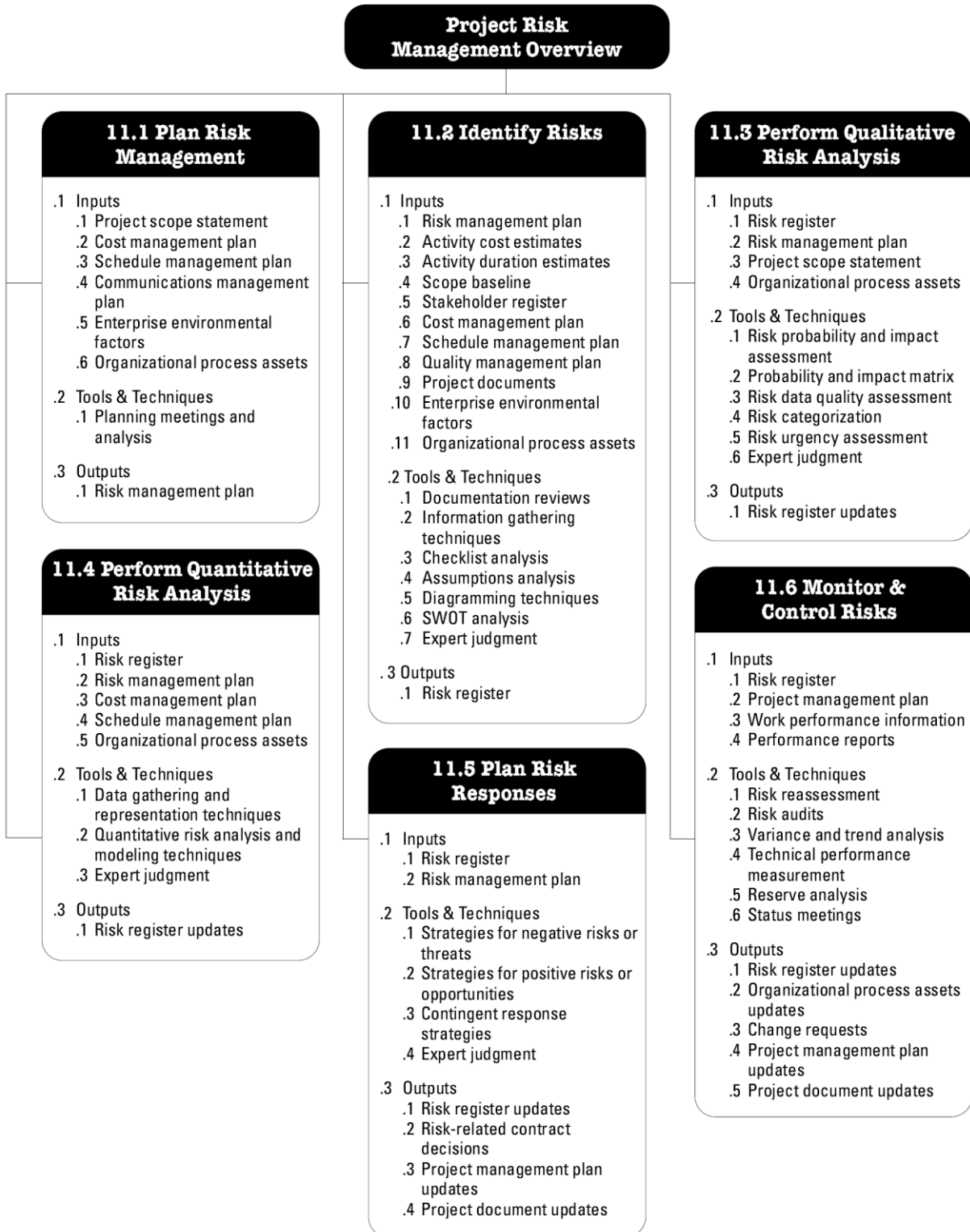


Figure 2-2. Project Risk Management overview (PMI, 2008)

2.4.1. Risk identification

A risk cannot be managed unless it is first identified. Consequently, after risk management planning has been completed, the first process in the iterative Project Risk Management process aims to identify all the knowable risks to project objectives (PMI, 2008).

Risk identification is the process of systematically and continuously identifying, categorizing, and assessing the initial significance of risks associated with a construction project (Al -Bahar and Crandall 1990). Risk identification determines risks that might affect the project and registration of their characteristics. Redmill (2002) explained that the purpose of identifying the source of risk is to prevent the events that can go wrong and lead to breaches of safety.

The identification should be performed on a regular basis throughout the project. The purpose is to identify risks to the maximum extent that is practicable. The fact that some risks are unknowable or emergent requires the identify risk process to be iterative, repeating the identify risks process to find new risks which have become knowable since the previous iteration of the process (PMI, 2008). By the progress of the project through its life cycle, new risks may appear. The project team should be involved in this process so that they can develop and maintain a sense of ownership of, and responsibility for, the risks and associated risk response actions (Mojtahedi et al, 2010).

Participants in risk identification activities can be the following: project manager, project team members, risk management team (if assigned), experts that are not member of project, customers, end users, other project managers, stakeholders, and risk management experts (Mojtahedi et al, 2010). Chapman (2001) pointed out that, since the risk management process builds heavily on the primary identification phase, the success of later risk management phases is directly comparable to the quality of the first identification phase.

The inputs of risk identification process include the project objective, risk management scope and plan and historical data related to project. The project related document, project participants and events occurring in the scope of project are some sources of information used to identify risks (Aleshin, 2001). Risk identification has to be employed equally effectively to identify opportunities as well as threats. However, the experience of most project teams is to focus on negative issues (Hillson, 2002).

A large number of techniques exist for risk identification, such as brainstorming and workshops, checklists and prompt lists, questionnaires and interviews, Delphi groups or Nominal Group Techniques, and various diagramming approaches (cause–effect diagrams, systems dynamics, influence diagrams, etc.) (Chapman, 1999). These include creativity techniques and those which draw on previous experience, and group approaches as well as methods (Hillson, 2002). Chapman (1998) stated that available identification techniques may be considered to fall into three distinct classifications: (1) identification conducted solely by

the risk analyst, (2) identification by the analyst interviewing a member of the project team, and (3) the analyst leading a working group. A list of available tools and techniques of risk identification, proposed by (PMI, 2008), is represented in Table 2.2, highlighting their strengths and weaknesses.

The brainstorming process, borrowed from business management and not specifically created for risk management, involves redefining the problem, generating ideas, finding possible solutions, developing selected feasible solutions and conducting evaluation (Chapman, 1998). Originated by Osborn (1963) in the early 1950s, brainstorming was proposed as a problem solving method which would produce a much larger quantity of ideas in less time than existing group problem solving techniques.

The Delphi Technique is a method for the systematic collection and collation of judgments from isolated anonymous respondents on a particular topic, through a set of carefully designed sequential questionnaires interspersed with summarized information and feedback of opinions, derived from earlier responses (Chapman, 1998).

The identification process is made easier if the project is broken down into activities/sub-activities. Del Cano and Cruze (2002) decomposed the project into four phases (initiation, balancing, maintenance and learning), each phase being more broken into sub-phases, activities and sub-activities. It is recommended to have 30 to 50 activities for major projects. This type of decomposition is the idea of “Work Breakdown Structure” (WBS). In construction projects, the relevant phases may be: feasibility, contract, design, construction and operation phase.

The identification process includes also the classification of identified risks, identification of their causes, characteristics, potential consequences (leading to risk), warning signs and their allocation, as well as the primary response. Having such information about identified risks, a documentation of risks can be established: the “risk register”. It contains all identified risks and detailed information for each one and can help the project team in reviewing project risks on a regular basis throughout the project. Patterson and Neailey (2002) synthesized the type of information or items which can be stored in risk register. For each identified risk the registered information can be summarized as below:

- the type, cause and description,
- the corresponding phase or task,
- its state (latent, apparent, disappeared), the consequences (on cost, time, performance, etc.; value, estimation technique),
- its detectability (consequences or causes, including precursor events),
- the probability of occurrence (qualitative-quantitative),
- its allocation/ responsible,
- risk response (avoid, transfer, mitigate) and needed resource,

- interdependencies with other risks and responses

Using a catalog of risks is a useful reference for the identification. However, it can be problematic in the case of construction projects, where projects are different in type, scale, objectives, regarding desired level of detail and perspective of stakeholders to risks. [Chapman \(2001\)](#) proposed to set up a systematically Risk Breakdown Structure (RBS), hierarchical structure of risks, to facilitate the identification of risk events. In the following sections, we will focus on the RBS, explaining its strength and weaknesses.

Table 2.2. Risk identification tools and techniques (PMI, 2008)

Technique	Strengths	Weaknesses
Assumptions & Constraints Analysis	<ul style="list-style-type: none"> – Simple structured approach – Can be based on assumptions & constraints already listed in project charter – Generates project-specific risks 	<ul style="list-style-type: none"> – Implicit/hidden assumptions or constraints are often missed
Brainstorming	<ul style="list-style-type: none"> – Allows all participants to speak their mind and contribute to the discussion – Can involve all key stakeholders – Creative generation of ideas 	<ul style="list-style-type: none"> – Requires attendance of key stakeholders at a workshop, therefore can be difficult to arrange and expensive – Prone to Groupthink and other group dynamics – May produce biased results if dominated by a strong person (often management) – Often not well facilitated – Generates non-risks and duplicates, requires filtering
Cause and Effect Diagrams (Ishikawa, 1990)	<ul style="list-style-type: none"> – Visual representation of project promotes structured thinking 	<ul style="list-style-type: none"> – Diagram can quickly become over-complex
Check List	<ul style="list-style-type: none"> – Captures previous experience – Presents detailed list of risks 	<ul style="list-style-type: none"> – Check list can grow to become unwieldy – Risks not on the list will be missed – Often only includes threats, misses opportunities
Delphi Technique	<ul style="list-style-type: none"> – Captures input from technical experts – Removes sources of bias 	<ul style="list-style-type: none"> – Limited to technical risks – Dependent on actual expertise of experts – May take longer time than available due to iterations of the experts' inputs
Document review	<ul style="list-style-type: none"> – Exposes detailed project-specific risks – Requires no specialist tools 	<ul style="list-style-type: none"> – Limited to risks contained in project documentation
FMEA/Fault Tree Analysis	<ul style="list-style-type: none"> – Structured approach, well understood by engineers – Produces an estimate of overall reliability using quantitative tools – Good tool support 	<ul style="list-style-type: none"> – Focuses on threats, not so useful for opportunities – Requires expert tools not generally available to those except experts
Force Field Analysis	<ul style="list-style-type: none"> – Creates deep understanding of factors that affect project objectives 	<ul style="list-style-type: none"> – Time-consuming and complex technique – Usually only applied to a single objective, so does not provide whole-project view
Industry knowledge base	<ul style="list-style-type: none"> – Captures previous experience – Allows benchmarking against external organizations 	<ul style="list-style-type: none"> – Limited to what has previously happened – Excludes project-specific risk
Influence diagrams	<ul style="list-style-type: none"> – Exposes key risk drivers – Can generate counterintuitive insights not available through other techniques 	<ul style="list-style-type: none"> – Requires disciplined thinking – Not always easy to determine appropriate structure

Interviews	<ul style="list-style-type: none"> -Addresses risks in detail -Generate engagement of stakeholders 	<ul style="list-style-type: none"> -Time consuming -Raises non-risks, concerns, issues, worries etc, so requires filtering
Nominal Group Technique	<ul style="list-style-type: none"> -Encourages and allows all participants to contribute -Allows for different levels of competence in common language -To a large extent, auto-documenting -Provides ideal base for affinity diagramming (grouping by risk categories for use in the Risk Breakdown Structure and Root Cause Analysis) 	<ul style="list-style-type: none"> -Can lead to frustration in dominant members who feel it is moving slowly
Post-project reviews/ Lessons Learned/ Historical Information	<ul style="list-style-type: none"> -Leverages previous experience -Prevents making the same mistakes or missing the same opportunities twice -Enhances the Organizational Process Assets 	<ul style="list-style-type: none"> -Limited to those risks that have occurred previously -Information is frequently incomplete: details of past risks may not include details of successful resolution; ineffective strategies are rarely documented.
Prompt Lists	<ul style="list-style-type: none"> -Ensures coverage of all types of risk -Stimulates creativity 	<ul style="list-style-type: none"> -Topics can be too high level
Questionnaire	<ul style="list-style-type: none"> -Encourages broad thinking to identify risks 	<ul style="list-style-type: none"> -Success depends on the quality of the questions -Limited to the topics covered by the questions -Can be a simple reformatting of a checklist
Risk Breakdown Structure (RBS)	<ul style="list-style-type: none"> -Offers a framework for other risk identification techniques such as brainstorming -Ensures coverage of all types of risk -Tests for blind spots or omissions 	<ul style="list-style-type: none"> -None
Root-Cause Analysis	<ul style="list-style-type: none"> -Allows identification of additional, dependent risks -Allows the organization to identify risks that may be related because of their common root causes. -Basis for development of pre-emptive and comprehensive responses -Can serve to reduce apparent complexity 	<ul style="list-style-type: none"> -Most risk management techniques are organized by individual risk. This organization is not conducive to identifying the root causes -Can oversimplify and hide existence of other potential causes -There may be no valid strategy available for addressing the root cause once it has been identified.
SWOT Analysis	<ul style="list-style-type: none"> -Ensures equal focus on both threats and opportunities -Offers a structured approach to identify threats and opportunities -Focus on internal (organizational strengths and weaknesses) and external (opportunities and threats) 	<ul style="list-style-type: none"> -Focuses on internally generated risks arising from organizational strengths and weaknesses, excludes external risks -Tends to produce high-level generic risks, not project-specific
System Dynamics	<ul style="list-style-type: none"> -Exposes unexpected inter-relations between project elements (feedback and feed-forward loops) -Can generate counter-intuitive insights not available through other techniques -Produces overall impacts of all included events and risks 	<ul style="list-style-type: none"> -Requires specialized software and expertise to build models -Focuses on impacts but difficult to include the concept of probability
WBS Review	<ul style="list-style-type: none"> -Ensures all elements of the project scope are considered -Provides for risks related to different levels of detail (from high-level to those related to individual work packages) 	<ul style="list-style-type: none"> -Excludes external risks or those not specifically related to WBS elements

2.4.2. Risk analysis

Risk analysis process is the vital link between systematic identification of risks and rational management of the significant risks. The risk analysis process aims to evaluate the consequences associated with risks and to assess the impact of risk by using risk analysis and measurement techniques (Flanagan and Norman 1993). This process leads to prioritize the identified risks for further actions.

The main input to risk analysis process is the identified risks from risk identification process. The probability and impact of identified risks are two key variables in assessing the risk. This process can range from very simple qualitative analysis to quantitative analysis which is more sophisticated:

- **Qualitative analysis** is based on a descriptive or nominal scale to describe risk events and their consequences. This analysis is mainly used in an initial evaluation of risks or for a rapid assessment. It can also be used when there is little knowledge about probability and/or impact. This method allows to identify the individual risks events with the most significant influence on project objectives. The risk events which are assessed as high priority may be further analyzed using quantitative risk analysis methods.
- **Semi-quantitative analysis** extends the qualitative analysis process by assigning numerical values to descriptive scale;
- **Quantitative analysis** uses numerical values of probability of risk events (or variables and risk factors) and their consequences.

The first step of risk analysis process is to determine in which progress level of project the evaluation has to be conducted. In this case, WBS diagrams are very useful. Work Breakdown Structures is the hierarchical decomposition structure of a project tasks and can be set at different level of detail (project/ phases/ tasks/ subtasks), each one attached to corresponding actor(s) and resources. Aleshin (2001) believes that the interconnection between WBS of a project and its Risk Breakdown Structure (RBS) is a useful technique to associate risks. WBS constitutes the basic framework for the management of a project; likewise, RBS can be used as a tool to structure the risk management process (Hillson et al., 2006). WBS can be further decomposed to see more details of each task. RBS does the same for risk identification, creating an organized list of risks that helps to better understand and interpret risks.

When the level of available information, progress of project and desired level of accuracy of analysis are defined, the convenient type of analysis can be selected easily. In Chapter 3, an innovated method which was developed in order to analyze and aggregate risk values of risk events through the RBS branches will be explained in detail. The method combines consistently the quantitative and qualitative approaches, allowing the user to choose the best one for risk assessment.

2.4.2.1. Qualitative analysis

The qualitative risk analysis process assesses and evaluates characteristics of individually identified project risks and prioritizes risks based on agreed-upon characteristics. Assessing individual risks using qualitative risk analysis evaluates the probability that each risk will occur and the effect of each individual risk on the project objectives. As such, it does not directly address the overall risk to project objectives that results from the combined effect of all risks and their potential interactions with each other. This can however be achieved using quantitative risk analysis techniques (PMI, 2008).

A typical qualitative risk assessment usually includes the following issues (Pipattanapiwong, 2004):

- a brief description of the risk;
- the stages of the project when risk may occur;
- the elements of the project that could be affected;
- the factors that influence risk to occur;
- the relationship with other risks;
- the likelihood of risk occurring; and
- how risk could affect the project.

The direct judgment, ranking options, comparing options and descriptive analysis are also considered as the qualitative risk measurement (Flanagan and Norman 1993).

The qualitative analysis can be based on a probability-impact matrix where the probability and impacts of each risk are assessed using defined scales plotted on a two-dimensional grid. Figure 2-3 illustrates an example of risk matrix proposed by WSDOT (2010). The consequences are evaluated in terms of potential impact on project success criteria. The scales depend of project size, strategies, the level of available information and desired accuracy. This matrix can be used for assessing threats and opportunities using two grids of negative impacts (threats) and positive impacts (opportunities) (Hillson, 2002). In both cases, high-probability/high-impact risks are prioritized.

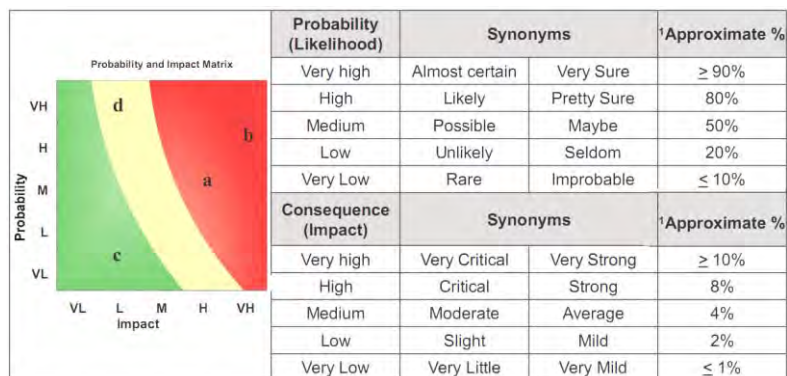


Figure 2-3. An example of risk matrix (WSDOT, 2010)

Probability analysis, sensitivity analysis, scenario analysis, simulation analysis, correlation analysis, portfolio theory, Delphi method, influence diagrams, decision trees, are some other available techniques for qualitative risk assessment (Flanagan and Norman 1993; Smith 1999).

2.4.2.2. Semi-quantitative analysis

The semi-quantitative risk analysis is very convenient in the case of rapid or comparative assessments. It is based on the qualitative analysis results and identification of numerical values through indicators or measure of possibility, consequences and priorities.

The risks can be quantified using standardized indices. For example, Assaf (2006) used two indices of frequency and severity, and for each risk defined the importance index as product of frequency and severity indices (on a 0-100% scale).

2.4.2.3. Quantitative analysis

Quantitative analysis seeks to quantify the combined effect of risk on project objectives, using tools such as sensitivity analysis, decision trees, risk breakdown structures and Monte Carlo analysis. These involve building a model of the whole project or key elements, reflecting identified uncertainties into the model, and analyzing the combined effect on project outcome (Hillson, 2002). Quantification process usually includes the following steps:

- project modeling and decomposition to tasks (ex. WBS),
- evaluation of degree of uncertainty in each schedule activity or cost element,
- set up the list of project objectives, constraints and acceptable uncertainties,
- determination of a relationship between uncertainty and degrees of risk.
- evaluation of overall project uncertainties/risks and corresponding actor(s).

However the first step is not essential for all risk quantification methods, but it provides a convenient base to better associate with project risks.

Many techniques can be used to describe uncertainties and their consequences on project. The probabilistic description is one of the most common techniques. The result is a probability distribution of the project's cost and completion date based on the identified risks in the project. Patterson (2002) cites quantitative analysis tools (such as @ Risk and Predict!) which allow the overall project plan to be modeled. Using Monte Carlo technique, schedule and cost distribution of the project can be simulated. It is from utilizing these simulation techniques to determine the spread in time and cost variables that the riskiness of the project can be ascertained. But in practice, usually, most decisions are based on a qualitative analysis, easier and faster to implement than quantitative assessments.

As a practical application, Washington State Department of Transportation (WSDOT) in order to better predict cost of large, complex infrastructure projects have developed a new method which takes into account risk and opportunity events. This risk- based cost estimation

method, known as the Cost Estimation Validation Process (CEVP), includes validation of the base cost of a project, along with explicit identification of high-cost and schedule risk drivers, leading to an ability to develop explicit risk management plans early in the project’s development (Reilly et al., 2004; WSDOT, 2008). CEVP develops a probabilistic cost and schedule model to define the probable ranges of cost and schedule required to complete each project. The results of the assessment are expressed as a probable distribution of cost and schedule for the project, as shown in Figure 2-4.

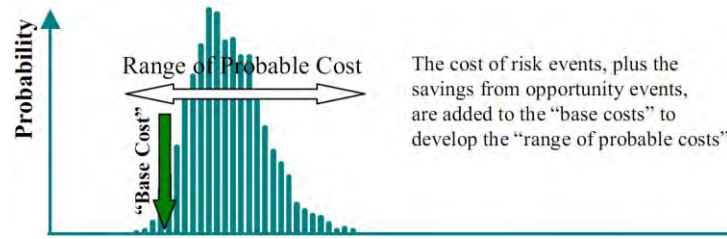


Figure 2-4. Cost estimation considering risk and opportunity events, based on CEVP (Reilly et al., 2004)

As another example, the “Decision Aids for Tunneling” (DAT) are a procedure and computer code that can be used to assess the effect of geologic/geotechnical and construction process uncertainties on construction cost and time (Einstein, et al., 1999; Haas and Einstein, 2002). This tool can be used for risk assessment and decision making prior to and during tunnel construction (e.g., investigation of the effect of problematic geologic conditions, comparison of different tunnel systems or alignments, comparison of different tunneling methods, resource management, geologic updating, evaluation of additional geologic exploration and etc.) (Min et al., 2008).

Quantitative and qualitative risk analysis processes are compared in Figure 2-5. An effective risk identification and qualitative risk analysis, appropriate project model, consideration of risk interactions in analysis, and collection of high-quality and unbiased risk data are the critical success factors for an effective quantitative risk analysis (PMI, 2008).

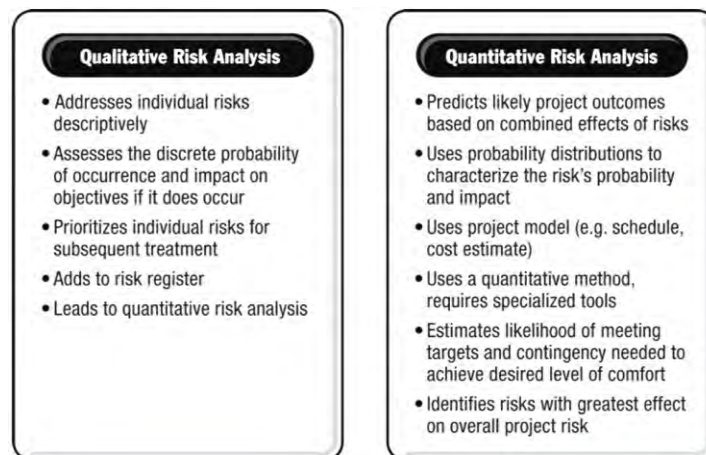


Figure 2-5. Comparison of outputs of qualitative and quantitative approaches (PMI, 2008)

2.4.3. Risk response planning

The next step after identification and analysis of project risk is to develop options, and determine convenient actions, focusing on most significant risks, in order to shift odds in favor of project success and to minimize the negative impacts of threats on project objectives. This process aims to determine effective response actions that are appropriate to the priority of individual risks and to the overall project risk. It takes into account the stakeholders' risk attitudes and the conventions specified in the Risk Management Plan, in addition to any constraints and assumptions that were determined when the risks were identified and analyzed. When the response actions are applied, they affect the project objectives and can generate additional risks. These are known as secondary risks and have to be analyzed and planned for in the same way as those risks which were initially identified (PMI, 2011). Figure 2-6 provides the key success factors of risk response planning.

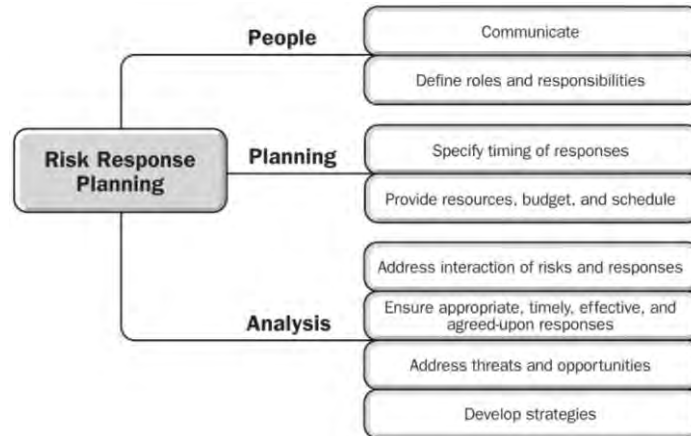


Figure 2-6. Critical success factors for risk response process (PMI, 2008)

Responses to risks (threats) can be one/combination of the following options (WSDOT, 2010; PMI, 2008; Norris et al., 1999):

- **Mitigate:** consists in reducing the probability and/or the impact of a threat to an acceptable threshold. It may take resources or time and hence may represent a tradeoff of one objective for another. This method is the most widely used and applicable strategy.
- **Avoid:** Risk avoidance involves changing the project plan to eliminate the risk or to protect the project objectives (time, cost, scope, quality) from its impact. When an organization or parties or individual refuse to accept risk, then risk is avoided. This means the exposure of risk is not allowed to exist. There are a number of ways through which risks can be avoided, for examples, tendering a very high bid, placing conditions on the bid, pre-contract negotiations as to which party takes certain risks, and not bidding on the high-risk portion of the contract (Baker et al., 1999).

- **Transfer:** is a strategy to transfer the risk to another partner or third party that is better positioned to address a particular threat. This method does not normally eliminate the risk but just makes someone else worry about it. An example would be transferring the financial impact of risk to an insurance company. Transference tools can be quite diverse and include, but are not limited to the use of: insurance, performance bonds, warranties, guarantees, incentive/disincentive clauses, etc.
- **Acceptance:** this strategy applies when the other strategies are not considered applicable or feasible. In this method, the benefits that can be gained from taking the risk should be balanced against the penalties. Acceptance entails taking no action unless the risk actually occurs. In this case, contingency or fallback plans may be developed ahead of time, to be implemented if the risk presents itself.

Risk response planning should combine responses that address the threats as well as those that provide for opportunities. Response to opportunities could be one/combination of: exploit, share, enhance and acceptance. Figure 2-7 provides a simple response matrix when the action is selected as a function of the risk level.

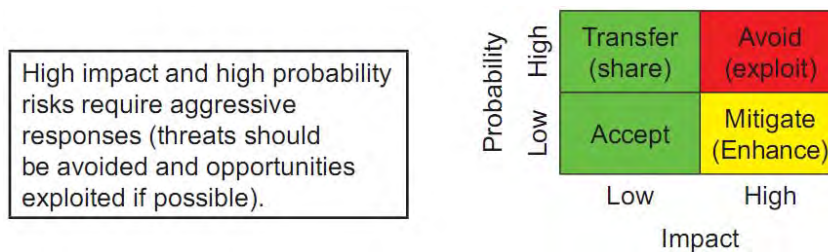


Figure 2-7. Simple response matrix proposed by WSDOT (2010)

2.4.4. Control and monitoring the risks

By the progress of the project, new information becomes available and the list of project risks changes by appearance of new risks, whether foreseen or unforeseen, or disappearance of some anticipated risks. The project risk management planning should therefore be kept current and the project manager should ensure that risk identification, analysis and response planning are repeated at reasonable intervals, or in response to project events.

Risk monitoring and control keeps track of the identified risks, residual risks, and new risks. It also monitors the execution of planned strategies on the identified risks and evaluates their effectiveness. Risk monitoring and control continues for the life of the project (OSPMI, 2007).

2.5. Techniques and tools for project risk management

With the need for improved performance in construction project and increasing contractual obligations, the requirement of an effective risk management approach has never been more necessary (Nieto-Morote and Ruz-Vila, 2011). Modeling project risks is a key challenge and many efforts are devoted to this purpose. Modeling can be useful for:

- classifying and ranking risk events, trying to identify the main sources of uncertainties and their possible consequences,
- estimating average expected performances (for instance in terms of cost and time) and their statistical distributions, thus being able to quantify the probability of exceeding any value,
- identifying the sensitivity of the final performance to any possible event, thus making it possible to define preventive strategies.

When modeling aims to predict the project performances, many options are possible. Breysse et al. (2009) identified four types of models:

- *Behavioral models*, aimed at analyzing the behavior of stakeholders. Mainly based on the analysis of inquiries and interviews, these models try to answer questions such as “what happens if...?”. Their basis lies in the field of human and social sciences. As an example, Wang and Yuan (2011), using literatures reviews, interviews and questionnaires tried to identify the main factors affecting contractors’ risk attitudes in China.
- *Functional models*, which establish structural relationships between risk events (or variables conditioning such events) and project performances. The question is mainly “what is the consequence of such an event?”.
- *Physical models*, which try to mimic the physics of the system/process. In this case, the project is seen as a series of tasks requiring resources, and its development in an uncertain environment is studied. A common result is a statistical distribution of costs or delays.
- *Black box models*, where one tries to estimate the value of the output variables Y as a function of input variables X, without necessarily explicating the real relationships between X and Y. These models are based on tools like heuristic algorithms or neural networks and require a learning stage before validation and use. Several research studies on the risk assessment of construction projects using fuzzy approaches or neural networks have been recently performed such as by Carr and Tah (2001), Zhang and Zou (2007), Kim et al. (2009), Nieto-Morote and Ruz-Vila (2011).

2.5.1. Risk Breakdown Structures: a helpful representation of risks

Risk identification often produces nothing more than a long list of risks, which can be hard to manage. The list can be prioritized to determine which risks should be addressed first, but this does not provide any insight into the structure of risks on the project (Hillson, 2002). The best way to deal with a large amount of data is to structure the information to aid understanding. It can be based on the Risk Breakdown Structure (RBS) which groups the identified risk events into different levels following a bottom-up approach.

Since different standards or guidelines may propose different definition of risk management concepts, in the following, to prevent any misunderstanding or confusion, we will consider:

- *risk factor*: the range of factors that combine to represent the potential for harm, injury, damage or loss to occur (Jeynes, 2002). Risk factors do not affect projects or activities directly but do so through risks events (Carr and Tah, 2001). For instance, “the building height exceeds the acceptable limit” and “applied snow loads are much less than the loading standard” are two examples of risk factors.

- *risk event* (RE) as any fact or event whose occurrence can have some impact/ consequence on at least one of the objectives of the project, and are themselves affected by risk factors (Carr and Tah, 2001). An event can also consist of something not happening (Din et al., 2010). Often the distinction between risk factor and risk event is somewhat artificial because it depends on how far we go back into analysis of the causes. As an example, “project design does not comply with building regulations standards and criteria” is a risk event which is itself affected by the mentioned risk factors.

- *risk category* (RC) as a way to group several risk events. Any category can be split into subcategories when a more detailed view is needed, or, conversely, can be grouped together with other categories when a more general view is required. As an example, the mentioned risk event in last part belongs to “poor or defective design” category.

Risk Breakdown Structure is a common and very practical tool, widely used during the various stages of project life in risk management. It can be used in risk identification stage and it can provide a support in the later stages (risk assessment and risk response), since it offers an overview on the risks which affect the project. Figure 2-8 illustrates an example of RBS proposed by Tah and Carr (2001).

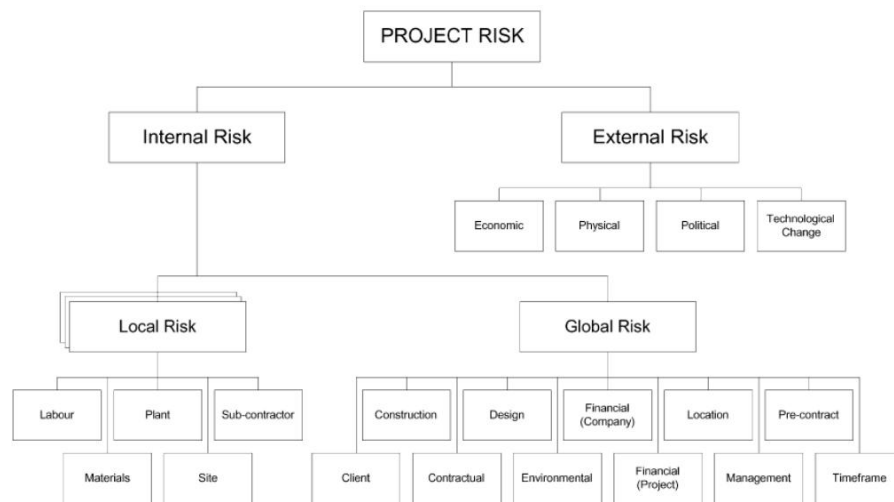


Figure 2-8. Example of a Risk Breakdown Structure (Tah and Carr, 2001)

Among the main properties of complex projects in the construction field, one can note that: (a) they involve many partners, each of them following his own objectives, (b) they are long time projects with a series of more or less dependent stages, (c) the data are more or less detailed according to the phases. The RBS seems to be a very opportune tool for risk management since: (a) it can offer different views of stakeholders to project risks, (b) during project life, its branches can be more or less developed as a function of available information and desired level of detail and (3) the temporal evolution of the tree is also affected by the rules according to which the project risks are calculated.

Williams (1995) has explained that the importance of each component of performance varies with the project phase. If a successful project is "cheap! quick! well done!", attention is focused more on technical performance during the definition phase, the cost dimension during the contractual phase, and delays during the construction phase. Finally, once the project has been completed, the main measure of success is the project's technical performance. Therefore, the challenges are to ensure: (a) self-consistency of any given view and between several views, (b) the RBS' ability to evolve, and (c) its ability to select a more appropriate picture, in accordance with explicitly defined criteria. Chapter 3 of this thesis aims to define these criteria and come up with mentioned challenges.

Hillson (2002) believes that the RBS is a powerful aid to risk identification, assessment and reporting, and the ability to roll-up or drill-down to the appropriate level provides new insights into overall risk exposure on the project. A common language and terminology facilitates cross-project reporting and lesson learning. The RBS has the potential to become the most valuable single tool in assisting the project manager to understand and manage risks to his project. However, RBS suffers several drawbacks such as lack of consensus on how to develop an RBS for a new project, lack of clarity and inconsistencies in definition of risk categories and lack of rules enabling transfer of qualitative/quantitative information of risks across the structure

(Mehdizadeh *et al.*, 2011). As for the last case, the common aggregation techniques for evaluation of the effect of all linked REs to each RC (ex. maximum value, average value, modified average value, etc. (Carr and Tah, 2001)) are not robust enough to consider both the values and the number of influenced REs. Therefore, they usually lead to produce unrealistic results.

Many different classifications of risks have been developed over the years (Cooper and Chapman , 1987; Aleshin, 2001; Tah and Carr, 2001; Pipattanapiwong, 2004; Zou, 2007; Tam et al., 2007; El-Sayegh, 2008); however, most of them have considered the source criteria as the most important (Ebrahimnejad, et al., 2010). It is also usual to categorize risks into dynamic/static, corporate/individual, internal/external, positive/negative, acceptable/unacceptable and insurable/non-insurable (Baloi and Price, 2003). The fact is that, it does not exist today any standard or consensus on how to classify risks.

Figure 2-9 illustrates the RBS proposed by Pipattanapiwong (2004) which is based on integration of all involved project parties, and distinguishes the “internal” and “external” risks; different project stakeholders are regrouped to the “project” category which belongs to internal risks. As another example, Hsueh et al. (2007) decompose the Chinese joint venture construction project risks from the perspective of foreign constructors. In this RBS (illustrated in Figure 2-10), the global project risks are decomposed into three main groups of internal, project-specific and external risks.

In the following chapter of this manuscript, we will focus more on risk breakdown structure, highlighting its advantages and drawbacks and explaining an innovative method to generate tailor-made RBS’s for any special case. Furthermore, it will be explained how the risk event values can be aggregated trough the RBS branches, following a quantitative-qualitative method.

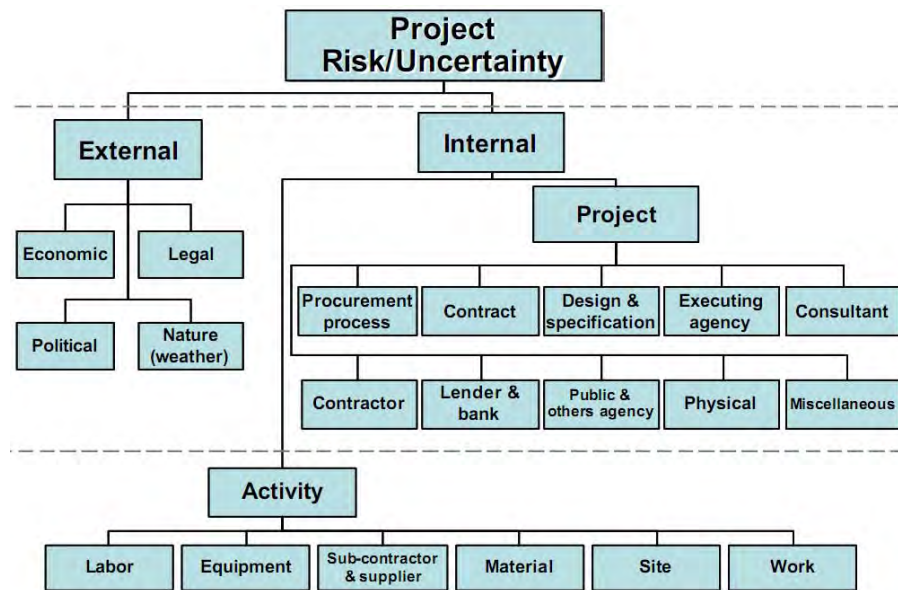


Figure 2-9. RBS proposed by Pipattanapiwong (2004)

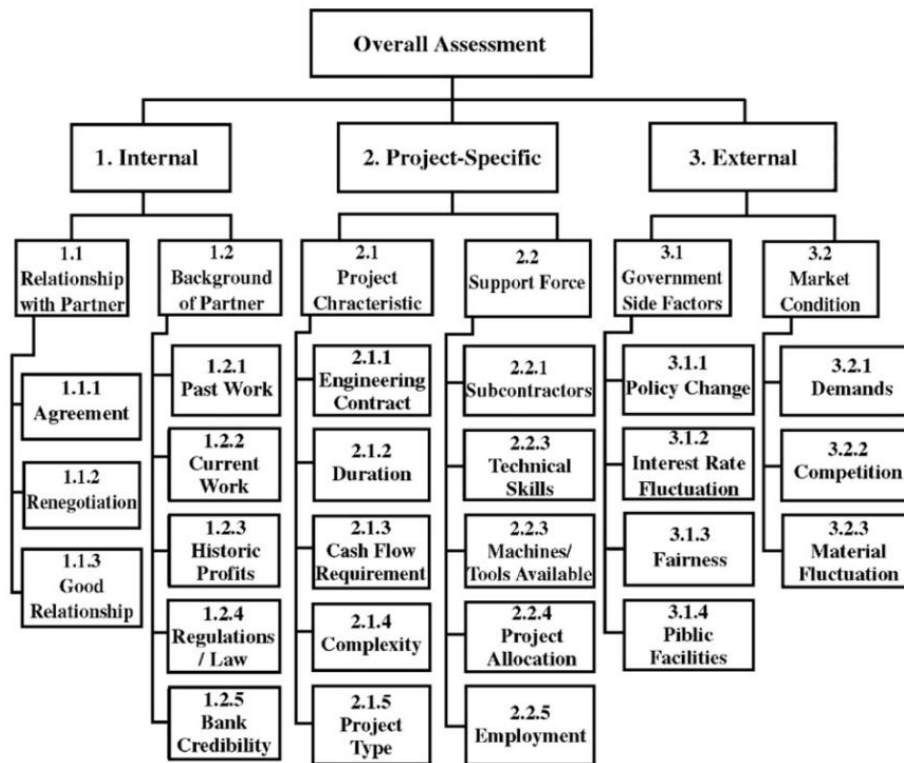


Figure 2-10. Hierarchy structure of the project risks (Hsueh et al., 2007)

2.6. Risk interactions

Project systems are in essence risky, as they are unique, constrained, subject to uncertainty and to complexity. They are composed of many interrelated objects of different natures and must reach many objectives which may be interdependent or even contradictory (Marle et al., 2010).

Dubois and Gadde (2001) stated that complexity in construction projects comes from two basic sources; interdependence of tasks and uncertainty. The interdependencies, not only exist between different tasks but also between different actors and different phases of the project. In a research by Marle (2002), with the aim of better decision making in projects, seven different components of each project have been identified (i.e. actors, activities, objectives, deliverable, etc.) and it was shown that the behavior of these components cannot be understood and managed unless integrating them all with their interactions. It was stated that different project components are tied together with interactions since:

- they may share a tool, a resource or applied method of another part, or use the result of another part's work,
- they may have priorities regarding the project calendar,
- they may have influence on progress or direction of each other,

- they have communication or exchange of information together.

Dependent components of the project are encountered with variety risks and thus the same types of interaction can be found between their corresponding risks events.

Martin (2012) has proposed a simulation model of construction projects which is based on three different approaches: temporal (tasks visualization), organizational (visualization of project actors) and functional (visualization of resource and information flows). This type of project simulation facilitates identification of existing interactions of project tasks and stakeholders and allows identifying the target point of identified risk events. Furthermore, it helps: to identify the critical phases and tasks, to evaluate the robustness of a project planning with regard to project risks, to identify the critical behaviors, and also to select convenient indicators to follow the efficiency of project risk management planning.

The project risk events are interrelated, meaning that they are not independent events. Most of the current methodologies neglect the existing interactions and consider them as if they were independent; however, some works have been done to model the complex interdependencies between risk events. In a recent research by Marle et al. (2010), an interaction-based clustering methodology was proposed which aimed to facilitate the coordination of complex projects by reducing interface when dealing with risks. The method is based on risk event clustering in a way that interaction rate is maximal inside clusters and minimal outside.

Chauveau (2006) point out that, to take into account the risk dependences in risk management process, it is essential to know when each dependency intervenes and what the effect is on the other risk events. In this research three main types of risk interdependencies have been identified:

- *destructive interaction*: this type of interaction implies for a case when a first risk event happens, one or some other REs can no longer exist,
- *creative interaction*: this type of interaction implies for a case when occurrence of a risk event leads to occurrence of a new one,
- *modifier interaction*: are the most usual dependencies. The occurrence of a risk event will modify the probability of occurrence or impact of another risk event.

To represent these interactions between different REs, Chauveau (2006) has proposed to use an oriented graph. In this case, a label is assigned to each arrow, including three parameters of $(type, i, p)$. “type” indicates the interaction form that can be one of the mentioned cases and i and p indicate the amount of modification on the probability and impact of target risk event (see Figure 2-11).

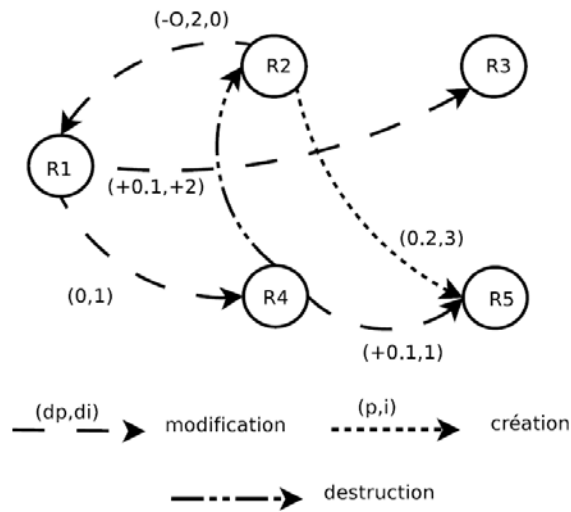


Figure 2-11. Application of oriented graph to represent the risk interdependences (Chauveau, 2006)

In another research by Tah and Carr (2001), the risk interdependencies are applied in risk analysis using risk breakdown structure. In this research, it was assumed that risk interdependencies can be considered even at Risk Categories level. Thus, the probability and likelihood of each risk category in RBS can be affected by the values of another category. “Dependence magnitude values” have been defined to express the level of dependence between any two dependent RC. Figure 2-12 provides an example of this method. The original figure was modified to make it compatible with the accepted definitions of risk event, risk factor and risk category, which are applied in this research. In this RBS, RC#3 is affected by two risk events and also by RC#4 which itself is affected by three risk events.

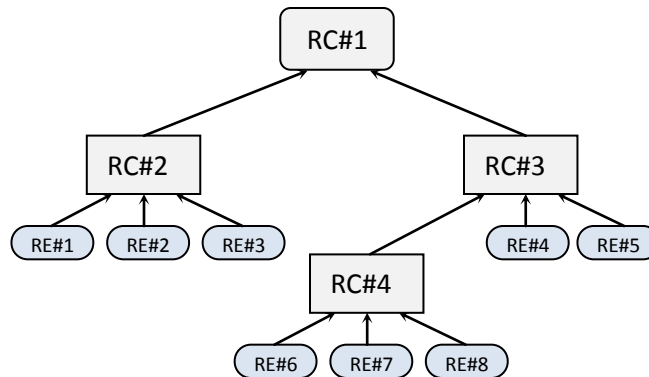


Figure 2-12. Consideration of risk interactions in risk analysis using RBS (Carr and Tah, 2001)

Remington and Pollack (2007) proposed a practical tool to facilitate the process of identification and monitoring the risk events and interdependencies between them. They believe that many of significant risk events go undetected because they arise not from an unseen single cause, but from the interaction of multiple, more easily identifiable risk factors.

It has been discussed that identification of risk interdependencies not only helps to precise the risk analysis process but also new risk events may be identified through this process. In the proposed method, the most important identified risk events are presented on a circle and the interactions between them are represented by vectors (see Figure 2-13). The risk events which are the initial point of many interaction arrows are the key risk events that if triggered could have significant effect on project. Conversely, a risk event could be triggered by many other REs and therefore the likelihood of being triggered can increase substantially. Having such information makes the project risk management proactive and allows the project manager to better monitor the relationships between risk events.

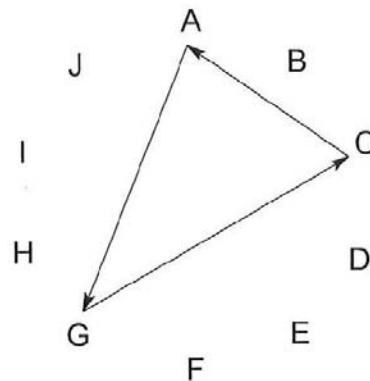


Figure 2-13. Representation of risk interdependencies, proposed by Remington and Pollack (2007)

Accounting for risk interactions in project risk analysis is not of the main objectives of this thesis. However, in the following chapter, it will be briefly explained how the proposed methodology for generation of tailor-made RBS's and risk analysis process can take into account risk event interdependencies.

2.7. Project risk management is a dynamic and iterative process

The construction projects are usually considered as long time projects which during their life cycle are encountered with variety of risk categories such as economic, environmental, political, financial, geological, technical, etc. By the progress of the project the level of available information about risks usually increases. Some predicted risks events occur while others will not, new unpredicted risk events may occur or may be identified, and the characteristics of those already identified may change. As a consequence, an iterative risk management should be carried out at all stages of the project life cycle, considering variety of risks which may appear in certain circumstances and for a period of time. Thus, as it was shown in Figure 2-1, a dynamic project risk management should be realized with frequent iterations (Xie et al., 2010; PMI, 2008, Chapman, 1997; Tah and Carr, 2001).

Chapman (1997) considered nine general steps for a generic Risk Management Process (RMP). He believes that, even before starting the project execution phase, the RMP has to be iteratively repeated to get an acceptable level of efficiency and clarity (see Figure 2-14). This is because of the fact that the aspects of the project may not be clearly defined when the RMP begins. Thus, the objective would be to identify and analyze the risks which were not evident in earlier iterations.

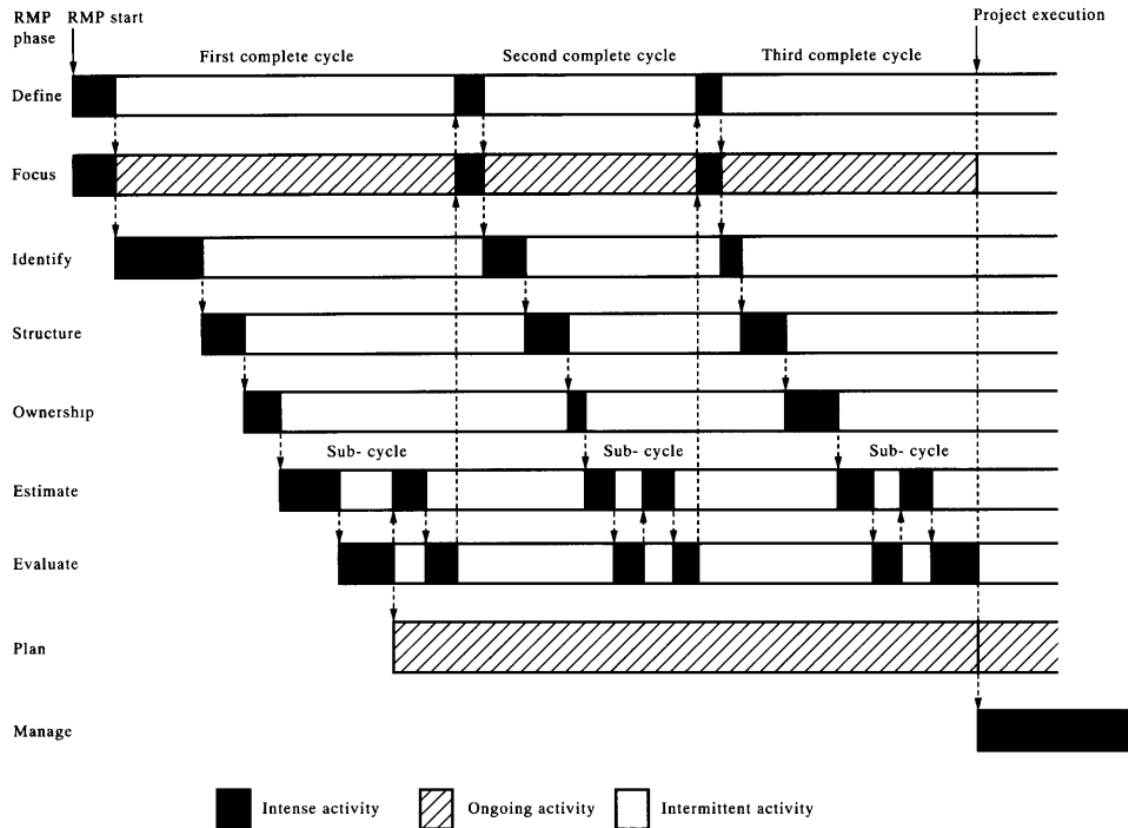


Figure 2-14. An example of iterative project risk management process over time (Chapman, 1997)

During the life cycle of the project, the manager has to be sure that the RMP remains effective, the identification and analysis of risks should be revised periodically, the efficiency of risk response actions has to be verified, and the action plans adjusted accordingly. Furthermore, regarding the project nature, progress level, criticality of tasks and required level of detail in RMP, may the project manager has to focus on some special circumstances, giving more details about their potential risks events, their criticality and priority, and convenient detailed response actions.

The proposed method in the following chapter of this thesis, supplies the project manager with an effective tool, providing a dynamic, multi-scale and multi perspective approach for a more systematic and tailored project risk management. It will be shown how the generation of tailored RBS's which are adapted to several constraints (i.e. level of available information,

staged progress of the project, required level of detail, etc.) is iterative and how the proposed approach facilitate the dynamic process of risk identification. Furthermore, it will be explained how the iterative process of risk analysis is applied to take into account for existing risk interdependencies.

2.8. Risk management of tunneling projects

The world-wide expansion in the development of civil engineering infrastructure over the subsequent three decades has led to a major increase in the numbers and types of tunnels constructed for road, railways and water supply/sewerage schemes (Atkins, 2006). The complexity of construction projects has forced project managers to develop better planning and more efficient risk management techniques. Tunnels in particular present serious problems due to the presence of high uncertainty and risk in their construction. The construction of tunnels entails many different hazardous situations that can cause to damage to tunnel construction or equipments and facilities or event can be extended to damage to third parties and body injuries (Breysse, 2012).

The frequency and the gravity of emergency situations during tunneling are higher than in other branches of civil construction because of the specific conditions of underground works (SeidenfuB, 2006). The fact is that, in most of the construction projects the knowledge about the construction material is relatively high and material properties show limited variations. The tunnel structure is not only founded on the ground as buildings are, but the ground itself is the major construction material for the whole structure. A tunnel is also loaded and supported by the surrounding soil or rock mass with a high level of uncertainties and complicated nature (Sousa, 2010). The consequence of these inherent uncertainties is significant cost overrun and delay risks as well as environmental risks which are imposed on all involved parties as well as on those which are not directly involved in the project (Eskesen et al., 2004). However, the tunnel failures may also happen during the operation phase. The Big Dig ceiling collapse, occurred on July 10, 2006, is one of the most famous cases (Breysse, 2012). In this accident, a concrete ceiling panel weighing 3 tons fell on a car, killing a passenger and injuring the driver.

During the last decade, with the aim of more efficient identification and management of tunneling project risks and to reduce their negative impacts on project objectives and safety of the work, many practices, codes and guidelines have been published but these were not relying on common methodologies and criteria. The International Tunneling Association (ITA) therefore set up a working group to report on these systems and make proposals for a unified approach. This was achieved in 2004 with the publication of their “Guidelines for tunnelling risk management” (Eskesen et al., 2004). This guideline shows how the project management process can be applied throughout three stages of a project: early design, tendering and contract negotiation, and construction phase. The guideline also explains the general

components of project risk management and briefly introduces some risk analysis tools. At the same time, Association of British Insurers (ABI) and the British Tunneling Society (BTS) began working together to prepare a Joint Code of practice for risk management for tunnel works in the United Kingdom and it was published in 2003 (BTS, 2003). The objective of this code is to promote and secure best practice for the minimization and management of tunnel works. It sets out practice for the identification of risks, their allocation between the parties to a contract and contract insurers, and the management and control of risks through the use of risk assessments and risk registers (BTS, 2003). This code was subsequently modified by International Tunneling Association (ITA) and the International Association of Engineering Insurers (IMIA) to make it applicable in different nations, regions or sites. It was published in 2006 (ITIG, 2006).

In 2006, Health and Safety Executive (HSE) published the results of a study on emergency events that have occurred during 1999-2004 in worldwid tunnel soft ground construction projects (Atkins. 2006). One year later, Workplace Health and Safety Queensland, published a code entitled “Tunnelling Code of Practice 2007”. The code was amended on December 2008 and August 2010. The purpose of this code of practice is to give practical advice about ways to manage exposure to risks associated with tunneling work. It provides a health and safety framework, including technical criteria and guidance, to help plan the tunnel construction (TCP, 2007).

Apart from the codes and standards, many researches have been developed during the last years. They address the specific environment of tunnels and try to estimate the risk levels in order to make the tunnels safer. Many topics have been discussed and a large number of important risk factors and hazards in tunnels have been identified (as example, refer to Sturk et al., 1996; Reilly, 2000; Yoo and Kim, 2003; Reilly and Brown, 2004; SeidenfuB, 2006; Idris, 2007; Aneziris et al., 2010).

Vlasov et al. (2001) summarized the main causes of tunnel collapses as below:

- unpredicted geotechnical conditions,
- errors in design and in specifications,
- errors in calculation or numerical analyses,
- errors during construction,
- and, errors in the control and management.

Sousa (2010) developed a database of 204 tunnel construction accidents in order to better understanding the conditions under which accidents occur. It was based on the construction of influence diagrams containing the main factors, and the interactions between them. In this research, the main causes of tunneling accidents were synthesized into two main groups of internal and external. Internal causes are related to the design and planning of the tunnel as well as basic construction and management errors during tunnel construction. The external causes are related to hydrological and geological conditions, as well as earthquakes and fires.

Figure 2-15 gives an overview of the main geological hazards, their effects or potential consequences and preventive actions in drill and blast tunneling, but it is also applicable for tunnel boring (TBM). This table is the result of study on hard rock tunneling in Norwegian mainland by Blindheim (n.d.).

Hazard	Water under pressure	Un-consolidated zones	High rock stresses	Poor con-fine-ment	Crushed or blocky rock mass	Gas, methane
Effects or potential consequences	<ul style="list-style-type: none"> • Flooding • Cave-in • Dangerous drill rod changing 	<ul style="list-style-type: none"> • Immediate cave-in • Cannot be controlled at face 	<ul style="list-style-type: none"> • Rock spalling or bursting • Slab or block falls 	<ul style="list-style-type: none"> • Block falls 	<ul style="list-style-type: none"> • Block falls • Cave-in 	<ul style="list-style-type: none"> • Explosion • Delay of work activities
Warning signals	<ul style="list-style-type: none"> • Water in probe or blast holes • Inflow through joints in the face • Karstic features 	<ul style="list-style-type: none"> • Water, mud, sand in probe or blast holes 	<ul style="list-style-type: none"> • Drilling problems in stress release cracks • Noises; crackling 'shots' • Visible deformations • May be lacking! 	<ul style="list-style-type: none"> • Drilling problems in open joints • May be lacking! 	<ul style="list-style-type: none"> • Drilling problems in crushed rock • Drizzling continues with time • May be lacking in blocky rock 	<ul style="list-style-type: none"> • Bubbles in seepage water • Rotten smell of associated gas
Preventive actions	<ul style="list-style-type: none"> • Probe drill to localise potential inflow • Pre-grouting and/or drainage • Do not blast until treatment is done 	<ul style="list-style-type: none"> • As for 'Water under pressure' • Ground freezing ahead of face 	<ul style="list-style-type: none"> • Scaling, bolting, sprayed concrete • Drill stress release holes 	<ul style="list-style-type: none"> • Pre-bolting 'spiling' • Scaling, bolting, sprayed concrete ribs 	<ul style="list-style-type: none"> • For intact contour: sprayed concrete and bolting • For lost contour, water present: cast-in-place concrete lining 	<ul style="list-style-type: none"> • Probe drill • Increased ventilation for dilution and circulation • Measurements and monitoring

Figure 2-15. An overview of the geological hazards, their effects and preventive actions (Blindheim, n.d.)

In the following chapter of this manuscript, we will explain how a database of the most common risks of construction projects has been developed. It will be shown how, to check the validity and extensibility of the database, it was extended to cover the tunneling projects as well. It will be explained how these risks events have been identified and how they can be categorized regarding different perspectives of the project partners and required level of detail.

2.9. Summary and conclusions

In this chapter, the main concepts of the project risk management were discussed in detail and some of the most important international practices in risk management of construction projects were introduced. In order to prevent any misunderstanding or confusion in the following parts of this thesis, the main terms of project risk management (such as “project”, “risk”, “risk management”, etc.) were precisely defined. After an introduction to the main steps of the Risk Management Process (RMP), different available tools and techniques of risk identification and analysis were introduced and compared. Risk Breakdown Structure as a very practical tool in different stages of risk management was highlighted. It was explained

why it can be a powerful aid in identification, assessment and representation of project risks. Its advantages and drawbacks were briefly pointed out and it was explained that a variety of risk classifications exist in literature which have been developed without following any guideline.

At the end of this chapter, the risk interaction concept was explained and different available methods for taking them into account in risk analysis process were introduced. It was discussed that regarding the nature of the construction projects, an iterative RMP should be applied at all stages of the project lifecycle. This is the reason why we have developed an innovative method for generation of tailor-made RBS's for more efficient risk management in construction. The following chapter aims to present this method in detail.

Chapter 3

ADVANCED METHODOLOGY OF RISK BREAKDOWN STRUCTURE DEVELOPMENT

3. Advanced methodology of Risk Breakdown Structure development

3.1. Introduction

Project Risk Management (PRM) is a dynamic process following the project life and contains the usual stages of risk identification, risk analysis (qualitative or quantitative), response definition and risk mitigation (Breysse, 2009b) to ensure that the project objectives are met (Dikmen et al, 2008). 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 map (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 hierarchically organized depiction of the identified project risks arranged by risk categories and subcategories that identifies the various areas and causes of potential risks (PMI, 2008). It represents the overall project and organizational risk factors and events organized by group and category (Holzmann and Spiegler, 2010). Many approaches have been suggested in the literature for classifying risks. El-Sayegh (2008), Aleshin (2001), Tah and Carr (2001) and Pipattanapiwong (2004) classify the risks according to their origin in two main groups of internal and external risks. Cooper and Chapman (1987) classified risks according to their nature and magnitude, making the difference between primary and secondary risks. Zou (2007) suggested a special risk categorization, regarding different phases of the project and allocation of risks to different partners of the project. Tam et al. (2007) classify the risks according to their magnitude and importance into three main groups of upper, middle and lower class risks. Nevertheless, it does not exist today any standard or consensus on how to classify risks.

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 provides a perspective of where are the risks coming from and concentrated at (Zacharias et al, 2008). Also Nilsson and Ohlsson (2003) state that having groups of similar risks which are hierarchically organized, it is easier to find double counting and recognize the dependencies between risks. Furthermore, it can be recognized how the different risks correlate to each other. It can be important when someone wants to track a risk to its origin.
- Each stakeholder can have his own view on the project, RBS can be helpful, at any stage of the project in offering different pictures of the same state of knowledge, being checked that the various pictures remain consistent,

- The RBS is compatible with time evolutionary and dynamic nature of project risks. It can “live” with the project, its branches being more or less developed (or replaced with others) when some risk categories become more or less important and according to the level of available information and to the desired focus of the user.
- It enables the aggregation of information along its branches, from the bottom to the top, once rules have been defined for this aggregation (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 et al, 2006).

However, RBS suffers several drawbacks, the main one being that there is no consensus on how to develop an RBS. For instance, at the first level, a possible decomposition consists in splitting “project risks” in “internal risks” and “external risks”. But other possibilities consist in splitting according to project phases (definition, contract, design, construction...) or according to the different stakeholders (client, consultant, contractor...). 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. One main criticism against RBS is that they have difficulties in accounting for (existing) interactions between risks, because of their hierarchical structure when the underlying processes of a real project are more complex. Thus, the objective is to develop a methodology which takes profit of all advantages of RBS, without suffering its usual drawbacks.

This research aims to come up with an algorithm to design tailored RBS’s in a more efficient way to identify and organize risks in construction projects. This method can provide the essential information to take a reasonable decision to select the effective response actions (avoid, transfer, share, etc.). 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 by some more subcategories in special fields. Of course, the methodology must be both general enough to cover all construction projects and specific enough to be adapted to a given particular project.

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 such as to ensure compatibility and avoid redundancy and/or confusion when the RBS will be built.

This database contains both specific trees which are unique and generic trees which can be duplicated in the RBS, because the same substructure can appear at several instances (e.g. several phases of the project or several stakeholders).

- (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 enable to quantify the “quality” of an RBS. This issue of quality is central, since there is not an “optimal RBS” but RBS’s which are more or less adapted to a given situation and a given purpose.
- (e) Elaborating a strategy for building an 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 has therefore to be adapted “in real time” to the context.
- (f) The last step will be to define the rules enabling the transfer of information (frequencies/ probabilities and magnitude/impact) from the bottom to the top of the RBS.

In this chapter, first, the three main components of the knowledge database including risk events, risk categories and micro trees are presented, evaluation and consistency control of the database is explained in detail. Then, the assembling algorithm which ties these micro-elements together, the quality criteria and ranking of the generated RBS’s to select the best one are fully discussed. The last part concerns with an advanced method of evaluation and aggregation of risk values on RBS.

3.2. Knowledge base

This work is based on a thorough analysis and literature review of more than 100 scientific papers and risk management cases for which RBS is the main method used for risk identification. About 90 RBS's 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.

Figure β -1 illustrates the process of development of the consistent database, where the expertise combined a bottom-up and a top-down analysis.

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). For instance, Aleshin (2001) decomposed the project risks into internal and external risks, the former being decomposed further to three subcategories of contract documents, performance of owner and problem with local authorities. Clearly, important risk events related to project management, performance and internal financial problems of the other stakeholders cannot be covered by any of these three categories, while all of them are expected to be considered as internal risks of project. As another example, in the RBS proposed by El-Sayegh (2008), a risk event such as “Change in/of design” is attached to “Owners” and “Designers” categories at the same time. Probably, this inconsistent case is due to poor and imprecise definition of the risk event that may induce misunderstanding. More examples of such inconsistencies are given in the following sections.

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 β -2):

- a library of Risk Events (RE),
- a library of Risk Categories (RC),
- a library of Micro-Trees (MT).

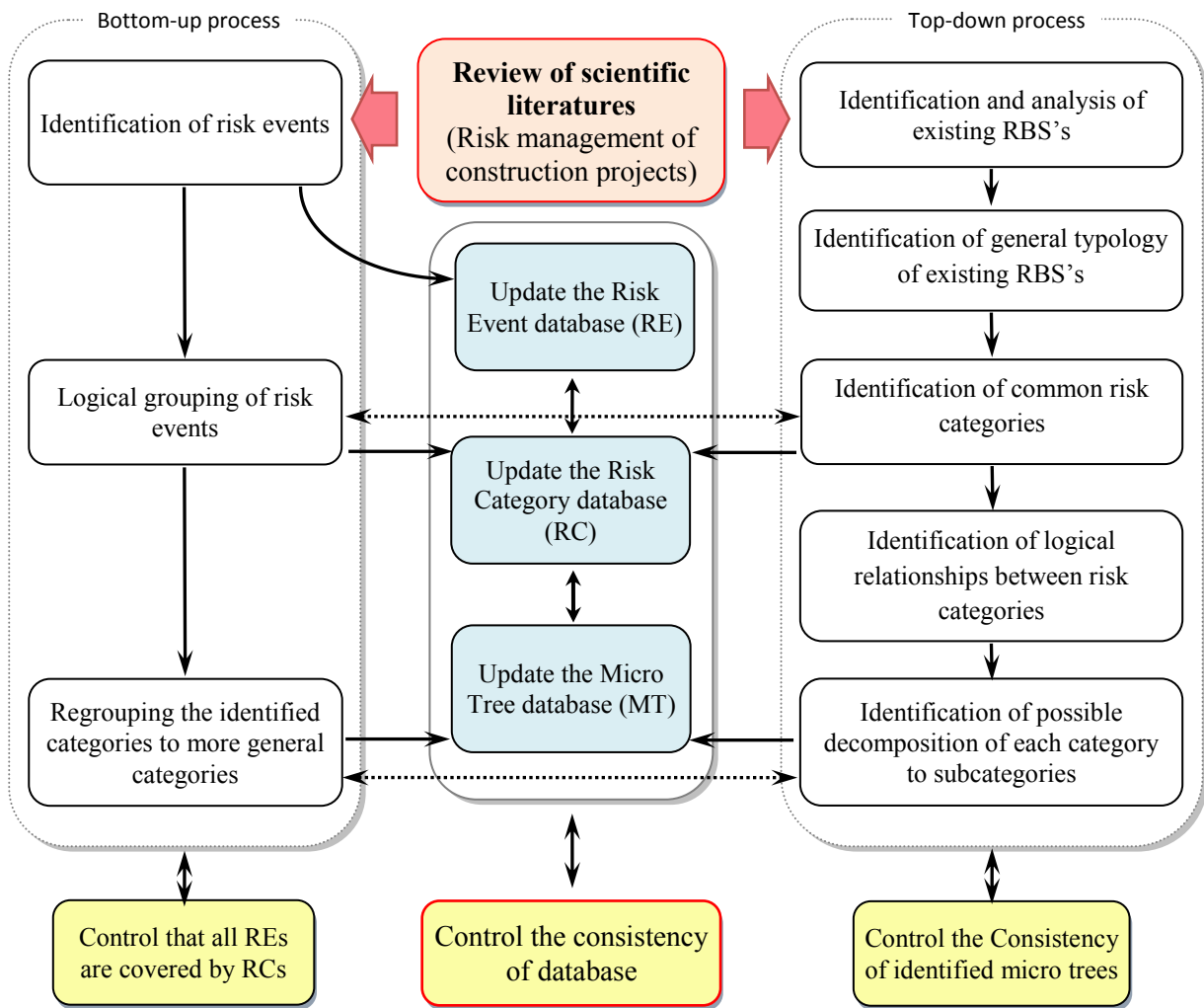


Figure 3-1. Development of the consistent database of risk events, risk categories and micro trees

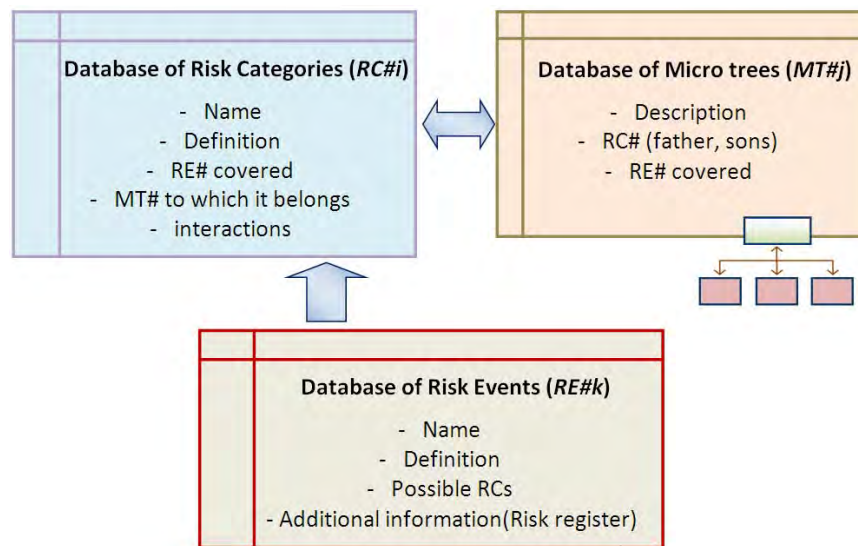


Figure 3-2. Relations between the three components of the database.

3.2.1. Risk events

Risk event (RE) is considered as any fact or event whose occurrence can have some impact/consequence on at least one of the objectives of the project. An event can also consist of something not happening (Din et al., 2010).

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. Clearly, such a list cannot be exhaustive. The issue is therefore to build a first version of the database, allowing future 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 projects or of their possible impact. The bibliographical analysis has led to more than 320 REs which had then to be classified and subjected to professional experts to get their perception. Thus, the contents of our database have been discussed and evaluated by the experts participating in a national research project of France (ANR-GERMA).

The classification stage consists of 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 3.1 represents a small part of the most frequent risk events available in RE database.

An interesting point is that the spelling of RE is somewhat more detailed than that usually given in RBS's. Many REs are defined as events linked with one of the stakeholders and one specific phase of the project. It is the only solution to ensure consistency when the RBS will be built. For instance, the RE “delay on payment to contractor during project implementation”

will possibly belong to RCs such as “project implementation”, “contractor”, “problems with payment”, which can be used in various RBS’s. Since it is precisely defined, the issue of knowing to which RC it can belong is made clear.

In the database, each risk event which is identified by a unique code (*RE#i*) and has a unique descriptive definition is connected to the corresponding categories, controlling the global consistency of the database. The full list of risk events of database is presented in Appendix 1 (Table 5.1 and Table 5.2).

3.2.2. Risk categories

A Risk Category (RC) is a group of several risk events. Any category can be split into subcategories when wanting a more detailed view or, reversely, grouped with other categories when a more general view is desired.

The development of the RC database raises the same type of questions than that of the RE database. The bibliographical analysis has led to more than 195 RCs, but they have been reviewed in detail, such as 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 to 146, while covering a wide variety of risk factors/events.

In the database, each RC is identified by a unique code (*RC#i*) and name and has a description which precisely explains the type of risks which are involved. The RCs which are not the father node of any MT in database are called the “bottom level categories” to which RE can be directly attached. For all other RCs, the REs are attached indirectly through the “father-son” relations. In final RBS’s, which will be built by combination of MTs, these categories cannot be decomposed anymore and are presented at the last levels of the RBS’s. This is not an intrinsic property of RCs, since new MTs can be added to the database to decompose a bottom level category, if this seems to be useful.

The REs have direct links with the bottom level categories and indirect links with the others. In the database, for each RE only the direct links are defined and the indirect links are generated regarding the father-son relations in MTs. As example, in Figure 3-3, *RE#f* has a direct link to *RC#i* which is a bottom level category and has indirect links to *RC#j* and *RC#k*, since they are the “father” and “grandfather” of this category.

Not only, the identified RCs have to be consistent locally, inside the RC database, but also the consistency has to be controlled with the other parts (REs and MTs). The RC database is represented in Appendix 1 (Table 5.3 and Table 5.5)

Table 3.1. List of the most frequent RCs in construction projects with some examples of REs.

Risk category	F*	Risk event examples
Political	30	<ul style="list-style-type: none"> • Instability of national politics during operation phase • National political conflict during feasibility phase • Instability of macro politics during operation phase
Design change	27	<ul style="list-style-type: none"> • Change of design because of poor understanding of customer needs
Financial (Internal and external resources)	27	<ul style="list-style-type: none"> • Restriction of public funding, budgetary cuts, delay, during implementation phase • Delay of bank in project fund allocation during feasibility phase • Contractual failure (bankruptcy) • Financial difficulties of owner of the project during implementation phase • Poor quality of operation process due to financial problems of financier • Poor project maintenance due to financial problems of owner
Unexpected weather	26	<ul style="list-style-type: none"> • Unwanted so cold weather during construction phase
Natural Constraints of site	26	<ul style="list-style-type: none"> • Difficulties of access and work on site due to specific geographical constraint of region
Time management	26	<ul style="list-style-type: none"> • Complexity of project time management due to complex nature of the project • Imposed unrealistic time planning for project due to insufficient or incorrect information • Poor time management due to change of manager or management strategies of the project • Inconsistency in time schedule of different stakeholders due to poor communication management
Economic/Financial	25	<ul style="list-style-type: none"> • Unpredicted increase of needed material price in implementation phase • Changes in exchange rates, convertibility during implementation phase • Economic slowdown, economic crisis during implementation phase • Low competition in internal market during feasibility phase • Difficulty to find suitable plant, because of high prices • Unpredicted increase of power price during implementation phase
Natural hazards	24	<ul style="list-style-type: none"> • Earthquake, flood, landslide, fire or wind damage during implementation phase
Defective design	19	<ul style="list-style-type: none"> • Mistake in design • Project design does not comply with building regulations
Quality management	17	<ul style="list-style-type: none"> • Poor quality management of the project due to frequent change of management strategies
Poor Communication (Project or stakeholder view)	15	<ul style="list-style-type: none"> • Poor communication between stakeholders of the project • Public concerns related to health and safety of the project due to poor communication • Poor exchange of information between designers • Poor exchange of information between contractors/ subcontractors

F*: Frequency of the risk category in 89 studied RBS's.

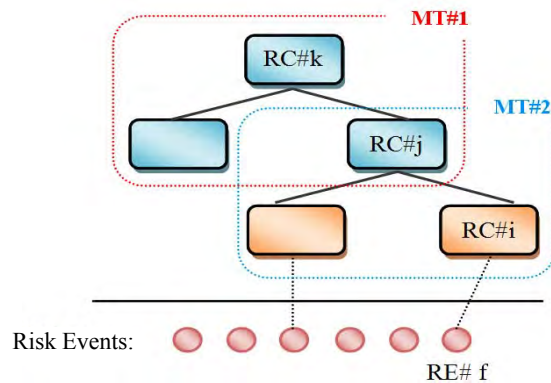


Figure β-3. Direct and indirect connection of a RE to Risk categories

3.2.3. Micro trees

3.2.3.1. Methodology

As it was discussed in previous sections, the possibilities of classification of project risks in literature are innumerable: according to actors, phases of project, by nature, etc. It is futile to search for a unique optimal structure. Thus, the approach is based on identification of some categories of relevant risks, and then on their hierarchical organization in the form of elementary trees (Micro Trees).

A micro tree is defined as decomposition of each risk category to subcategories or in other words, the connection between the “father” and “son” categories. Search for elementary trees is based on a thorough analysis of existing RBS’s, published in the technical and scientific literatures in the field of risk management of construction projects. A database of existing RBS’s is prepared synthetically, containing all hierarchical relationships in detail. A spreadsheet allows to synthesize information and make it accessible for further analysis (Figure β-4).

The analysis of information in the mentioned (RBS) database includes both visions of top-down (possibilities for variants of decomposition of risks at different levels) and bottom-up (possibilities for consolidation of risk events / risk factors) procedure.

Table β.2 represents an example of synthesis of existing RBS’s to find the logical relations of RCs. In this table, a partial analysis of “External risks” category is represented. Level of the category in RBS, the “father node”, the “brothers”, the subcategories and the general typology of the studied RBS are the analyzed parameters for each category. The results of this analysis together with empirical and scientific knowledge led to construction of the initial version of RC and MT database that then had to be compared with the database, generated by the bottom-up procedure and revised iteratively considering the consistency criteria of database (see Figure β-1).

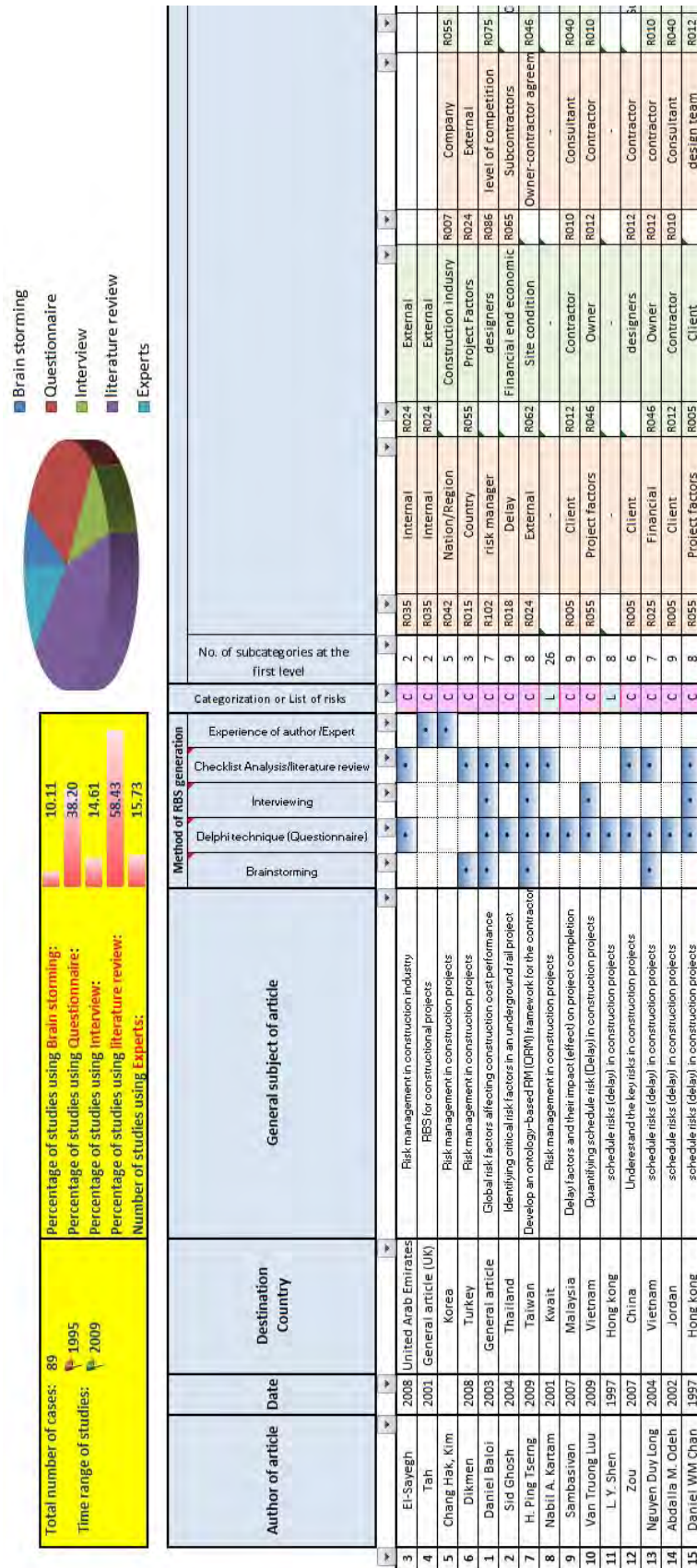


Figure 3-4. A partial view of database of identified RBS's in literature

Table 3.2. Synthesis of “External” risk category decomposition in existing RBS’s in literature

RBS Code/ Ref.	General properties		Subcategories	Same level categories
RBS 1 <i>El Shayegh, 2008</i>	Name of category:	External risks	Political Social & Cultural economic Natural Others	Internal
	Level in RBS:	1		
	Number of subcategories:	5		
	No. of the same level categories (N.S.L.C.):	1		
	Father node:	Project Risks		
RBS 2 <i>Zou et al., 2007</i>	Name of category:	External risks	feasibility design construction operation	Client Designers Contractors Subcontractors/ suppliers Government
	Level in RBS:	1		
	Number of subcategories:	4		
	N.S.L.C.	5		
	Father node:	Project Risks		
RBS 4 <i>Aleshin, 2001</i>	Name of category:	External risks	Action of the third parties unforeseen circumstances weather condition	Internal
	Level in RBS:	1		
	Number of subcategories:	3		
	N.S.L.C.	1		
	Father node:	Project Risks		
RBS 5 <i>Hillson, 2007</i>	Name of category:	External risks	Legislation Exchange rates Site/facilities Environmental/Weather Competition Regularity Political Country Social/Demographic pressure groups Force majeure	Technical risks Management risk Commercial risk
	Level in RBS:	1		
	Number of subcategories:	11		
	N.S.L.C.	3		
	Father node:	Project Risks		
RBS 6 <i>Zacharias et al., 2008</i>	Name of category:	External risks	unforeseen Circumstances Political economic social	Management risk Project implementation operational program planning
	Level in RBS:	1		
	Number of subcategories:	4		
	N.S.L.C.	3		
	Father node:	Project Risks		
RBS 7 <i>Ebrahimnejad et al., 2010</i>	Name of category:	External risks	Legal subcontractor and suppliers Political and social force majeure events Economics	Organizational risks technical risks
	Level in RBS:	1		
	Number of subcategories:	5		
	N.S.L.C.	2		
	Father node:	Project Risks		
RBS 87 <i>Liu et al.</i>	Name of category:	External risks	natural hazards site condition surrounding property/structure thief/war/unproductive labor and strikes	Internal Management risk
	Level in RBS:	1		
	Number of subcategories:	4		
	N.S.L.C.	2		
	Father node:	Project Risks		
RBS 38 <i>Wang & Chou, 2003</i>	Name of category:	External risks	Political and economic natural environmental factors Third party factors	Internal
	Level in RBS:	1		
	Number of subcategories:	3		
	N.S.L.C.	1		
	Father node:	Delay		

To understand the logic that prevailed for development of the MT database, the simplest way is to look at the top level (“level 0”), where three logics prevail for decomposing the global risks of a project. Global risks 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 to “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 to “project stakeholders”, “external risks” and “management” subcategories).

In the last two cases, the risks of interfaces that can be called as “Project management risks” are essential. It is well known that risks often lie at interfaces, as they will appear in the case of poor management. Cleland (1986) and Jergeas et al. (2000) consider that efficient management of the relationships between the project and its stakeholders is an important key to project success. Also Aaltonen et al. (2008) and Yang et al. (2010) state that the key issue in project stakeholder management is management of the relationships between the project team and its stakeholders. Thus, the category “management” must be highlighted.

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. For instance, a possibility for subdividing “external risks” is to consider three subcategories at level 2 (Figure β-5): country risks, environmental risks and force majeure. These new categories can, in a further step, be subdivided, for instance, “country risks” covers economic risks, political risks, legal risks and other risks within this context.

Generation of each of these micro trees was based on deep analysis of available information in RBS database (for external risks, Table β.2) to identify all the risks that have to be covered by each category, finding the confusing and inconsistent cases in decompositions and then, proposing the minimum number of subcategories which completely covers the corresponding risks of the category. Also it should be checked that the proposed subcategories have not overlap with each other. As an example, analyzing the given data in Table β.2, led to find many confusions. For example: in RBS 7, “Subcontractor and supplier” category is considered as external risks of the project! In RBS 5, the subcategories of “external risks” such as legislation, exchange rates and political overlap with “Country” category. In RBS 87, the name of “thief/ war/ unproductive labor and strikes” category should be shorter and

representative of all mentioned risks. Such analysis led to propose the illustrated micro trees in Figure 3-5.

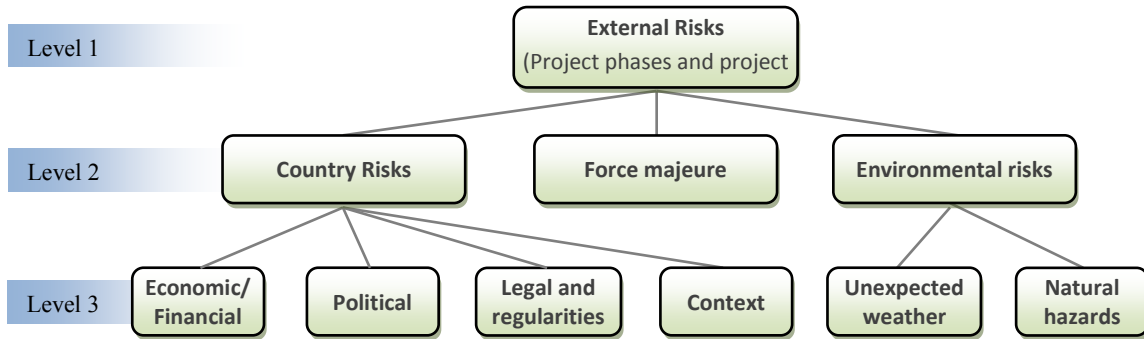


Figure 3-5 . Decomposition of “External Risks”. (This Picture contains 3 different micro trees)

As another example, for decomposition of the global risks of project:

- If one considers the project phases, “contract phase” can be divided at level 2 in : conflict in documents, delay in contract issues, ambiguous contract, non standard contract form, external risks during the contract phase;
- If one considers the “project stakeholders”, one can consider at level 2: owner/client, financier, designer, consultant, contractor, supplier.

3.2.3.2. Consistency checking

The main difficulty at this stage is to avoid a factorial multiplication of the possibilities. Since the many existing RBS’s in the relevant documentation (guidelines, scientific papers...) have not been built with the idea of any “standard”, one can find, for instance, many trees in which “political risks” is placed directly below “external risks”, without being grouped first in an intermediate category, here “country risk”. It is only through many comparisons and iterations that we could define a limited number of categories and elementary trees that cover a very large percentage of existing trees.

At the end of the process, the database contains a list of MTs and a list of RCs, with all belonging relations defining:

- For any MT, all RCs it contains,
- For any RC, to which MTs it can belong (all the possible father nodes).

These rules ensure the aggregation of belonging properties from the bottom level to the top level in the RBS.

The database currently contains 72 micro-trees that can be used to rebuild a very large number of possible RBS's. Special attention was given to control the consistency of these MTs at the both local and global scale. Figure 3-6, schematically illustrates the local consistency constraints of the MT database. The controlled items are:

- (a) a MT must have at least 2 subcategories,
- (b) a category can be presented as the father node of a MT, only if it is the subcategory of another MT (the exception is for “Project risks” category at level 0),
- (c) a subcategory in a MT, cannot be the “father” of its father in another MT,
- (d) a category can be presented only once as the subcategory of a MT,
- (e) a category cannot be the father and also the subcategory of a MT,

However, a category can be the father node of different MTs.

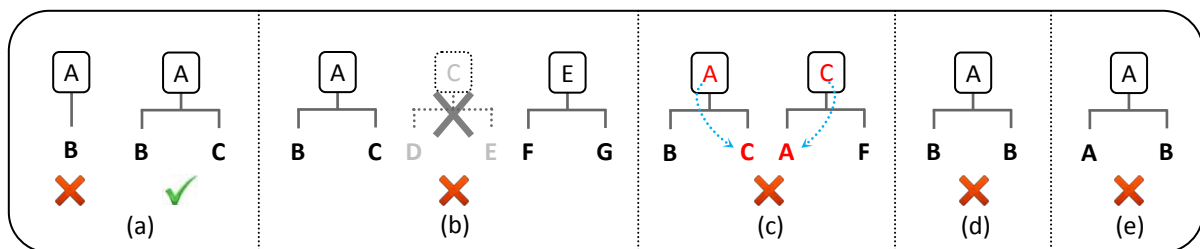


Figure 3-6. Internal consistency constraints of the micro trees database

We are fully aware that the solution for covering a large amount of existing RBS's is not unique and that our choices have been somehow subjective. These choices result from a long maturation process, during which the criteria for decisions were: elimination of useless solutions, reduction of the possibilities, consistency checking. The list of all MTs in database is presented in Appendix 1 (Figure 3-1).

3.2.4. Validation of the knowledge base

3.2.4.1. Global consistency of information in database

The development of the full database clearly appears as an iterative process which requires careful attention to detail. However, since a factorial growth of possibilities quickly appears in such processes, it was necessary to develop few automatic procedures in order to check the consistency of the database. The general idea is that, in any RBS which can be built by assembling a variety of MTs in several levels, any RE can be attached once (and only once) to one of the RCs belonging to the lower level. So 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 , each RE# j can be attached to one (and only one) of the subcategories in that micro-tree (see Figure β -8). Any impossibility to attach or any possible double attachment reveals some inconsistency, which must be corrected.

To see how this constraint prevents the ensuing problems, when the REs have to be propagated on generated RBS's, take a look at Figure β -7. If in database, the user connects RE# i to RC# k and RC# q , the first consistency for MT# i which is at the upper levels of the RBS, is not valid due to more than one connection of the RE to its subcategories (which here are indirect links). So this constraint doesn't let to save these two new links into database and prevents the following troubles. Therefore, we are sure that “A risk event cannot be attached to more than one RC in RBS” when the first constraint is controlled for all the MTs.

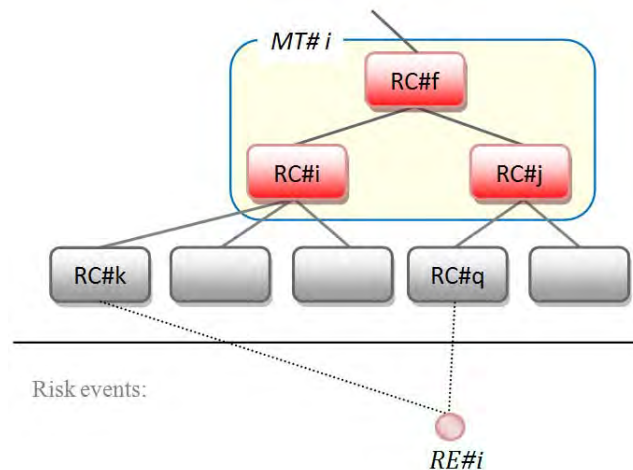


Figure β -7. A risk event cannot be attached to more than one RC of an RBS

The second constraint is related to the micro trees with the same father node. The 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. These two constraints are schematically illustrated in Figure β -8. 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. Since this check is automatic, further changes of the database will be easier. Developing the initial database means adding new REs, new RCs or new MTs, to cover a wider field of application or to cover a given field at a more detailed level. Since the initial database is consistent, it is easy to check the consistency of any addition, since it affects only a very limited part of the full database. This is important since the developed database is viewed as the first version of a knowledge database whose development and adaptation will be

possible. Extension of the database to cover the most common risk events of tunneling project (Mehdizadeh et al., 2011) and temporary structures (Mehdizadeh et al., 2012) prove this issue.

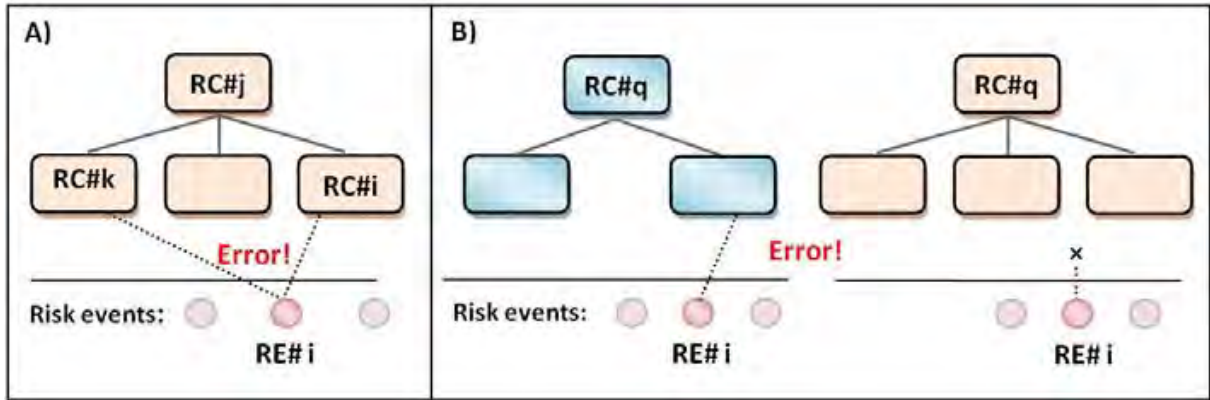


Figure 3-8. Consistency control of information in database. A) any RE can be affected once (and only once) to one of the subcategories of a MT. B) For the MTs with the same father node, if one of them can cover a RE, the others have to (necessarily) cover it as well.

As the third constraint, a RE can have direct links only to the bottom level Risk categories. A bottom level category has no subcategories in database or in other words, a bottom level RC is not the father of any MT in the database. This constraint is controlled when one defines the connection of REs with corresponding RCs in database.

3.2.4.2. In depth analysis and checking based on existing RBS's in literature

In last sections, RBS was fully introduced, the advantages and drawbacks were discussed and development of a consistent database of micro trees which then will be combined to generate the convenient RBS's was explained in detail. The idea is to develop a methodology which takes profit of all advantages of RBS, without suffering its usual drawbacks.

In this section, the existing RBS's in literature which are the basis of generation of our consistent database are synthesized in detail, one by one. The drawbacks are highlighted and compared with the proposed MTs of the consistent database. Furthermore, we have to be sure that by assembling the available MTs in database, each RBS can be regenerated either as it is or more consistent. However, they will not be exactly similar, but the objective is to cover all the mentioned risk domains of the RBS.

About 90 RBS's have been synthesized one by one and a part of results are represented in Appendix 2. Table 3.3 illustrates an example of this analysis.

Table 3.3. An example of synthesis of RBS's in technical and scientific literatures

RBS 1	
<p>Reference: Sameh Monir El-Sayegh, Risk assessment and allocation in the UAE construction industry. <i>International Journal of Project Management</i>, Volume 26, Issue 4, May 2008, 431-438.</p> <p>Web link: Click here</p> <p>General subject of the Article/ document: Risk management in construction industry</p> <p>Destination country: United Arab Emirates</p> <p>Number of levels: 2</p> <p>Method of development of the RBS:</p> <p> <input type="checkbox"/> Brainstorming <input checked="" type="checkbox"/> Checklist Analysis/literature review <input checked="" type="checkbox"/> Delphi technique (Questionnaire) <input type="checkbox"/> Experience of author <input type="checkbox"/> Interview </p>	
<p>Schematic of the RBS:</p> <pre> graph TD PR[Project Risks] --> IR[Internal Risks] PR --> ER[External Risks] IR --> O[Owners] IR --> D[Designers] IR --> C[Contractors] IR --> SC[Sub-Contractors] IR --> S[Suppliers] ER --> P[Political] ER --> SC[Cultural & Social] ER --> E[Economic] ER --> N[Natural] ER --> Oth[Others] O --- O_risks["Delayed Payments to Contractors Unreasonably Imposed Tight Schedule Improper Intervention Change of Design Lack of Scope Definition Delays in Obtaining Site Access Breach of Contract Sudden Bankruptcy"] D --- D_risks["Defective Design Deficiency in Drawings Changes in Design Documents not Issued on Time"] C --- C_risks["Construction Accidents Poor Quality Low Productivity Technical Problems Contractors' Incompetence Lack or Departure of Qualified Staff"] SC --- SC_risks["Poor Performance Breach of Contract"] S --- S_risks["Material Quality Problems Delay of Material Supply"] P --- P_risks["War Threats Labor Strikes Changes in Laws Corruption & Bribes Delays in Approvals"] SC --- SC_risks["Criminal Acts Substance Abuse Conflicts due to Differences in Culture"] E --- E_risks["Inflation Currency Fluctuation Shortage in Material Availability Shortage in Manpower Availability Shortage in Equipment Availability"] N --- N_risks["UNExpected Incident Weather Unforeseen Site Conditions"] Oth --- Oth_risks["Delays in resolving contractual issues Delays in Resolving Litigation Unfairness in Tendering Local Protectionism Difficulty in Claiming Insurance"] </pre>	
<p>Comments:</p> <ul style="list-style-type: none"> In this RBS project risks are decomposed into two groups, according to their source, into internal and external risks. Internal risks are those that are project related and usually fall under the control of the project management team. External risks are those risks that are beyond the control of the project management team (El-Sayegh, 2008). This form of categorization of project risks at the first level is comparable with MT#1 in database. 	

- In this RBS, internal risks are decomposed regarding the allocation of risks to different stakeholders of the project. In fact two different perspectives to project risks are mixed (source and allocation of risks). However, performance and characteristics of the stakeholders are considered as internal part of the project, and this form of decomposition is correct, but combination of different perspectives and decomposition criteria can cause to inconsistent cases, when RBS development is aimed to be general.
- Construction projects, by a general view, have some other partners which are not considered in this RBS such as “Funding partner” and “Consultant”. However in this RBS (the corresponding project of this RBS), the owner is also the financier of the project (since “Delayed payment to contractor” is attached to this RC) but it is not a general form and so, this RBS may not be applicable in a new project if it is different (in the case of finance). In the data base, MT#8 regroups six different partners of the project (designers, financiers, owner/clients, contractor/subcontractors, suppliers and consultants) to “Project stakeholders” which is comparable with decomposition of internal risks in this RBS.
- The interface between different stakeholders that can be called as “Project management” is not considered in this RBS. MT#2 in database includes different stakeholders and project management risks, as the interface between different partners.
- External risks are categorized to 5 categories which is comparable with MT#4. In this RBS some external risks such as financial problems (external resources), legal and regularities and context are not considered.
- Some of risk events attached to the RCs are not precise enough that can cause misunderstanding or some of them are attached to different categories at the same time. For instance, two REs of “Change of design” attached to “Owner” and “Change in design” attached to “Designers” category, are they the same REs? If yes, it is an inconsistent case, since a RE is attached to two RCs of an RBS. If not, it is a case of complexity, since their definition and differences are not clear and user cannot distinguish them. One could for instance say: “change of design ordered by owner” and “inability of designer to account for change of design”.
- As another example, “Labor strikes” is not necessarily a political issue and in our database, this RE is considered as “Force majeure” which is more general. “Changes in law” is considered as political risks but also it can be considered as another issue regardless of politic. And what about the change of codes and standards which are also the same type of risk as change of laws, but not necessarily a political issue? They are not considered in this RBS.
- Shortage in material, manpower and equipment are considered as economic risks, however, they can also be considered as context risks, since such resources may be not available in the project area. Such problems are due to bad or imprecise definition of REs. During definition of RE in database, it was carefully checked their consistency and corresponding RCs. For instance, the RE “Change of design because of poor understanding of customer needs” is precise enough that can be affected just by “Designers” category.
- The type of corresponding risks of the “Others” category may be clear enough for the

3.2.4.3. Extensibility of the database for special fields

As it was mentioned before, the methodology must be both general enough to cover all construction projects and specific enough to be adapted to a given particular project. The original version (V_0) of the database contained 129 risk events and 73 micro-trees which correspond to a very large number of possible RBS's. It had to be verified its validity and extensibility for any given particular type of project. Therefore, the challenge is to extend the database for a particular type of project. The choice was tunneling projects, one of the most complex and riskiest fields (Mehdizadeh et al., 2011).

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 (USACE). Tunnel accidents can cause loss of life, equipment damage, damage to tunnel structure and loss to 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.

By a deep analysis of technical and scientific literature related to design, implementation and operation of tunneling projects such as codes and standards and risk management reports (BTS, 2003; USACE; TCP, 2007 ; Sousa, 2010 ; MED, 2008 ; Blindheim), 129 new risk events were identified. Table 3.4 represents a part of these REs and the complete list is available in Appendix 1 (Table 5.2). These new REs have to be consistent with the available information in database (V_0). Thus, the code and definition of each RE have to be unique and illustrative.

In a first step, these new REs were added into the database and each one was connected to the corresponding bottom level categories, controlling the consistency criteria of database. It was then possible to identify bottom level categories which have links with many REs. As example, RC#50 "poor or defective design" is a bottom level category and has connection with 3 REs related to general construction projects. This number was increased to 48 when the new REs were added. Table 3.5 illustrates the list of available REs and a part of new ones corresponding to "poor or defective design" category.

As a general rule, the large number of REs attached to a bottom level category necessitates its decomposition by new MTs. Thus, following the same procedure as the initial database was developed, all the bottom level categories with notable number of REs have to be decomposed to lower levels. Thus, new risk categories and micro trees have to be defined.

Table 3.4. List of Risk Events in database (tunneling projects)

No.	RE Code	Risk Event
1	168	Poor preliminary assessment and evaluation of tunneling methodologies
2	172	Poor preliminary assessment and evaluation of ground movement and settlements
3	176	Poor preliminary assessment and evaluation of hazardous materials
4	179	Poor preliminary risk management of different proposed options of design, contract form, contractors, etc
5	181	Allocation of risks to the parties is not mentioned or is not clear in the contract
6	187	Calculations, analyses and assessments don't consider intermediate stages of construction.
7	198	Conflict in design of tunnel including the dimensions, shape, excavation tolerance of the excavation, and the tunnel support and lining design
8	199	Inadequate definition of timeframes for excavation work
9	200	Defective design due to incorrect evaluation of the nature of ground
10	201	Defective design due to incorrect evaluation of the water table level
11	205	Poor design due to disregarding to the proximity of existing underground services, such as water mains, sewerage drainage, electricity, gas and telephone
12	208	Poor design due to disregarding to the heavy loadings, above or adjacent to the tunnel (e.g. roadways, railway lines, buildings)
13	209	Poor design due to disregarding to the existing chemical contamination of soil and ground water
14	210	Poor design due to disregarding to the presence of methane, or other hazardous gases
15	213	Poor design due to disregarding to the effect of explosion on surrounding strata and tunnel stability
16	217	Defective stability analysis of tunnel (tunnel face)
17	218	Defective or inconvenient design of TBM or excavation machine (Type of machine, structure)
18	221	Defective design of ground freezing system
19	223	Inadequate blasting design (type, quantity,...)
20	225	Poor or defective design due to disregarding to considering the ground pressure water
21	229	Poor definition of stages and sequential activities of remedial action by designers
22	231	Defective selection of tunneling method
23	232	Disregard to considering the 3D effects in design (such as the effect of existing tunnels)
24	245	Air contamination or oxygen depletion due to inconvenient design of ventilation system of the tunnel
25	246	Poor traffic management in tunnel during construction phase
26	248	Accident due to use of compressed air and high pressure hydraulics by inexperienced contractor
27	250	Accident due to wet or other slippery surfaces
28	252	Accident due to reduced visibility
29	255	High level of noise in tunnel, and workers without safety equipments
30	256	Falling of the workers from heights due to poor performance of contractor in safety of site
31	258	Fire of excavation machine due to irregular mechanical control
32	260	Inadequate storage, transport and use of explosives (inexperience contractor)
33	264	Disregard to clearance of blasting fumes and dust.
34	265	Poor inspection of the tunnel works by contractor
35	266	Inappropriate permanent ground support used by contractor
36	271	Inappropriate or unsafe Personnel-riding vehicles
37	272	Inappropriate or unsafe Rolling stock-locomotives and rail cars are used by contractor
38	274	Poor electrical safety (electric cables, electrical articles, portable generators) by contractor
39	276	Disregarding to sequential and staged activities of remedial action by contractor
40	281	Damage to installed lining during the work due to poor performance of contractor

Table 3.5. List of available and new REs corresponding to “Poor or defective design” category

No.	RE Code	Existing Risk Events (construction projects)
1	90	Mistake in design
2	151	Project design does not comply with building regulations standards and criteria
3	296	Poor or defective design due to disregarding to environmental effect of the project (poor environmental analysis)
New risk events (Tunneling projects)		
8	187	Calculations, analyses and assessments don't consider intermediate stages of construction.
9	188	Design process doesn't include sensitivity study to assess the impact of changes and unwanted variation of design parameters
10	189	Design process doesn't include sensitivity study to assess the impact of natural hazards
11	205	Poor design due to disregarding to the proximity of existing underground services, such as water mains, sewerage drainage, electricity, gas and telephone
12	207	Poor design due to disregarding to the adjacent excavations (e.g. shafts, tunnels or trenches) ground support
13	208	Poor design due to disregarding to the heavy loadings, above or adjacent to the tunnel (e.g. roadways, railway lines, buildings)
14	209	Poor design due to disregarding to the existing chemical contamination of soil and ground water
15	210	Poor design due to disregarding to the presence of methane, or other hazardous gases
16	211	Poor design due to disregarding to the dynamic loads or ground vibration near an excavation due to traffic (highway or rail), excavation equipments (TBM,...) or explosives.
17	212	Poor design due to disregarding to ground vibrations, overpressures from blasting and fly rock
18	213	Poor design due to disregarding to the effect of explosion on surrounding strata and tunnel stability
19	219	Defective or inconvenient design of TBM operation parameters (Speed, balance pressure in face, ...)
20	220	Disregarding to the ground water level fluctuation on design of diaphragm wall, tunnel, or other structures
21	222	Poor or defective back analysis
22	225	Poor or defective design due to disregarding to considering the ground pressure water
23	229	Poor definition of stages and sequential activities of remedial action by designers
24	231	Defective selection of tunneling method
25	232	Disregard to considering the 3D effects in design (such as the effect of existing tunnels)
	:	

The analysis of new REs corresponding to “poor or defective design” category, clarifies that this category can be decomposed into four main categories of:

- Incorrect or insufficient design data,
- Disregarding to the involved factors in technical design,
- Mistake of designer in calculations and analysis,
- Inappropriate applied method, model or design tool.

This MT and the four new identified RCs can be added to the database when the consistency criteria are controlled. According to the third consistency check of the database, the REs have direct links only to the bottom level categories and for the others, the REs are attached indirectly through the “father-son” relations of categories. Therefore, all the direct

links of REs to RC#50 (which is not a bottom level category anymore) have to be removed and new direct links are made to the subcategories of this new MT. The indirect links will be generated automatically. Figure 3-9 represents schematically the process of adding a new MT to database and modification of direct links.

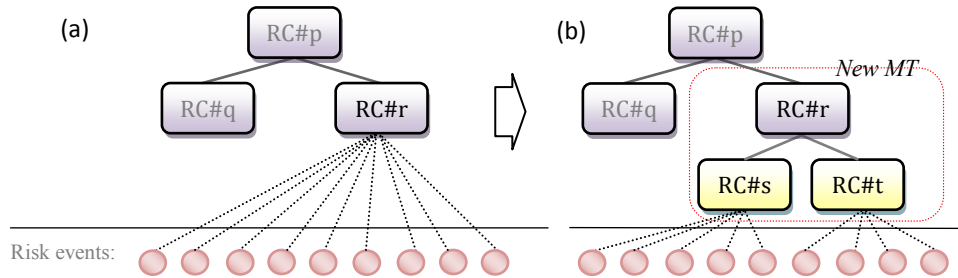


Figure 3-9. Adding a new MT to database and modification of the direct links to bottom level categories

The same procedure was repeated for all the bottom level categories to find the new RCs and MTs. The result is an extended database for tunneling projects, which is specific enough to focus on very small details, where risks may come from, and is compatible with the original (V₀) general database of construction projects. Since the initial database is consistent, it is easy to expand it for any specific project while the consistency criteria are controlling any changes in the database. The full database of REs, RCs and MTs of tunneling projects is represented in Appendix 1 (Table 5.2, Table 5.4 and Figure 5-2).

It should be noted that, however, the proposed database is general enough to cover all construction projects and is adaptable to any given particular type of project, the user is able to build his own original database of risks if he has different preferences. As an example, for Public-Private Partnership (PPP) projects, user may have different logic to decompose the project risks: For instance, the “PPP project risks” can be decomposed to three subcategories of “Upstream phase”, “Procurement phase” and “Downstream phase”. Each of these subcategories can be further decomposed when new MTs are identified. Figure 3-10 illustrates four possible MTs of this new database. Our methodology is compatible with any database which is generated following the mentioned criteria and development procedures of a consistent database.

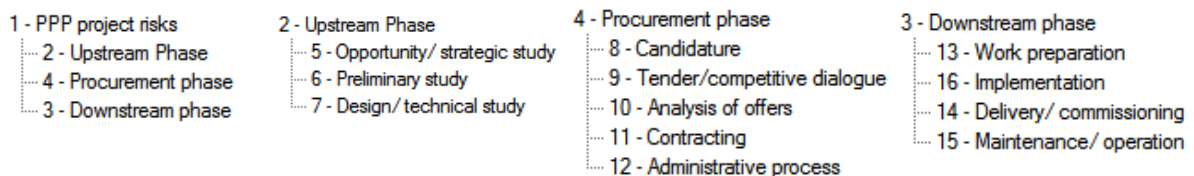


Figure 3-10. A new database of Micro Trees for PPP construction projects

3.3. RBS building process

3.3.1. General algorithm of RBS building process

The issue is now to define a process enabling the building and the selection of a “convenient” RBS to be used in PRM 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 ($V_1=V_0+\text{additionnal}$) presently contains 78 micro-trees which correspond to a very large number of possible RBS’s (several billions). This number reduces to few thousand if one adds the constraint of developing the homogeneous RBS’s 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 RBS’s and to consider them as candidates as the “best ones”. These different RBS’s are all representing different pictures of the same base of knowledge and for each particular situation, one of these pictures is the most convenient one. All the generated RBS’s will be ranked regarding the main criteria of quality of the RBS’s and considering the general requirements and objectives of user and selected REs which have to be aggregated through the RBS. The most convenient RBS is selected regarding the global notes of the RBS’s, the one with the highest ranking. Then the quality of this RBS will be improved by further development of risky categories and cutting negligible and unimportant branches regarding the level of details and criticality.

The main steps of generation, ranking and selection of the most convenient RBS, illustrated in Figure 3-11, are more explained in the ensuing sections.

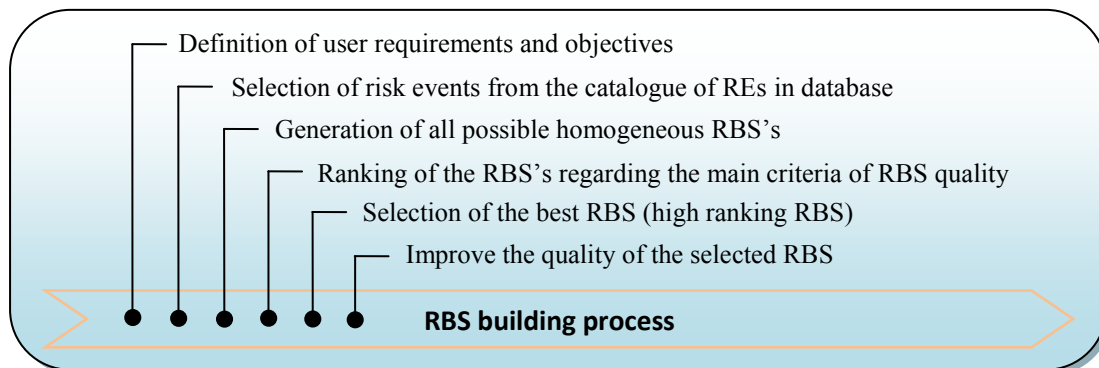


Figure 3-11. RBS building process

3.3.2. User requirements and objectives

The first step is to define the main requirements of user as for the project phases, project stakeholders and the main objectives of the Project Risk Management. User can be interested to focus on one of the project phases (feasibility, contract, design, implementation, operation) or maybe the whole project lifecycle. The decomposition structure can represent the particular

perspective of one of the project stakeholders (designers, financiers, owner/ clients, contractors/ subcontractors, suppliers and consultants) or can be a shared tool to aggregate their different perspectives to project risks. The objectives can be managing time, cost, quality or maybe all of them. The final RBS has to be compatible with all of these requirements.

3.3.3. Selection of risk events through the risk event database

The dynamic and evolutionary nature of project risks requires an iterative process of risk identification and assessment. The generation of convenient RBS's, is not only sensitive to special requirements of the user but also to the level of available information and the identified probable risk events and their values. This means that, if in a special case or stage of the project, the probable risk events are known, the generation process of the convenient RBS's will also be sensitive to the number and propagation of the selected REs on RBS branches which lead to have more equilibrated number of attached REs to each bottom level category. If the values of the selected REs are also known, the contrast of risk values on RBS branches will also be an effective parameter in selection of the most convenient RBS's. Thus, the question is that: how in each stage of the project, the possible REs and their values can be identified?

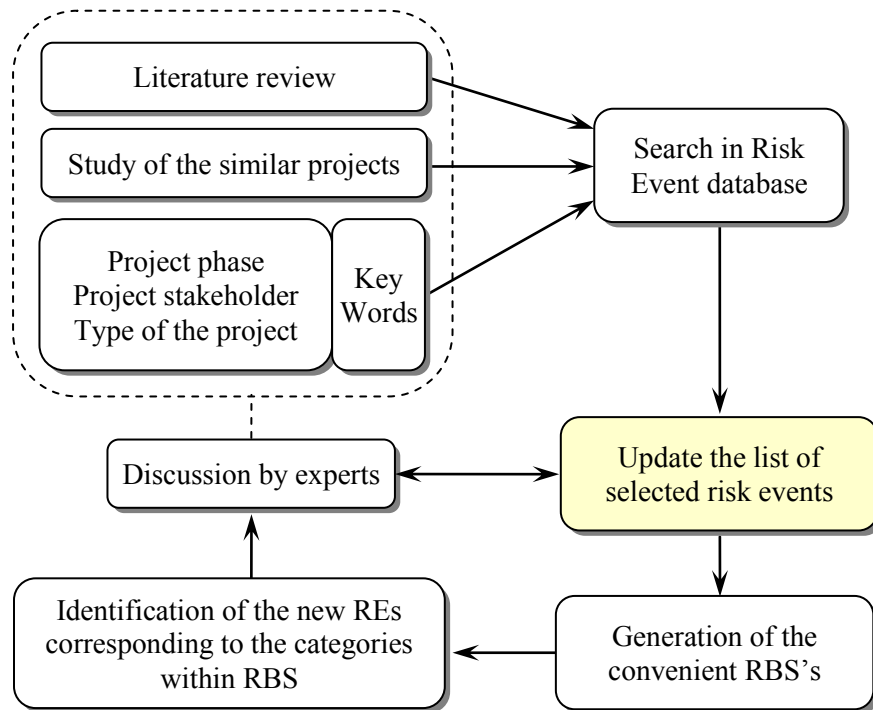


Figure 3-12. Iterative identification of risks events

As is illustrated in Figure β -12, in the very beginning steps of risk identification process, by searching the keywords related to the main requirements of the user, the type and nature of the project, a preliminary list of probable REs can be identified through the catalogue of risk events (or “risk register”). In this process, study of similar projects, literature and available statistical information, experience of experts, questionnaire forms, meetings and interview with the project manager(s) can also be helpful to identify the maximum number of probable risks events.

Since not all risks can be identified at any given point in the project, it is essential that risk identification is repeated throughout the project life cycle. This should be done periodically, at a frequency determined during the Risk Management Process. Risk identification might also be repeated at key milestones in the project or whenever there is significant change to the project or its operating environment (PMI, 2008).

When the convenient RBS’s corresponding to a particular situation are built, they can also be helpful to identify new REs which may have been forgotten in the previous steps. The new identified risk events are added into the database and generation of the convenient RBS’s is repeated again. This iterative process continues during the whole life time of the project, by updating the database and proposition of the more convenient and compatible RBS’s.

3.3.4. Generation of all possible homogeneous RBS’s

For taking a decision in a complex context, if the number of possibilities is great, then a simplifying strategy could be appropriate (Elms and Brown, 2012). As already discussed, the number of possible RBS’s can be reduced, by adding the constraint of generation of homogeneous RBS’s at the same level on all branches.

In a homogeneous RBS with n levels, all categories must be decomposed to reach the n^{th} level if they are the father nodes of MTs in database. By this definition, a homogeneous RBS may have branches which are not decomposed as the others, just because there is no MT in database to decompose it to reach the desired level. Figure β -13 schematically illustrates the process of generation of all possible RBS’s. By combination of the five represented MTs, four different homogeneous RBS’s have been generated (Figure β -13-III). RBS#2 and 3 are two different decompositions of category A up to level 2 and RBS#4 up to level 3, however, except category H, the others have ended up at level 2 since they are not the father node of any other MTs.

It is noted that, without consideration of the homogeneous level restriction, combination of the four MTs, shown in Figure β -13, results in 8 different RBS’s (Figure β -13-II).

These different RBS’s are all representing different pictures of the same base of knowledge and for each particular situation, one of these pictures is the most convenient one.

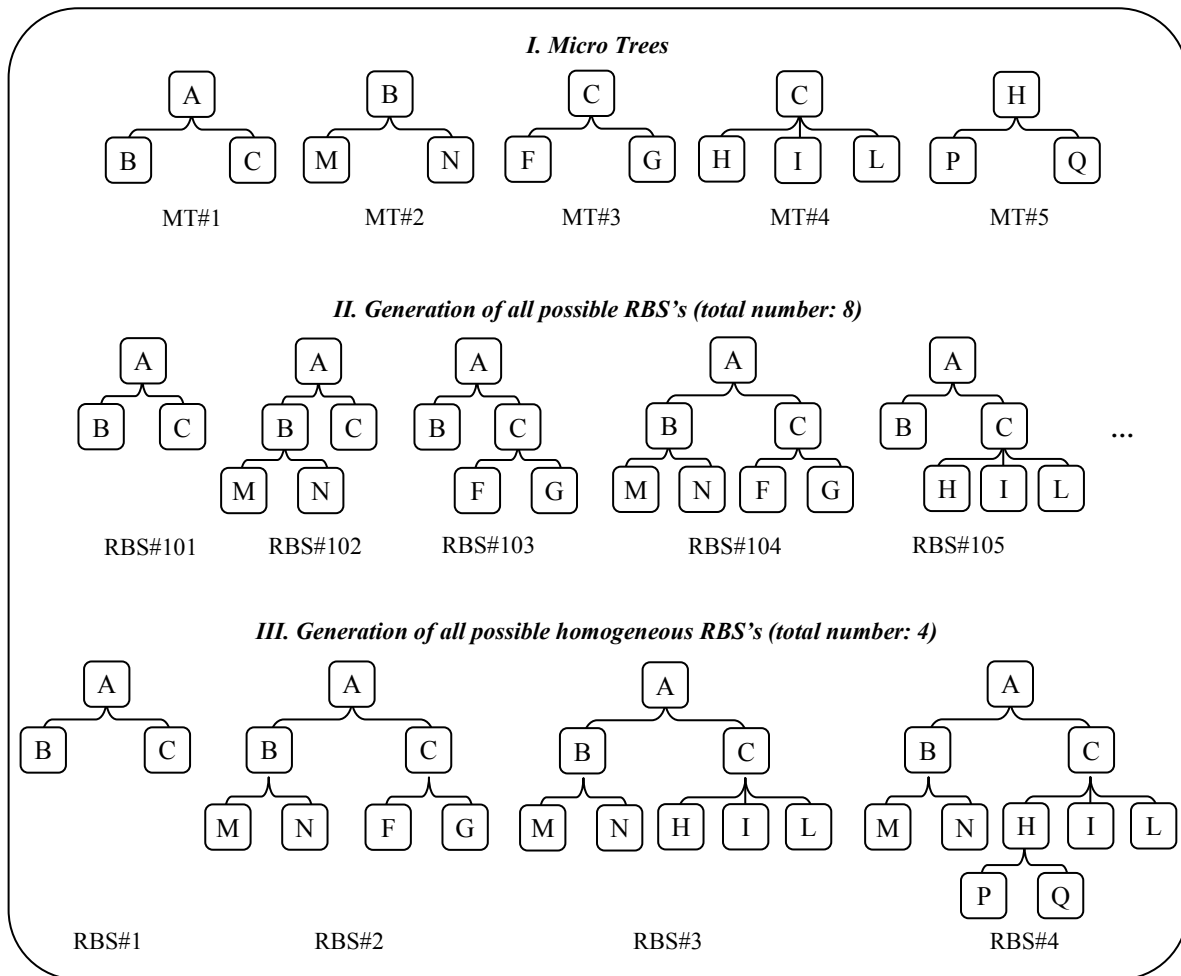


Figure 3-13. Assembling process, generation of all possible RBS's

3.3.5. Criteria for selecting a convenient RBS

After generation of all possible homogenous RBS's, one must define according to which criteria the RBS's can be evaluated, ranked and selected. The criteria defining what is a "good" RBS are the following ones:

- (a) an 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 wasn't, the solution would be to broaden or to deepen the database by adding new REs, new RCs and new MTs.
- (b) an RBS must be developed at a "convenient" level (neither too much nor too little),
- (c) an RBS must decompose the risks in agreement with the user's view: what are his objectives? on what performance does he want to focus?,

(d) an RBS must decompose the risks such as to highlight the more important ones.

On this basis, a set of notes can be calculated for each possibility of decomposition (RBS), and using any multi-criteria decision method, a global “quality” note can be obtained for each one. Elms and Brown (2012) pointed out that these kinds of notes are never objective or intrinsic to the objects (RBS’s) but are a combination or product of the objects and estimator. Let us consider how these criteria are accounted for.

3.3.5.1. Adequacy of the decomposition level

The first important criterion (criterion (b)) is that of the adequacy of the level of detail of the RBS. It is related to the total number of selected REs, n_T (from few units to hundreds). To limit the number of possible RBS’s, it was chosen in a first stage to consider only variants with a same number of levels on all branches of the RBS. However, due to the nature of REs considered, some branches (thus RCs) can cover many REs while some others cover few or even none REs. In such a case, these branches can be reduced and the number of levels on these parts of the RBS will be lower. The RBS must be adapted so as to keep a more or less uniform number of REs (n_{RE}) in each category at the lower level (bottom level RCs). The criterion is based on the choice of a relevant number of events (A_v). If a RC contains too many events, $n_{RE} > A_v$, the RC must be further decomposed. Reversely, if it is too low for all subcategories of a MT, $n_{RE} < A_v$, these subcategories can be grouped and the corresponding branch of the RBS can be reduced. Since the RBS contains k bottom level RCs, a note (n_{conv}) can be calculated for each of them, and aggregated so as to obtain a global note N_{conv} for the RBS:

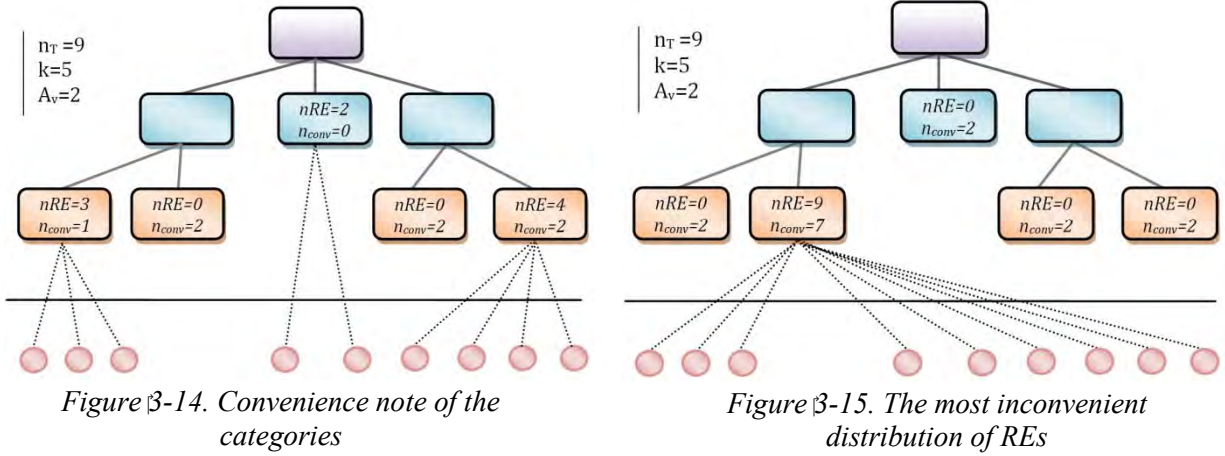
$$n_{conv (RC\#i)} = |n_{RE(RC\#i)} - A_v| \quad \text{Equation } \beta\text{-1}$$

$$N_{conv} = 1 - \frac{\sum_{i=1}^k n_{conv(RC\#i)}}{(n_T - A_v) + (k-1)A_v}, \quad (n_T \geq A_v), \quad (0 \leq N_{conv} \leq 1) \quad \text{Equation } \beta\text{-2}$$

where k is the number of bottom level RCs of RBS. n_{conv} can be calculated for each bottom level category using Equation 3-1. This note represents the difference between the number of attached REs (n_{RE}) and target number of REs (A_v). The absolute value of each difference makes them all positive numbers (to avoid negative values which would reduce the final convenience note). The numerator of fraction in Equation 3-2 is a simple summation of all convenience notes (n_{conv}) of bottom level categories. To normalize this value, it is divided by the maximum possible value of this summation which corresponds to the case when all REs (n_{RE}) are attached to just one of the bottom level categories.

Figure $\beta\text{-14}$ illustrates an example for calculation of N_{conv} and Figure $\beta\text{-15}$ illustrates the same RBS when all of the REs are attached to one of the bottom level categories. For the first RBS $\sum N_{conv} = 7$ and for the second one $\sum N_{conv} = 15$ which is the maximum possible value of $\sum N_{conv}$ for this RBS with this number of REs. In other words, Figure $\beta\text{-15}$ represents the worst

distribution of REs on RCs. As result, the convenience note of this RBS (Figure β -14) is $N_{conv} = 1 - (7/8) = 0.53$, when $N_{conv} = 0$ for Figure β -15.



Following Equation 3-2, the higher N_{conv} , the more equilibrated is the number of REs in each “bottom RC”. The maximum value $N_{conv} = 1$ is obtained when each of the bottom RCs contains A_v risk events, which is the most convenient situation. By default, $A_v = 2$ which means the target number of attached REs to each bottom level category is 2. The user can select any other value regarding the desired level of detail of RBS and the number of selected REs (nRE). As a rule, higher values of A_v should be taken if less level of details of RBS (RBS with few number of levels) is desired.

3.3.5.2. Adequacy to the objectives and requirements of the user

The second important criterion (criterion(c)) 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). The choice has been made to ask the user what are its preferences. For instance, if the user wants to focus on stakeholders, MT#2 shown in Figure β -16 is more convenient. If he prefers to focus on a phase, another MT would be better.

The idea is to evaluate each RBS considering the adequacy of its MTs for requirements and objectives of the user. In the database each micro-tree has received a prior note (in the [0,1] range) regarding these three possible focus: n_{phases} , $n_{stakeholder}$, $n_{objective}$. These notes are MT intrinsic properties. Similarly to what is done for the first criterion, these notes are combined through the RBS, so as to obtain three global notes N_{phases} , $N_{stakeholder}$, $N_{objective}$ for the RBS:

$$N_{phases} = (\sum_{i=1}^m \omega_l \cdot n_{phases} (MT\#i)) / \sum_{l=0}^L nMT_l \cdot \omega_l \quad \text{Equation } \beta\text{-3}$$

$$N_{stakeholders} = (\sum_{i=1}^m \omega_l \cdot n_{stakeholders} (MT\#i)) / \sum_{l=0}^L nMT_l \cdot \omega_l \quad \text{Equation } \beta\text{-4}$$

$$N_{objective} = (\sum_{i=1}^m \omega_l \cdot n_{objective} (MT\#i)) / \sum_{l=0}^L nMT_l \cdot \omega_l \quad \text{Equation } \beta\text{-5}$$

where L is the maximum level of the RBS, l is the level of the father node of the MT in RBS, m is the total number of MTs in RBS, nMT_l is the number of MTs in level l of the RBS and ω_l is a weighting factor depending on level l .

These equations calculate the weighted mean of the MT notes for each RBS. The three N notes represent the overall adequacy of an RBS regarding each of the possible three focuses. The weighting factors (ω_l) are defined in order to give more importance to upper level (macro) micro trees that to lower levels. Since all MT notes are weighting factors belong to $[0, 1]$ range, the value of the quality notes (N_{phases} , $N_{stakeholder}$ and $N_{objectives}$) will be also between 0 and 1, as it is the case with N_{conv} .

Definition of the micro tree notes:

How the micro tree notes are defined in the database is explained here just for few MTs, illustrated in Figure 3-16.

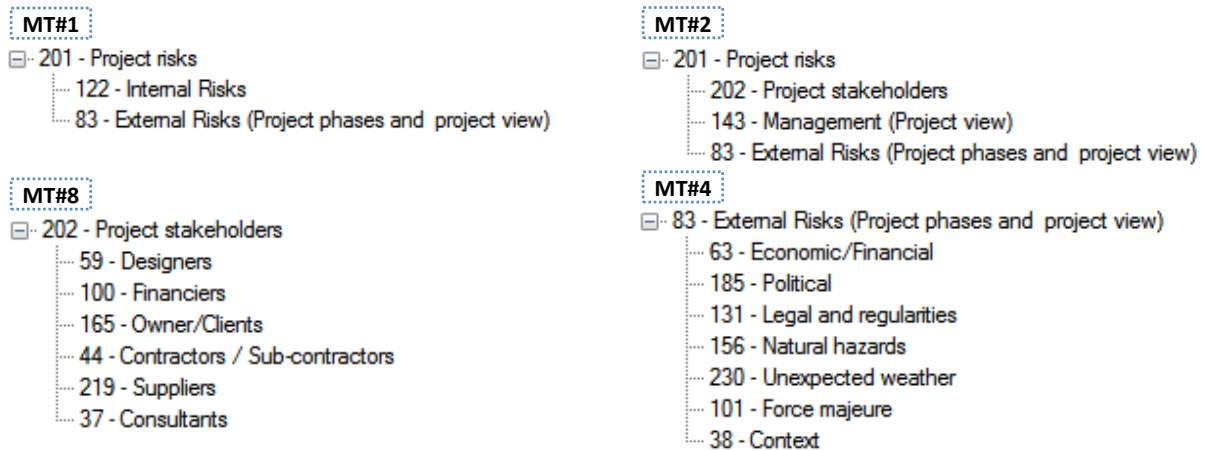


Figure 3-16. A part of micro tree database (the numbers are the RC codes)

MT#2 is more convenient when the objective is to focus on different stakeholders of the project, while MT#1 is not adapted in the same context. Thus, $n_{stakeholder}$ of MT#1 is zero and for MT#2 is 1.0. With the same idea, MT#8 is more convenient than MT#1 regarding different phases of the project. However MT#8 doesn't categorize the risks clearly considering different phases of the project, but decomposition regarding project stakeholders is more convenient than decomposition of MT#1 because of the sequential and time dependency of the performance of stakeholders. When the objective is to focus on one of the project phases, presence of MT#4 as one of the RBS branches is highly recommended. Thus n_{phase} of this MT for each of the project phases is 1.0. The same pair comparisons have been done for all MTs available in database and a set of 17 notes has been defined for each one including:

- 7 notes corresponding to project stakeholders: designers, financiers, owner/ clients, contractor/ subcontractors, suppliers, consultants or all project stakeholders

- 4 notes corresponding to project risk management objectives: price, time, quality management or all items.
- 6 notes corresponding to project phases: feasibility, contract, design, implementation, operation phase, or all project phases

Table 3.6 represents a part of the MT notes database concerning the mentioned MTs in Figure 3-16 and the full table is given in Appendix 1 (Table 5.6).

Table 3.6. Micro Trees notes

MT Code	Project Stakeholders							Objective of project risk management				Project Phases					
	Designers	Financiers	Owner/ Clients	Contractors	Suppliers	Consultants	All the St.	Price	Time	Quality	All the objectives	Feasibility	Contract	Design	Implementation	operation	All the phases
1	0	0	0	0	0	0	0	0.4	0.4	0.6	0.6	0	0	0	0	0	0
2	1	1	1	1	1	1	1	1	0.6	1	0.8	0.4	0.4	0.4	0.4	0.4	0.4
4	0.2	0.2	0.2	0.2	0.2	0.2	0.8	1	1	0.4	0.8	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	0.6	1	0.8	0.4	0.4	0.4	0.4	0.4	0.4

These notes, however remain somewhat subjective, for each MT they are defined by answering to this question: regarding the requirement or objective of the user, how much is the preference or interest of presence of this MT as one of the RBS constituents? In other words, how much is the ability of the MT to express the desired objective or requirement of the user? The user has always the possibility to change the prior notes of micro-trees to apply his own requirements and objectives.

Weighting factors of RBS levels (ω_l):

The weighting factors (ω_l) are defined so as to give more importance to higher levels of the RBS. Since the quality notes of the RBS's have to be compared, the values of ω_l are constant for all of the RBS's during the calculation of the quality notes of the generated RBS's, however they have different number of levels. For the RBS's with the maximum number of levels= n , ω_l is calculated by the ensuing equation:

$$\omega_l = \frac{\omega_0}{\alpha^l}, (l= 0, \dots, n) \quad \text{Equation 3-6}$$

where ω_0 is the weighting factor of level zero defined by user and the value of coefficient α is considered so that it fulfills the following constraint:

$$\sum_{l=0}^n \omega_l = 1 \quad \text{Equation 3-7}$$

As an example, considering RBS's with maximum number of levels= 7, (except the root which is considered at level zero) and $\omega_0=0.4$ (as default value) the value of α is calculated as below:

$$0.4 \cdot \sum_{l=0}^7 \frac{1}{\alpha^l} = 1 \Rightarrow \alpha=1.6463$$

and then considering Equation 3-6, the weighting factors are:

$$\omega_0=0.40, \omega_1=0.24, \omega_2=0.15, \omega_3=0.09, \omega_4=0.05, \omega_5=0.03, \omega_6=0.02, \omega_7=0.01$$

The greater the values of ω_0 , the more important are the MTs at the higher levels of RBS's. Reversely, the smaller the values of ω_0 , the more equilibrated is the contribution of different levels in global quality notes.

The user has always the possibility to change the weighting factors of RBS levels and prior notes of micro-trees to better fit his own purpose.

As an illustrative example, let us calculate the phase conveniency note (N_{phase}) of an RBS, like that illustrated in Figure β -17, which contains 5 MTs:

$$N_{phase} = [0.8 \times 0.4 + (0.6 + 0.8) \times 0.15 + (0.2 + 0.4) \times 0.09] / [1 \times 0.4 + 2 \times 0.15 + 2 \times 0.09] = 0.66$$

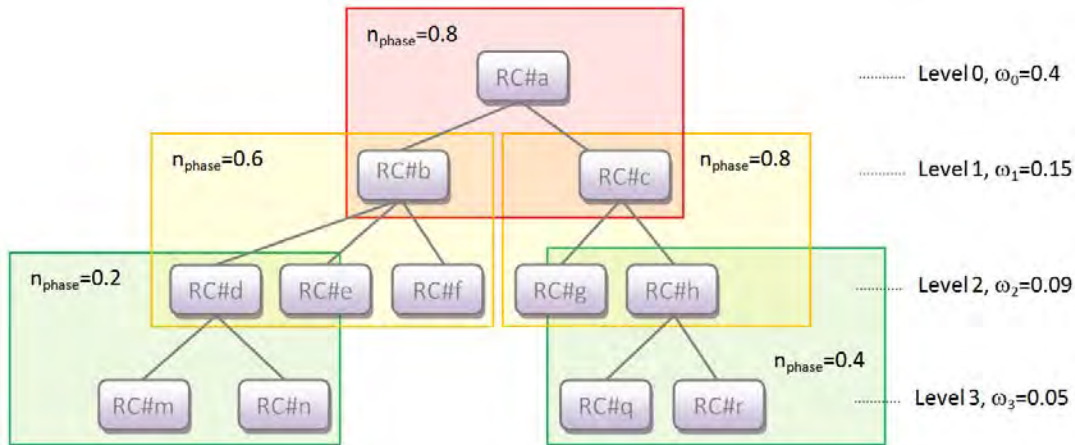


Figure β -17. Calculation of N_{phase}

3.3.5.3. Contrast of risk values within RBS

The last criterion (criterion(d)) is not an intrinsic function of the RBS but requires to know the risk values of categories in RBS. The idea is to favor RBS's having the higher contrast between risky domains and non-risky domains. Figure 3-18 demonstrates schematically the main concepts of this criterion:

- a) an RBS with higher contrast of risk values is preferred to one with less contrast.
- b) an RBS with higher contrast at the higher levels is preferred to the RBS with high contrast at the lower levels (Figure 3-18-B).

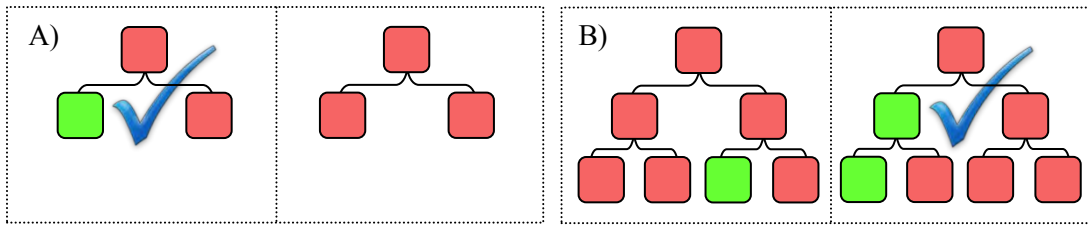


Figure 3-18. Contrast of risk values on RBS

The structural form of the RBS (how RCs are decomposed) and risk values of selected REs (and then RCs) are two effective parameters on value of global contrast note ($N_{contrast}$). The calculation process of this note is as following:

- At the bottom level, the risk values are computed for each RE, from their probability/impact. Many methods exist for valuating risks, either quantitatively or qualitatively, as example see Zhi (1995), Baccarini and Archer (2001), Aleshin (2001), Carr and Tah (2001), Eskesen et al. (2004), Zou et al. (2007), Zayed et al. (2008), Ismail et al. (2008), Nieto-Morote and Ruz-Vila (2011) and Dey (2010). It is assumed in the following that the risk value is scalar but the method developed here can be adapted to other risk measurements (e.g intervals or fuzzy values). At section 3.4, an advanced method of measurement and aggregation of risks on RBS will be described in detail which can easily be adapted to this method.
- For each RC, the value of risk is calculated by aggregation of the values from below, and this process is iteratively repeated throughout the whole RBS,
- For each MT, a contrast value ($n_{contrast (MT\#j)}$) is calculated, corresponding to the normalized standard deviation of risk values of its subcategories and is attached to the father node (see Figure 3-19).

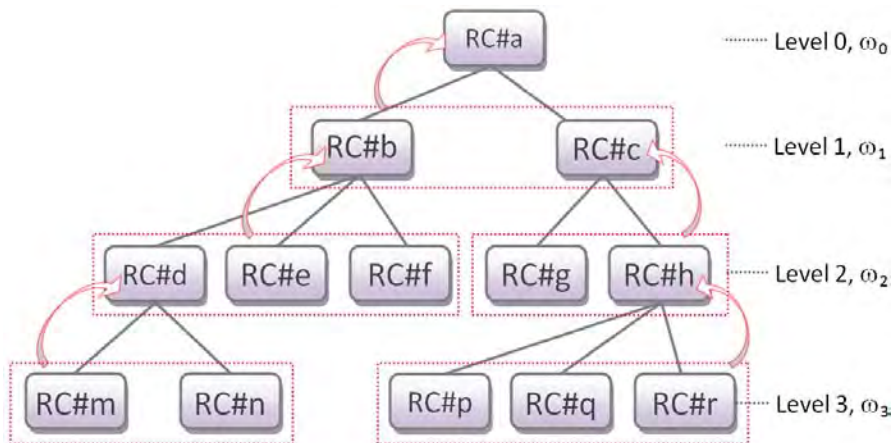


Figure 3-19. Calculation of contrast note of the RBS

$n_{contrast}$ is calculated as:

$$n_{contrast} = \frac{SD}{SD_{max}} \quad \text{Equation 3-8}$$

where SD is the standard deviation of risk values of the subcategories and SD_{max} is the maximum possible value of SD which can be calculated as below:

$$SD_{max} = \sqrt{\frac{Ns \cdot m \cdot (1-m)^2 + Ns \cdot (1-m) \cdot m^2}{Ns}} = \sqrt{m(1-m)} \quad \text{Equation 3-9}$$

where N_s is the number of subcategories of MT#j and m is the average of risk values of the subcategories. In this case, $N_s \times m$ subcategories have the maximum value (1.0) and $N_s \times (1-m)$ categories have the minimum value (zero). It is assumed that, the real case and the case with SD_{max} have the same average value (m), but that SD_{max} corresponds to a binomial distribution.

- The mean value of contrasts at level l [$M_l (n_{contrast})$] is computed between the $n_{contrast(MT\#j)}$ values for all MTs at this level.
- Then the global note is calculated:

$$N_{contrast} = \frac{\sum_{l=0}^{L-1} \omega_l \cdot M_l(n_{contrast})}{\sum_{l=0}^{L-1} \omega_l}, \quad (0 \leq l \leq L-1), \quad (0 \leq N_{contrast} \leq 1) \quad \text{Equation 3-10}$$

where L is the maximum level of the RBS, l is the level number, ω_l is the same weighting factor than in Equation (3-3, 3-4 and 3-5) and $\sum_{l=0}^n \omega_l$ is summation of weighting factors of the RBS levels which have contrast values. Weighting factors ω_l are applied to give more importance to the contrast notes of the higher levels. Since the standard deviation values were normalized, the final contrast note is also in the [0, 1] range, the same scale than for the other quality notes.

It is on the basis of the set of five notes (N_{conv} , N_{phases} , $N_{stakeholder}$, $N_{objectives}$, $N_{contrast}$) that all RBS's can be compared and the best ones selected, using a final multicriteria decision process.

3.3.6. Ranking and selection of the most convenient RBS

When for each RBS, the five quality notes (N_{conv} , N_{phases} , $N_{stakeholder}$, $N_{objectives}$, $N_{contrast}$) are calculated, then, the question is how to rank them and select the best one. In this case, decision can be taken, applying any multi-criteria method such as Analytic Hierarchy Process (Saaty 1990), ELECTRE TRI (Brito et al. 2010).

The global quality note (N_{global}) can also be calculated using a simple method being the weighted average of the five quality notes:

$$N_{global} = \frac{\Phi_1 \cdot N_{conv} + \Phi_2 \cdot N_{phases} + \Phi_3 \cdot N_{stakeholder} + \Phi_4 \cdot N_{objectives} + \Phi_5 \cdot N_{contrast}}{\Phi_1 + \Phi_2 + \Phi_3 + \Phi_4 + \Phi_5}, \quad (\sum \Phi_i = 1) \quad \text{Equation 3-11}$$

where the weighting factors (Φ_i) indicate the preferences of the user for each quality note. Therefore, the notes with a high weight contribute more to the global quality note than do the notes with a low weight. These notes (Φ_i) can be calculated by a series of judgments based on pair-wise comparisons of the five quality notes, similar to Analytical Hierarchical Method to prioritize the elements of the hierarchy.

As long as risk notes of REs are not known, $N_{contrast}$ is meaningless and N_{global} is calculated with the four quality notes and $\Phi_i=1,4$. When the global notes of the RBS's are calculated, the best one can be identified, the one with the maximum value of the global note.

3.3.7. Quality improvement of the selected RBS

At this step of the process, all the generated RBS's are homogeneous at the level of extension of branches. This constraint was applied to reduce the very large number of possible RBS's, generated by combination of different MTs.

The quality of the final selected RBS with the highest ranking can be further improved by extending of the bottom level categories with high-risk value and removing the negligible MTs regarding the level of details and criticality. The result will be a new RBS with new quality notes and is not necessarily homogeneous.

Figure 3-20 schematically illustrates the further quality improvement process of the selected RBS. It combines the reduction of a low risk MT (Blue) and the extension of a high risk category (red).

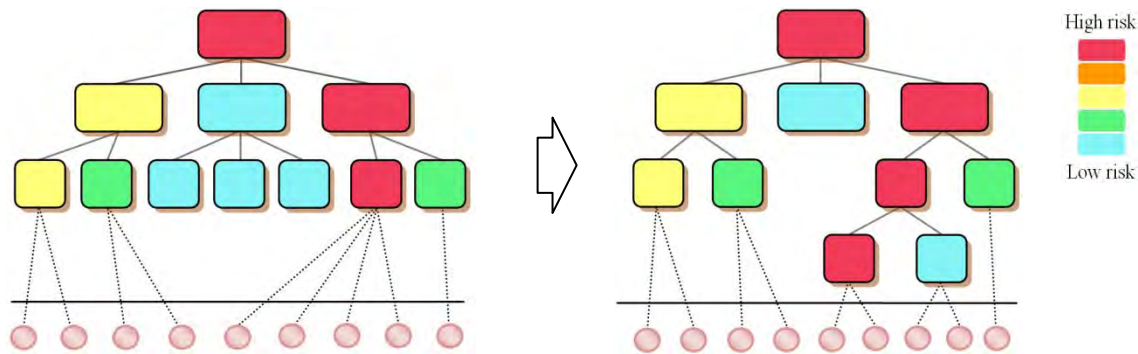


Figure 3-20. Quality improvement of the selected RBS

3.3.8. Sensitivity of the RBS quality notes to the applied values and parameters

Table 3.7 synthesizes all the required items and parameters when a new item has to be added into the database, the risk values have to be aggregated or to calculate the global quality notes of the RBS's. This table distinguishes between the parameters which have default values but can be modified by the user and the parameters which are defined directly by the user.

Table 3.7. Synthesis of the parameters applied to the methodology

Item/ Parameter		Comments	Directly defined by user	Have default value(s), but user can modify
To add a new item to database				
Risk Event	RE code	the code should be unique and valid (RE#i)	×	
	RE name	should be unique and descriptive	×	
	RE links with RCs	the consistency criteria should be controlled	×	
	RE Probability	the default value is zero		×
	RE impact factors	the default value is zero		×
Risk category	RC code	the code should be unique and valid (RC#i)	×	
	RC name	should be unique and descriptive	×	
	RC description	it can also be defined or modified later	×	
Micro Tree	MT code	the code should be unique and valid (MT#i)	×	
	MT father and subcategories	the consistency criteria has to be controlled	×	
	MT adequacy notes	14 adequacy notes in the range of (0, 1)	×	
To rank and aggregate the risks through RBS, using the developed database				
the REs to consider		the probable REs, have to be selected among the RE database	×	
the probability and impact factors of the selected REs		The default values can be modified for each particular case by experts		×
adequacy notes of MTs		the notes in the range of (0, 1)		×
A_i (desired number of attached REs to each bottom level category)		the default value is 2		×
ω_0 (the weighting factor of level zero of RBS)		the default value is 0.4 and for the other levels, Equation 1-6 is proposed		×
Φ_i (the weighting factors of the five quality notes)		by default, $\Phi_i=0.2$ ($i=1$ to 5)		×
w_i (the weighting factors of three risk values concerning the three objectives)		these weightings are used to calculate the global risk value. By default $w_i=0.33$		×
the root category of the RBS's		by default is "Project risks" category		×
the requirements of the user (project phase)		user can chose between: feasibility, design, contract, implementation, operation or all the project phases	×	
the requirements of the user (project stakeholder)		user can chose between: owner/ clients, financiers, designers, contractor/ subcontractors, suppliers, consultant or all the project stakeholders	×	
the requirements of the user (project objective)		user can chose between: time, final cost, quality or all the project objectives	×	

In the following, some the values and parameters which users are allowed to change regarding their preferences and requirements are discussed:

- *The probability and impact factors of selected risk events*

If these values are known for the selected REs, the contrast of risk values on RBS will be an effective criterion for selection of the most convenient RBS. In our database, by default, these values are defined regarding the frequency of occurrence and their impacts in the studied projects and from literature. Of course, in each new project, the user is able to change these values regarding the context and main strategies of the project.

- *The adequacy notes of micro trees (n_{phases} , $n_{stakeholder}$, $n_{objective}$)*

Each micro tree has 17 local adequacy notes which are defined in the database. The three global adequacy notes of RBS are explicit functions of these local values (Equations 3-3, 3-4, 3-5). The way these default values are selected is explained at section 3.3.5.2. Of course the user can change these values, to better apply his own requirements and objectives. He must also provide these values for all new MTs he will add to the database.

- *A_v (desired number of attached REs to each bottom level category)*

This factor is applied in Equations 3-1 and 3-2 and directly impacts the size of the RBS. By default $A_v=2$ which means the desired number of attached REs to each bottom level category is 2 but of course user can select any other values regarding the desired level of details of RBS and the number of selected REs.

A sensibility analysis was performed to evaluate the influence of changing A_v on final results (N_{conv}). This global note is independent of RE values and other requirements of the user. It depends on the total number of REs and on how they are grouped in categories in RBS. Thus, in a case, 35 REs (with the risk value = 0) were selected randomly through the catalogue of risk events in database. Generation of all possible homogeneous RBS's and calculation of N_{conv} is repeated with different values of A_v which are varied between 1 and 5. In each try, the RBS with the maximum N_{conv} was selected. The results are shown in Table 3.8 and the corresponding RBS's are represented in Figure 3-21 to Figure 3-24. Since the REs have not value, all the categories which are connected to REs have a unique color (green).

Table 3.8. Effect of A_v on level of details of the RBS's

	Max (N_{conv})	N. of levels of the corresponding RBS	Corresponding RBS
$A_v=1$	0.5897	4	Figure 3-21
$A_v=2$	0.5747	3	Figure 3-22
$A_v=3$	0.5301	2	Figure 3-23
$A_v=4$	0.5490	1	Figure 3-24
$A_v=5$	0.5454	1	Figure 3-24

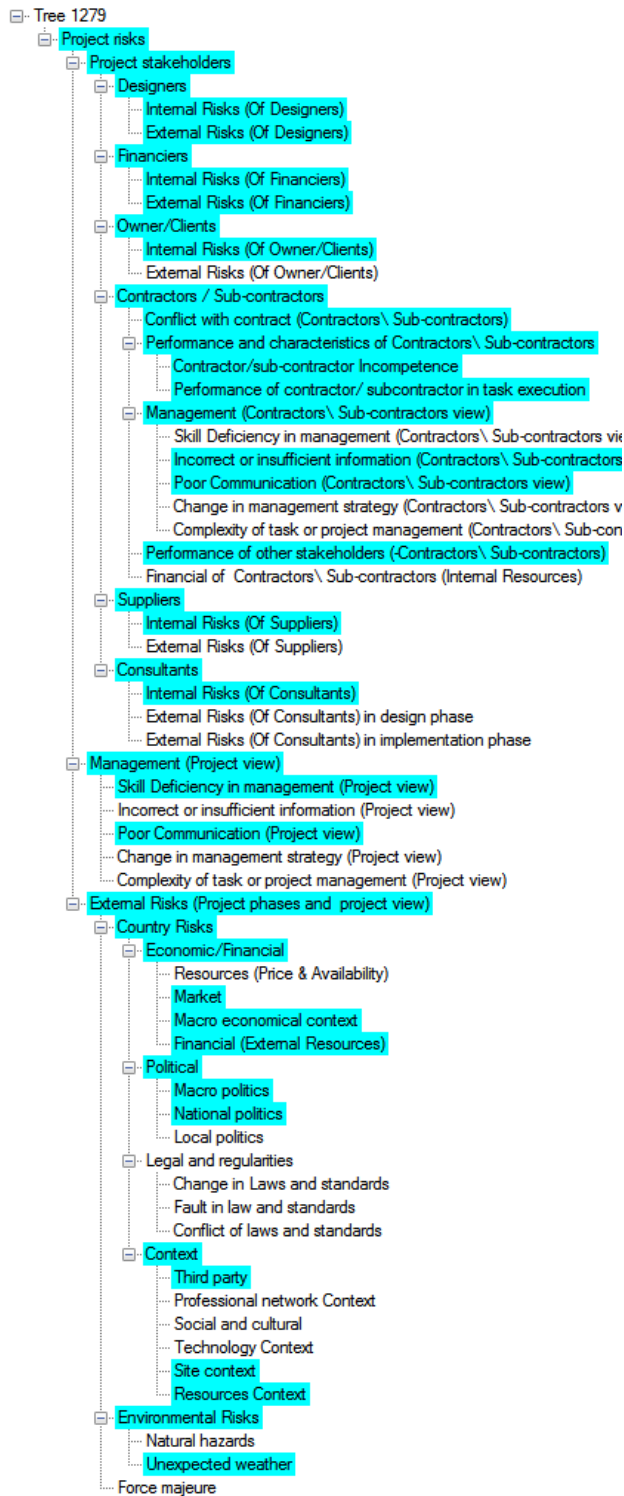


Figure 3-21. RBS with the maximum value of N_{conv} ($A_v=1$)

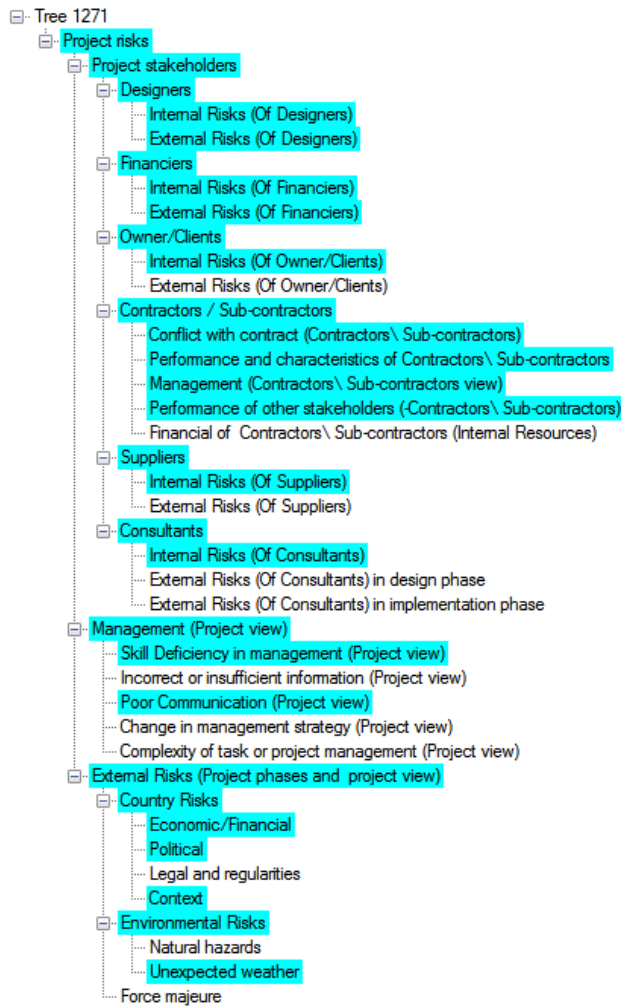


Figure 3-22. RBS with the maximum value of N_{conv} ($A_v=2$)

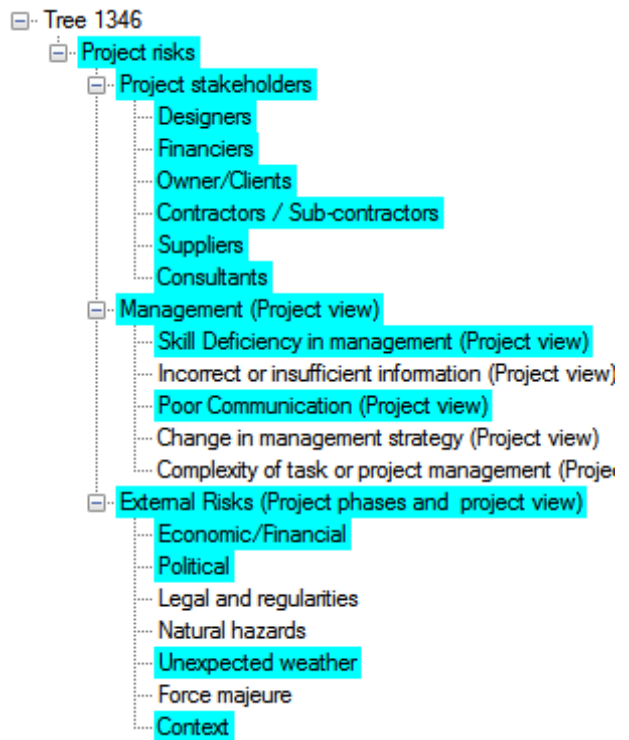


Figure 3-23. RBS with the maximum value of N_{conv}
($A_v=3$)

The results clearly prove that this criterion and the corresponding formulas can effectively apply the desired level of details. As conclusion, the higher values of A_v should be taken if less level of detail of RBS (RBS with few numbers of levels) is desired.

- ω_0 (the weighting factor of level zero of RBS)

By default $\omega_0=0.4$. The value of this factor is subjective and the user can change it to better fit his own purpose. The idea is to give more importance to the properties of MTs at the higher levels of RBS. The greater the values of ω_0 , the more important are the MTs at the higher levels of RBS. This factor is used also to define the weights of the other levels. We have proposed Equation 3-6 but of course the project manager can adopt a more convenient distribution which would be more adapted to his special requirements.

The influence of this parameter on weighting factors of the other RBS levels was studied. Table 3.9 represents the calculated weighting factors of RBS levels by Equations 3-6 and 3-7 for different values of ω_0 with 7-levels RBS.

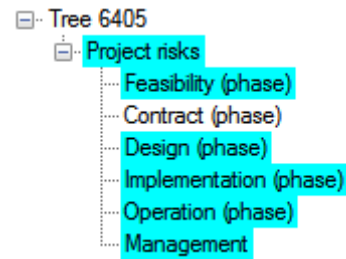


Figure 3-24. RBS with the maximum value of N_{conv}
($A_v=4, 5$)

Table 3.9. RBS levels weighting factors for different values of ω_0

ω_0	0.2	0.4	0.6	0.8
ω_1	0.17	0.24	0.23	0.16
ω_2	0.15	0.15	0.1	0.03
ω_3	0.12	0.09	0.04	0.01
ω_4	0.11	0.06	0.02	0
ω_5	0.1	0.03	0.01	0
ω_6	0.08	0.02	0	0
ω_7	0.07	0.01	0	0
Σ	1.0	1.0	1.0	1.0

These results show that:

- smaller values of ω_0 lead to more smooth distribution of weighting factors on different RBS levels,
- greater values of ω_0 lead to a sharp deviation of weighting factors to the higher levels of RBS.

3.4. Advanced method of measurement and aggregation of risks in RBS

In this section a new method for evaluation and aggregation of risk notes in RBS is explained in detail. The aim is to develop an advanced method to get more realistic results without suffering the usual weaknesses of available methods in literature to calculate the risk value of a category, as a function of values of corresponding risk events (Taillandier et al., 2011). Different steps of this method, illustrated in Figure 3-25, are explained in the following.

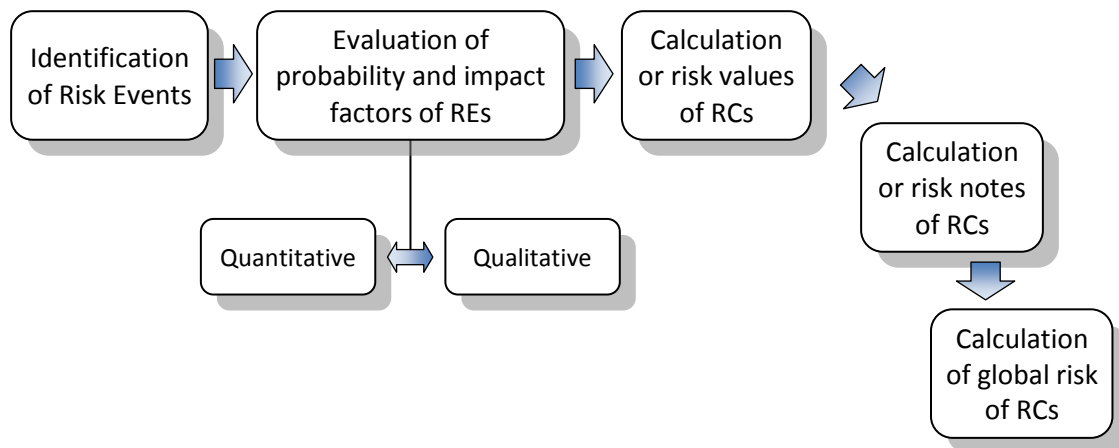


Figure 3-25. Evaluation and aggregation of risks in RBS

3.4.1. Probabilities and Impact factors of risk events

Frequently, it may be extremely difficult to assess the risk associated with a project due to the great uncertainty involved. The imprecision comes from a variety of sources such as, unquantifiable information, incomplete information or non-obtainable information (Chen and Hwang, 1992). When the members in a risk assessment group have inexact information about risks associated with a project, the assessments cannot be exact but approximate. In these circumstances, the judgments of the members in a risk assessment group are expressed by means of linguistic term instead of real numbers (Nieto-Morote and Ruz-Vila, 2011).

A deep analysis of scientific literature (covering the decade 2000–2009) by Marhavidas et al. (2011) shows that the quantitative methods present the highest relative frequency (65.63%) while the qualitative a lower one (27.68%). Furthermore, the hybrid methods (qualitative-quantitative, semi-quantitative) remain constantly at a very low level (6.70%). The reason for this is that the qualitative assessments are generically easier and less costly to complete than utilizing quantitative simulation techniques. Nevertheless, as a result of this, qualitative assessments can contain more uncertainties and potentially less accurate information than quantitative analysis methods (Patterson and Neailey, 2002).

In both quantitative and qualitative methods, risks are generally assessed according to two fundamental characteristics (IEC, 2001): how likely the uncertainty is to occur (probability), and what the effect would be if it happened (impact) (Hillson and Hulett, 2004). In our method, we resume this principle, considering the impacts on three main objectives of most construction projects (Chan, 1997): cost, time and project performance. The word “performance” is general and can cover a variety of items: technical performance of the works, safety of workers during construction, impact to environment and etc. Thus, we consider four characteristics for assessment of each risk event:

- Probability of occurrence,
- Impact on the final cost of the project,
- Impact on the schedule of the project,
- Impact on the quality and performance of the project.

For the assessment, we use both quantitative and qualitative approaches, using two concomitant scales: a continuous cardinal scale for some characteristic (€, days...) or by discrete notes in the range of [1, 5]. The note 5 indicates the situation with the greatest risk. Only the impact on performance cannot be expressed by a continuous scale and will be inevitably assessed by discrete scale. Indeed, performance is composed of numerous components and cannot be easily expressed by physical value.

These two scales have their own advantages. Continuous scale is closer to physical reality. It has more a concrete meaning and is more accurate. Discrete scale has a strong symbolic value: it allows, via a color system, a fast and intuitive vision of the situation. It is easier to reach consensus and more appropriate when the risks cannot be quantified accurately. Applying these two approaches together, allows the user to choose the best method for risk assessment, based on the available information and level of required accuracy. Thus, special attention should be given to control the consistency and compatibility of these two scales. In the following, to distinguish the assessment by these two scales, we will use two different words: “*evaluation*” for assessment by continuous scale and “*score*” for assessment by discrete scale.

In order to define the equivalence between *evaluation* and *score*, we propose to build a qualification grid expressing score bounds. Table 3.10 provides an example of qualification grid. It should be noted that the values and ranges in this table are only indicative and can be changed regarding the type, scale and main strategies of each project (to see some other examples, refer to Tah and Carr, 2001; Baccarini and Archer, 2001; Ismail et al., 2008; Vose, 2008). Furthermore, as is illustrated in this table, there is no continuous scale for evaluation of impact on performance and it can be evaluated only by discrete notes. Since this grid has a significant impact on final results, it is indispensable to spend time and conduct a real concerted action for its construction.

Table 3.10. Risk Qualification grid of risk events

Note	Probability		Impact				
	Class	Range	Cost (K€)		Delay (day)		Performance
			Class	Range	Class	Range		Class
		0		0		0	
1	Very low (Rare)		Very low (very mild)		Very low (very mild)		Very low (very mild)
		1/100		1		5	
2	Low (unlikely)		Low (mild)		Low (mild)		Low (mild)
		1/30		10		10	
3	Medium (possible)		Medium (average)		Medium (average)		Medium (average)
		1/5		100		40	
4	High (likely)		High (strong)		High (strong)		High (strong)
		1/2		1000		100	
5	Very high (almost certain)		Very high (very strong)		Very high (very strong)		Very high (very strong)
		1		10000		500	

Assessment of risk probability and impacts with specific percentage or decimal values introduce spurious apparent precision where reality is less certain, and fixed ranges are artificial and do not usually reflect the real range of probability for a given risk (Hillson and Hulett, 2004). Thus, in this method, assessment can be done via a *score* or an *evaluation*; score is less accurate and reflects the imprecision of the data; but for data with quantifiable and moderate uncertainty, we propose to use an *evaluation* and indicating the uncertainty. The uncertainty reflects the imprecision of the evaluated values. The uncertainty can be expressed by the Margin of Variation (M_V %) considering the predicted value and expressing the confidence of prediction of the average value. As an example, the evaluated value of 20 k€ with $M_V = 10\%$ indicates the value can be varied between 18 k€ and 22 k€ (mean value=20, standard deviation=0.1×20). Table 3.11 represents an illustrative example of evaluation of 5 selected risk events.

Table 3.11. Evaluation of probability impact factors of selected risk events

RE Code	Probability of happening			Impact							
	Average	Margin of Variation	or	Performance							
				Average	Margin of Variation	or	Note				
1	0.1	20%				1	35	30%			4
2	0.01			8	15%		25	15%			1
3			2	15	20%		45	25%			1
4	0.05	10%				2				2	1
5	0.35	25%				4	10	10%			2

3.4.2. Consideration of uncertainty

Most of the assessors have an aversion to uncertainty. That means they prefer a certain situation, even with more loss, to an equivalent situation but with uncertainty. To consider the uncertainty of evaluated values, the average values are modified using the following equation:

$$X = \alpha \cdot X_m \cdot (1+U) + (1-\alpha) \cdot X_m \cdot (1-U) \quad \text{Equation } \beta\text{-12}$$

Where X is the desired variable (probability or impact factor), X_m is the average value of variable X , U is the uncertainty value (Variation Margin, $0 < U < 1$) and α is the uncertainty aversion factor. The greater is the value of α , the more are penalized the uncertain values (usually $\alpha > 0.5$). As example the modified probability of RE#1 is calculated as below (assuming $\alpha=0.7$):

$$P_{RE\#1} = 0.7 \times 0.1 (1+0.2) + (1-0.7) \times 0.1 (1-0.2) = 0.108$$

3.4.3. Conversion of values to notes

The modified values of probability and impact factors can be easily transformed to notes using risk qualification grid (Table β .10). This conversion of continues values to discrete notes of risks, makes the assessment more comprehensible. As an example:

Modified probability of RE#1 = 0.054

In Table β .10: $1/30 < 0.108 < 1/5 \rightarrow \text{Note } (P_{RE\#1}) = 3$

3.4.4. Conversion of notes to values

Since the final aggregation of risk values on RBS to calculate the risk values of RCs is based on the RE values (not the RE scores), the RE scores should be convertible to values. The values can be converted easily to notes just by comparing with the boundary values and finding the corresponding notes in Table β .10. To calculate the corresponding value of each note, the following equation is used:

$$V_N = \alpha \cdot S_{R(N)} + (1-\alpha) \cdot I_{R(N)} \quad \text{Equation } \beta\text{-13}$$

where V_N is the corresponding value of note N , $I_{R(N)}$ is the lower bound corresponding to note N , $S_{R(N)}$ is the higher bound corresponding to note N and α is the uncertainty aversion factor. As example, the corresponding value of $N=2$ of probability is calculated as below (assuming $\alpha=0.7$):

$$V_{N=2(\text{probability})} = 0.7 \times 1/30 + (1-0.7) \times 1/100 = 0.0263$$

Table β .12 represents the corresponding values of notes of probability and impact factors.

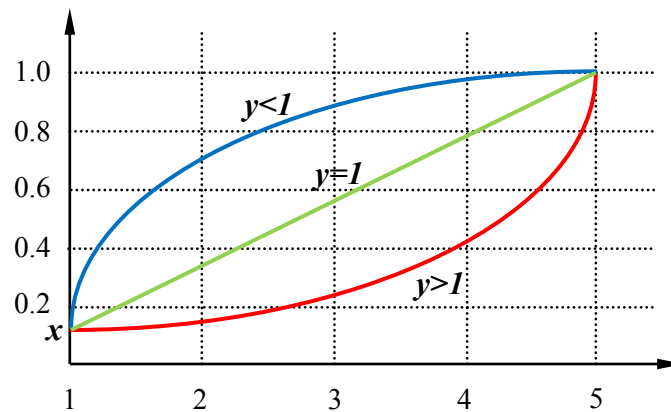
Table 3.12. Corresponding values of notes

Note	Value			
	Probability	Cost (K€)	Delay (day)	Performance
1	0.007	0.7	3.5	0.0010
2	0.02633	7.3	8.5	0.0049
3	0.15	73	31	0.0634
4	0.41	730	82	0.3171
5	0.85	7300	380	1.0000

As it was shown in Table 3.10, the evaluation of impact on performance of the project is just by the discrete notes. To convert these notes to continuous values, a continuous scale, varying between 0 and 1 was constructed. This conversion is based on the following function:

$$V_N = x + (1 - x) \cdot \left(\frac{N-1}{4}\right)^y \quad \text{Equation } \beta-14$$

Where V_N is the corresponding value of note N , x is the value for $N=1$ and y provides the concavity of the curve. The parameters x and y are defined to ensure the correspondence between the equation and the perception of the decision maker on performance impact. If $y=1$ then the curve is linear (Figure 3-26). In most cases, the curve is convex ($y>1$), reflecting risk aversion: a strong performance impact ($N=4$) would be considered more serious than four RE with very few impact ($N=1$). As an example, considering $x=0.001$ and $y=4$, the notes are calculated as represented in Figure 3-27.

Figure 3-26. Performance curve with different values of y

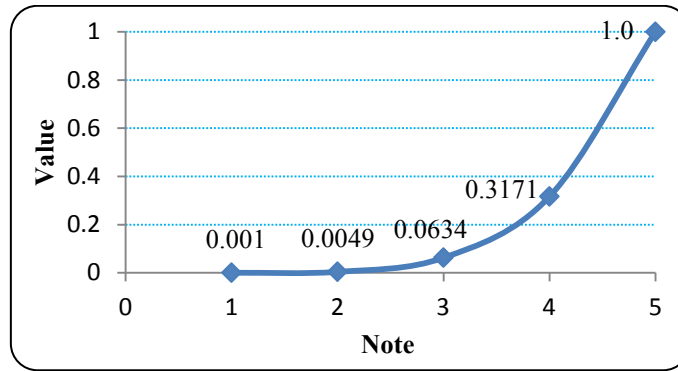


Figure 3-27. Conversion of performance impact notes to corresponding values

Now to calculate the boundary values (inferior and superior ranges) corresponding to each note of performance impact, the same function is used as was applied for calculation of the corresponding value of each note (Equation 3-13):

$$V_N = \alpha \cdot S_{R(N)} + (1-\alpha) \cdot I_{R(N)} \rightarrow S_{R(N)} = (V_N - (1-\alpha) \cdot I_{R(N)}) / \alpha$$

By default, the inferior range of $N=1$ is 0 and the other ranges are calculated as represented in Table 3.13.

Table 3.13. Risk Qualification grid

Note	Impact							
	Probability		Cost (K€)		Delay (day)		Performance	
	Class	Range	Class	Range	Class	Range	Class	Range
		0		0		0		0.00
1	Very low (Rare)		Very low (very mild)		Very low (very mild)		Very low (very mild)	
		1/100		1		5		0.0014
2	Low (unlikely)		Low (mild)		Low (mild)		Low (mild)	
		1/30		10		10		0.0057
3	Medium (possible)		Medium (average)		Medium (average)		Medium (average)	
		1/5		100		40		0.0778
4	High (likely)		High (strong)		High (strong)		High (strong)	
		1/2		1000		100		0.3768
5	Very high (almost certain)		Very high (very strong)		Very high (very strong)		Very high (very strong)	
		1		10000		500		1.1557

Thus, all the notes and values of probability and impact factors are reversely convertible. The primary values, defined by the user in Table 3.11, were converted and the final results are shown in Table 3.14.

Table 3.14. Modified values considering uncertainties and corresponding notes

RE Code	Impact							
	Probability		Cost (K€)		Delay (day)		Performance	
	Modified probability	Note	Modified impact	Note	Modified impact	Note	Impact value	Note
1	0.108	3	0.7	1	39.2	3	0.3171	4
2	0.01	1	8.48	2	26.5	3	0.0010	1
3	0.026	2	16.2	3	49.5	4	0.0010	1
4	0.052	3	7.3	2	8.5	2	0.0010	1
5	0.385	4	730	4	10.4	3	0.0049	2

3.4.5. Calculation of risk values of risk events

The risk values of REs are calculated, using the modified values (continuous scale) of probability and impact factors, using the simple classic function:

$$\text{Risk} = \text{Probability} \times \text{Impact}$$

So for each RE, three values of risks are calculated by multiplication of probability and impact factors on cost, time and performance of the project. These values, in another step, can be transformed to risk scores. Following the last example (Table 3.14), the risk values are represented in Table 3.15.

3.4.6. Risk notes

The calculated risk values of risk events can easily be transformed to discrete notes of 1 to 5 (the note 5 is the most risky one). Therefore, the range of values corresponding to each note has to be defined. They can be obtained easily by multiplication of the ranges of probability and impact factors (see Table 3.17). For each RE, the risk value is compared with the risk bounds (Table 3.17) to find the corresponding note.

Table 3.15. The Risk values

RE Code	Risk (Cost, K€)	Risk (Delay, day)	Risk (Performance)
1	0.0756	4.2336	0.03425
2	0.0848	0.2650	0.00001
3	0.4266	1.3035	0.00003
4	0.3796	0.4420	0.00005
5	281.0500	4.0040	0.00189

Table 3.16. Risk notes of REs

RE Code	Risk (Cost, K€)	Risk (Delay, day)	Risk (Performance)
1	2	3	4
2	2	2	1
3	3	3	2
4	3	3	2
5	4	3	3

Table 3.17. Risk grid

Risk Note	Risk cost (K€)	Risk Delay (day)	Risk Performance
1	0.0000	0.0000	0.00000
2	0.0100	0.0500	0.00001
3	0.3333	0.3333	0.00019
4	20.0000	8.0000	0.01557
5	500.0000	50.0000	0.18845
	10000.0000	500.0000	1.15578

3.4.7. Aggregation of risk values on RBS

The risk value of each RC within RBS, is the simple summation of risk values of attached REs. As example, for the RBS represented in Figure 3-28, the risk value of RC#k is summation of risk values of RE#1, 2 and 3 and for RC#f is the summation of the values of all REs.

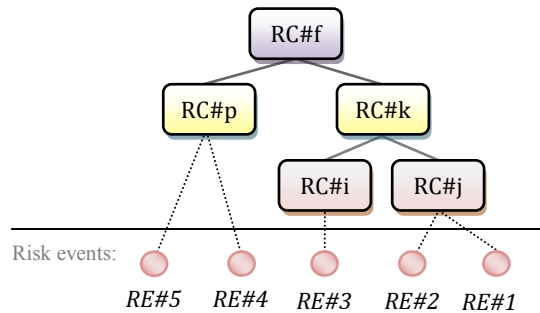


Figure 3-28. Aggregation of risk values within RBS

Regarding the risk values of RC#k in Table 3.15:

$$R_{\text{cost (RC\#k)}} = 0.0756 + 0.0848 + 0.4266 = 0.5870 \text{ (K€)}$$

$$R_{\text{delay (RC\#k)}} = 4.2336 + 0.2650 + 1.3035 = 5.8021 \text{ (day)}$$

$$R_{\text{performance (RC\#k)}} = 0.03425 + 0.00001 + 0.00003 = 0.03430$$

thus, for each RC, three values of risks are calculated. To better understand the levels of calculated risks, these values can be transformed to risk notes using the risk grid table represented in Table 3.17. As example, the risk notes of RC#k are:

$$0.3333 < R_{\text{cost (RC\#k)}} = 0.5870 \text{ (K€)} < 20.0 \rightarrow \text{Note 3}$$

$R_{\text{delay (RC\#k)}} = 5.8021 \text{ (day)} \rightarrow \text{Note 3}$

$R_{\text{performance (RC\#k)}} = 0.0343 \rightarrow \text{Note 4}$

3.4.8. The global risk of each category

Any multi-criteria decision making method (AHP, ELECTRE TRI, etc.) can be used to transfer the three risk notes of each RC or RE (notes of 1 to 5), corresponding to three project objectives, to a global risk note with the same ordinal scale (Figure β -29). It should be noted that for this aggregation process, the notes of risks which have the same ordinal scale have to be used, not the risk values which have different scales for different objectives.

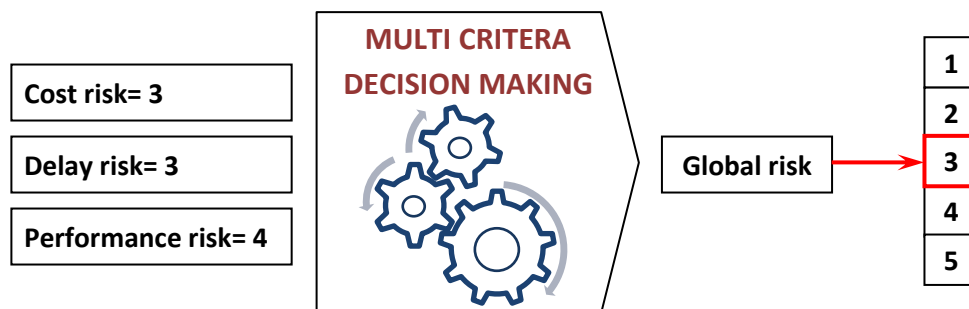


Figure β -29. Calculation of global risk note

3.4.9. Consideration of risk interactions in risk analysis

In construction projects, like in other complex systems, the risks and their properties cannot be fully understood and efficiently managed unless integrating them all with their interactions. Each partner of the project has his own risks and difficulties, whose poor management, not only threatens the objectives of the partner but can have negative effects on performance of other stakeholders or on external environment of the project. It can cause to have some new risk items which can be possibly allocated to the other partners. This kind of interactions of risks not only can be seen between different partners but also exists between different phases of the project.

In available methods and techniques, project interdependent risks are indeed often managed as if they were independent (Marle et al., 2010). Actually, whatever the criteria used for the decomposition of an initial risk list, and whatever the rigor and detail level used, there will always be interactions between risks which do not belong to the same cluster (Marle, 2002), at least because the project is a dynamic process and risk event appearing at a given stage can have effects at a later stage in other domains of the RBS.

One main criticism against RBS is that they have difficulties in accounting for (existing) interaction between risks, because of their hierarchical structure. Our choice is to modify the values of risk events regarding their interactions before aggregation through the RBS branches. This kind of interaction between project risks can be explained by a cause-effect relation, where a first risk event, when it happens, influences the occurrence, severity or criticality of another risk event in project. It can be described as a vector, which has a specific direction and a value, which indicates the strength of this influence and is somewhat subjective.

As an example, if “Poor preliminary site and ground investigation during feasibility phase”, “Defective design due to poor or insufficient geotechnical investigation” and “Occurrence of construction accidents and collapses during the implementation phase” are three probable REs of a project, occurrence of the first one can effectively increase the probability of the two other ones. It is noted that the first RE is related to the feasibility phase and owner of the project, the second one can happen during the design phase and is allocated to designers and the last one is corresponding to contractors and implementation phase of the project. Figure β-30 is an example of existing interactions between risk events (given in Table β.18). This Figure illustrates the corresponding phase and stakeholder of each RE and the possible interaction vectors.

Regarding Figure 3-30, RE#160 has interaction with RE#235 which means occurrence of the first one during feasibility phase can increase the probability of RE#235. Furthermore, implementing any effective response action to decrease the probability and the consequences of RE#160 can also affect the occurrence of the other one. Consideration of these interactions in risk analysis requires a dynamic process of risk assessment and analysis and the values have to be modified iteratively. Even if it makes the project and project management more complex, it can lead to more realistic results. An example, given in chapter 4 will help to clarify this dynamic process and will show how interactions can be accounted for to improve the results of risk analysis process. For each new project, these interactions and their impact vectors are defined by the project/ stakeholders' experts and are applied during the dynamic risk analysis of the project.

Accounting for risk interactions in project risk analysis is not of the main objectives of this thesis. However in the following, it will not be further detailed, it can be the subject of future works.

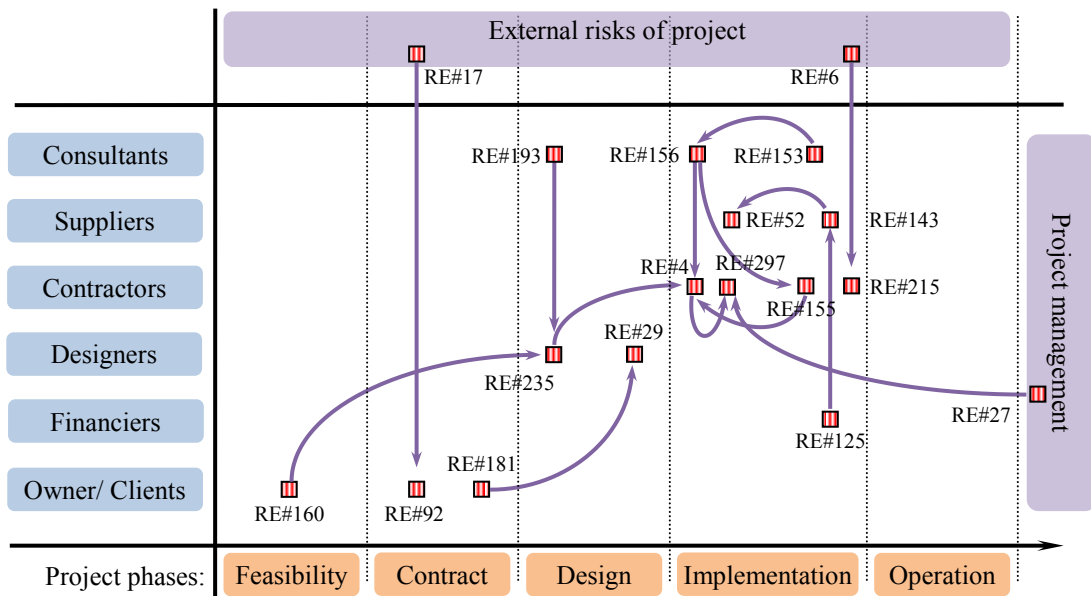


Figure 3-30. Risk interactions between different risk events

Table 3.18. List of the risk events illustrated in Figure 3-30

RE Code	Risk Event
RE#4	Occurrence of construction accidents and collapses during the implementation phase
RE#6	Unwanted so cold weather during construction phase
RE#17	Improper intervention of government during contract phase
RE#27	Poor communication between stakeholders of the project to manage the project schedule
RE#29	Conflict with contract (Designers)
RE#52	Poor performance of supplier(s) during implementation
RE#92	Delay in contract issue by owner of the project
RE#125	Poor performance of financier during implementation phase
RE#143	Delay payment to suppliers during project implementation phase
RE#153	Consultant has not adequate number of staff during implementation phase
RE#155	Technical mistakes during construction stage by contractor
RE#156	Irregular or inadequacy of site inspection by consultant during implementation phase
RE#160	Poor preliminary site and ground investigation during feasibility phase
RE#181	Allocation of risks to the parties is not mentioned or is not clear in the contract
RE#193	No proper design review and checking by consultant
RE#215	Excavation and spoil-removal equipments of contractor are not adapted for cold operation
RE#235	Defective design due to poor or insufficient geotechnical investigation
RE#297	Project schedule is not respected by contractor

3.5. Summary and conclusions

We have explained the reasons and the methodology for developing a more formal and synthetic approach for building Risk Breakdown Structures for a better management of risks in construction projects. This work consisted in identifying relevant risk categories and hierarchical relations between these categories such as to identify and define elementary micro-trees. A comprehensive knowledge base has been constructed to ensure consistency between all basic information, and to facilitate any further development and updating. It contains three interactive components: risk events, risk categories and micro trees, which have been developed based on a thorough analysis of literature. This knowledge base is general enough to cover all construction projects and specific enough to be adapted to a given particular project. However, following the proposed procedure and criteria, the user is able to build his own original database if he wants so.

In parallel, efforts have been devoted to the automatic rebuilding of RBS that must be scalable, adaptable to the project development and allow multi-views from each of the stakeholders. This 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's are compared with regard to a set of five notes, enabling one to have, at the same time, different "best RBS's" for different project partners and making communication between partners easier. The first note, N_{conv} , evaluates the adequacy of RBS regarding the level of detail (number of RBS levels). The higher is N_{conv} , the more equilibrated is the number of attached REs in bottom level categories. Furthermore, to evaluate the ability of each RBS to fully show the main requirements of the user (the target phase, stakeholder and objectives), three notes of n_{phases} , $n_{stakeholder}$, $n_{objective}$ are calculated which are in the range of (0, 1), as is the case for the other notes. $N_{contrast}$, the last quality note, is calculated for each RBS to evaluate the contrast of risk values on RBS branches. The idea is to favor RBS's having the higher contrast between risky domains and non-risky domains. Finally, it is on the basis of these five notes that all RBS's can be compared and the best ones selected, using a final multicriteria decision process.

The quality of the final selected RBS with the highest ranking can be further improved by extending the bottom level categories with high-risk value and removing the negligible MTs regarding the level of details and criticality. The result will be a new RBS with new quality notes.

To aggregate the risk values through the RBS branches, an innovated method was explained in detail. The aim was to develop a more coherent approach to get more realistic results without suffering the usual weaknesses of available methods in literature to calculate the risk value of categories in RBS. The method combines consistently the quantitative and qualitative approaches, allowing the user to choose the best one for risk assessment at any level, based on the available information and required accuracy.

Since PRM deals with both project threats and opportunities, this methodology can be used to identify and analysis of opportunities as well. However, evaluation of contrast of values on RBS needs further study in such a case.

Chapter 4

APPLICATION AND CASE STUDIES

4. Application and case studies

4.1. Development of a software based on the proposed method

As it was discussed in Chapter 3, development of the consistent database of risk events, risk categories and micro trees is an interactive process which requires careful attention to details and consistency control of data. By the increase of information in such a nested database with complex links and interfaces and factorial growth of possible RBS's, it was necessary to develop few automatic procedures such as to check the consistency of the database, generate and rank all the possible homogeneous RBS's and to aggregate the risk values on RBS.

Thus, a software has been developed for an easy application of the proposed methodology in real projects. This software integrates all the concepts and algorithms with a user friendly interface. It can be used in an advanced level, by risk management experts and project managers. However, anybody who has the basic information of project risk management can use this software easily.

The software was developed by C# (an object-oriented programming language developed by Microsoft) and the database, using Microsoft SQL Server Express. Figure 4-1 illustrates the main structure and Figure 4-2 the main window (risk category database) of the software.

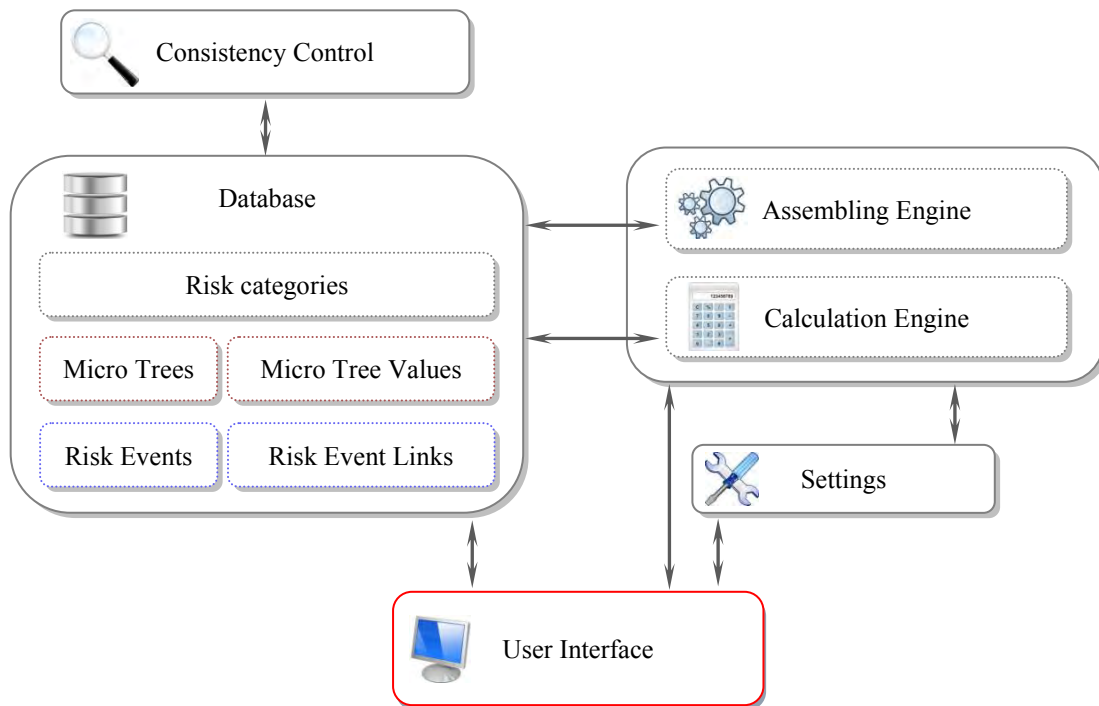


Figure 4-1. Software structure

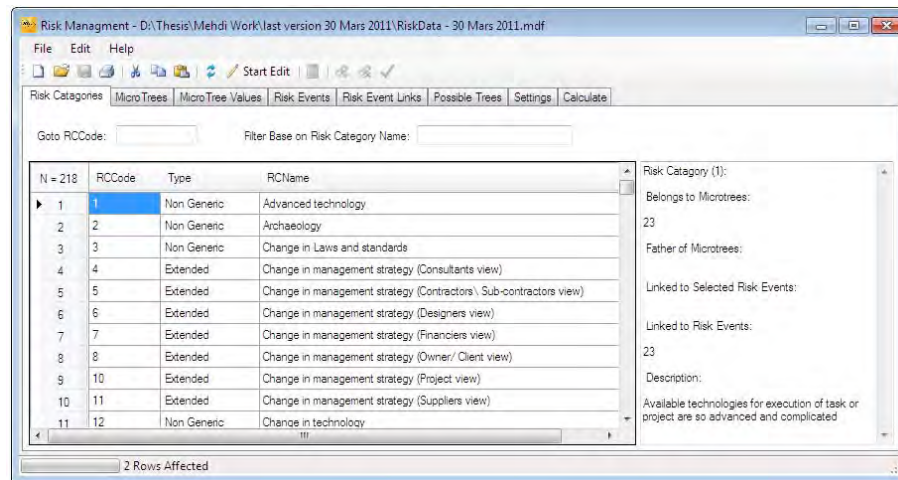


Figure 4-2. Software main page (RC database)

As is demonstrated in Figure 4-2, the program has 8 main tabs which can be classified into 4 main groups. The first group includes the database of Risk Categories (RC), Micro Trees (MT), the values of micro trees, Risk Events (RE) and the links of REs with RCs. The second part represents the results of the assembling process which generates all possible homogenous trees. The next part is *Settings*, where user can define the required parameters and values. The last part is the calculation tab which represents the results of the calculation process.

Each user can build his own database of risk events, risk categories and micro trees and the software controls the consistency of data at each step. It is impossible to make a change in database which could cause an inconsistent situation. Furthermore, user can use the database of other managers. They can share the information of their own databases.

The risk values of selected risk events (selected by user) are aggregated through the branches of trees to highlight the most risky parts of the project. If a category, at the end of a branch is risky or if user is interested to find more details about the category, it can be easily decomposed again to a lower level. In this case, all the information, distribution of risk events, risk values and the quality ranking of the decomposition system will be recalculated automatically. Figure 4-3 illustrates a part of the micro tree database and Figure 4-4, the calculation tab, the graphical representation of one of the RBS's and manual decomposition of a risk category.

Comprehensive introduction of this software is presented in appendix 3. Different parts of the software are introduced in detail and it is explained how to manage the information in database, how to control the consistency of data, how to solve the errors and how to interpret the results of generation and ranking of RBS's. Furthermore, some applicable examples are presented at the end of Appendix 3 to show how can use this software in practice.

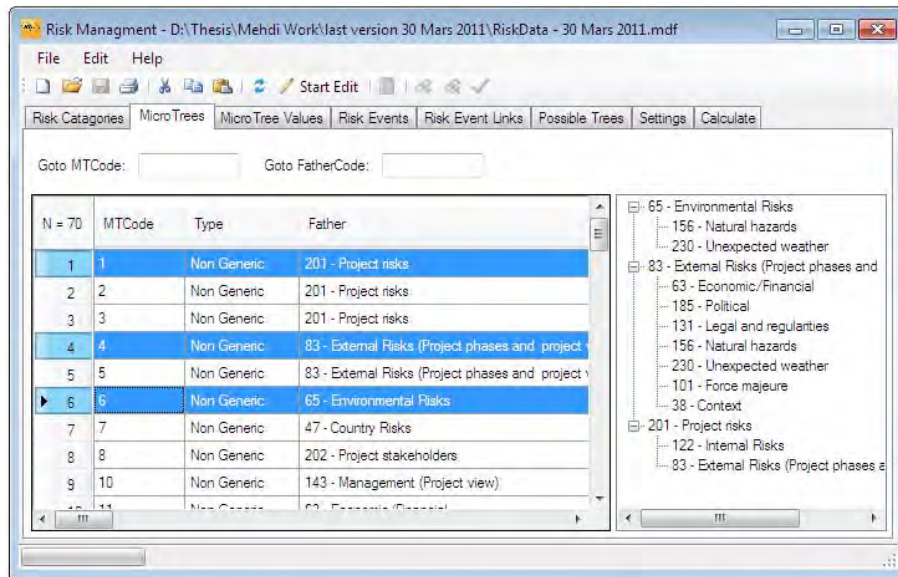


Figure 4-3. Micro trees database

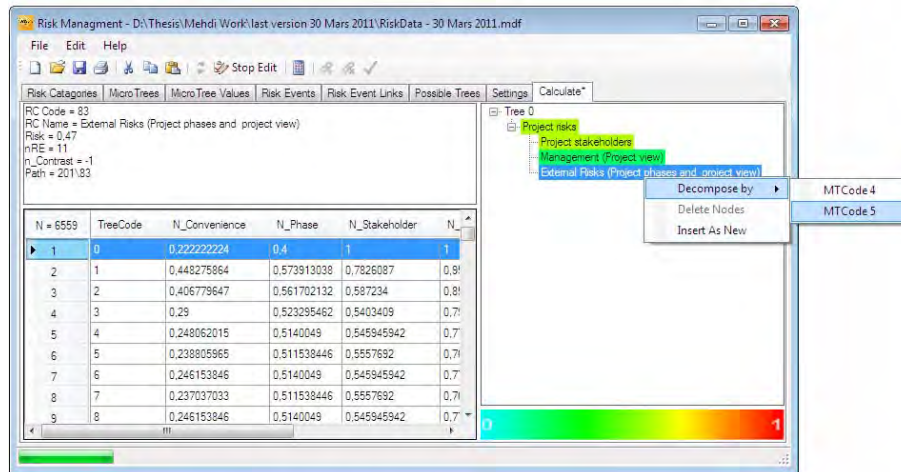


Figure 4-4. Calculation tab, the results and manual decomposition of a RC

4.2. Case study presentation

In this section, our purpose is to show how the proposed method can be applied in a real project. It will be shown how this method can be useful in identification and analysis of the project risks and how different perspectives of the project partners can be considered in this process. Furthermore, it will be discussed how the project risk management is dynamic and how risk interactions can be considered to get more realistic results.

To have a detailed and comprehensive explanation of all mentioned concepts, a complex construction project had to be selected involving several stakeholders and successive phases and tasks which are faced with many potential risks and difficulties. The choice was the extension project of line B of Lyon metro; a complex project to extend the public transport network of Lyon. It includes crossing the Rhone River in a difficult geotechnical context, construction of a new station and connection to the available stations on both sides of the river. This project was selected because of its complexity, large size and variety of applied technologies, methods and structure types. Furthermore, this project encountered serious geotechnical challenges, including the construction of a 1.3km tunnel (300 meters being underneath the Rhone river), cut and cover trenches, diaphragm walls and excavation of shafts in urban area using blasting method. Thus, this project appeared to be a convenient case to show the abilities and efficiency of our methodology for a more advanced and systematic project risk management.

It should be noted that we have not been involved directly in this project and we have just used the available project information to show the efficiency of our methodology. The identified risk events and assessments are not extracted from the official project dossier, but are reasonable estimations based on the available project data. This project is only an illustrative support and the values, analysis and the results are not validated. In the following, to prevent any confusion, the available project information is distinguished, using a *different font and text format*, from our opinions, reflections and hypothesis

4.2.1. Project presentation

4.2.1.1. Project phases and schedule

The project comprises a 1.8 km extension of Line B of Lyon Metro from Gerland station to Oullins in the south of the Lyon city center. The extension crosses the Rhône River and includes a new station. 1.3 km tunnel was excavated by TBM, including 300 meters below the Rhone. Figure 4-5 and 4-6 represent the satellite and section view of the project, respectively. In the following, general information about the project, participating stakeholders and project schedule is represented. This information is referred to the official website of SYTRAL association, the organizing authority of public transportation in Lyon area (Sytral, 2011).

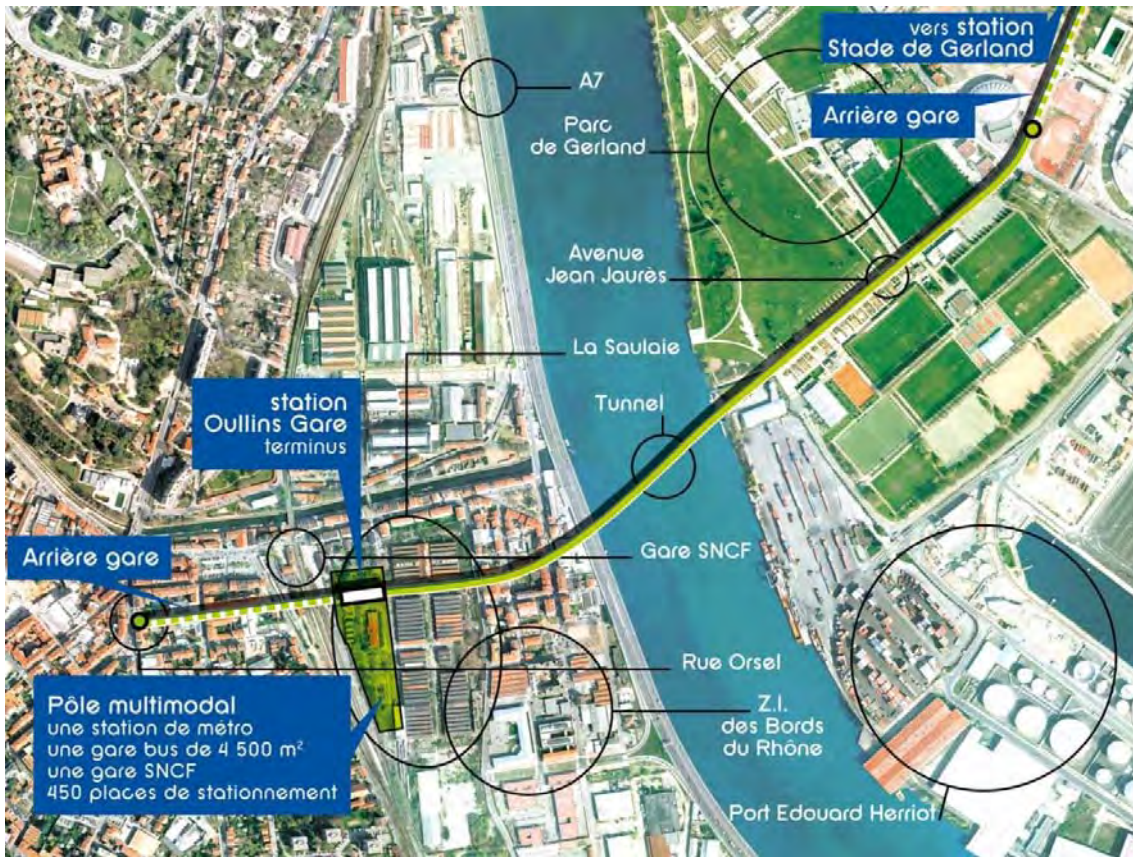


Figure 4-5. Satellite view of the project

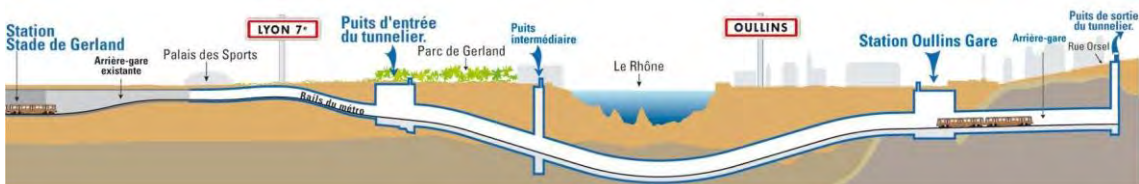








Figure 4-6. Section view of the project

General information of the project:

- *Distance:* 1.8 km (300 m below the Rhône) and 1.4 km tunnel
- *An additional station:* Oullins Gare
- 2 new park and ride TCL offering about 450 parking spaces
- *Travel time Oullins Station to Part-Dieu:* less than 15 minutes
- *Project cost:* 222 million euros
 - 160 M€ for construction works
 - 62 M€ for equipment, autopilot etc ...
- *Commissioning:* end 2013

Project stakeholders:

The first step in an efficient project risk management is the precise study and analysis of project documents, identification of stakeholders, their role in the project, different phases and corresponding tasks. Referred to the project documents, published by SYTRAL (the owner of the project) and other available information on the Web, the involved stakeholders of this project are:

-  SYTRAL, *the client:* the organizing authority of public transportation in Lyon area. As such, SYTRAL defines, finances and carries out the development projects of the public transport network of Lyon (TCL), including the extension of line B.
-  Egis Rail, *the prime contractor:* designed the project and provides technical and financial monitoring of the project.
-  KEOLIS Lyon, *the AMO operator:* Assists the client on aspects related to the proper operation and maintenance of future metro, working closely with the main contractor.
-  APAVE, *the Office of Technical Inspection:* ensures the robustness of the structures and technical compatibility of tunnel excavation with the existing buildings.
-  CERTIFER: verifies and validates the operation safely of the extended line B.
- NOVICAP and ESPACE ÉTUDE , *the SPS Coordinators (Safety Protection of Health).* They control respecting of the security rules and health of the stakeholders in the site.
-  The consortium of civil engineering. Chantiers Modernes Rhone-Alpes, a subsidiary of Vinci leads the grouping of nine companies selected by SYTRAL to execute the project.

These stakeholders and their interfaces are schematically illustrated in Figure 4-7. The project starts with the preliminary studies of SYTRAL during the feasibility phase which then continues with the contract, design and execution phases of the project. The operation phase is scheduled for December 2013. The following section will focus more on the project schedule, extracting and introducing the corresponding tasks of the main phases of the project.

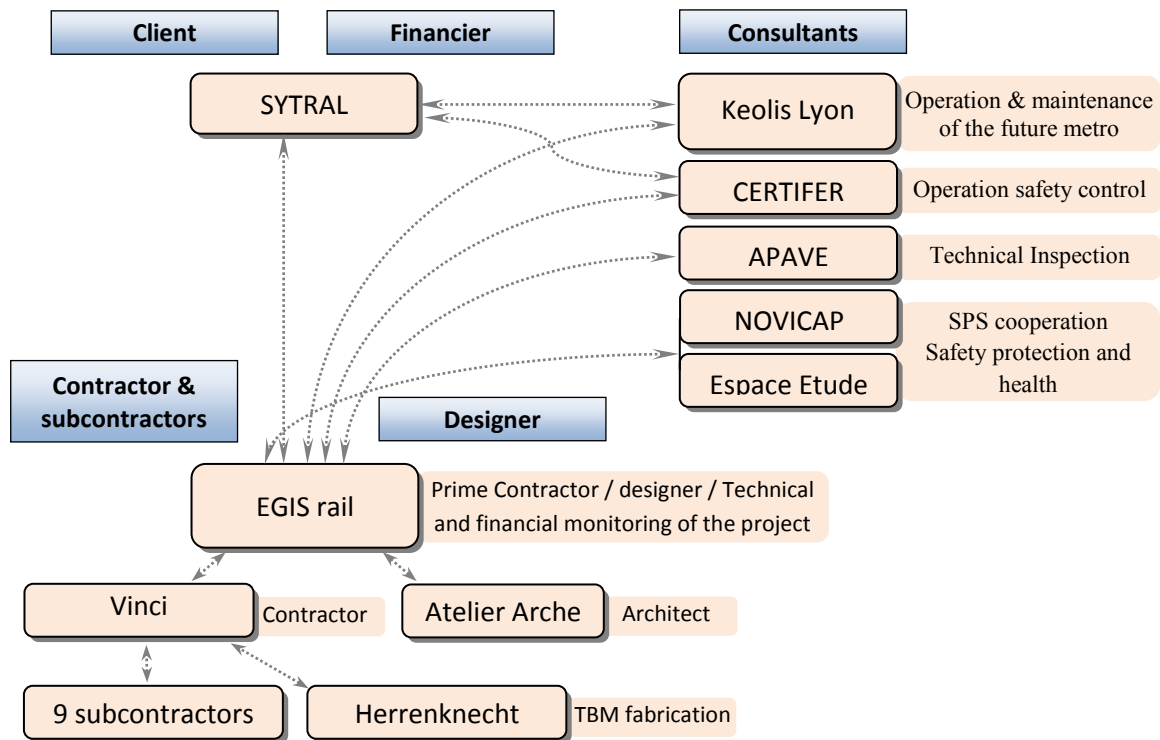


Figure 4-7. Project Stakeholders (extension project of line B of Lyon metro)

Project schedule

September 2006 -- January / February 2008

- SYTRAL conducted studies for the subway extension of line B in Oullins in September 2006 and initiated the prior consultation of the project in February 2007 before launching a public inquiry in January / February 2008.

December 2008 -- July 2009: Start of the preparatory works (diversion of water systems, gas and electricity) ...

Summer 2009 -- summer 2010

- Execution of the cut and cover trench between the Palais des sports and Gerland Park.
- Excavation of the TBM entrance shaft in the Gerland park.
- Fabrication and assembly of TBM in the Gerland park.
- Digging of the intermediate shaft in Saulaie (future metro station "Oullins Gare")
- Excavation of the TBM exit shaft in the Orsel Street.
- Descent of the TBM in the entrance shaft in Gerland.

Autumn 2010

- Start of the tunnel digging under the Rhône river.
- Construction of new metro station "Oullins Gare".

Year 2011

- Arrival of the TBM to Oullins Gare, 2 March, 2011.
- Maintenance of the TBM, 3 to 18 Mars.

- Restarting the TBM to dig the last 300 meters, 21 March.
- Exit of the TBM from the Orsel shaft, the end of 2011.

Mid-2012 -- Late 2013

- Installation of the equipment in the metro tunnel (ventilation, railways ...).
- Construction of the Oullins Gare station.
- Testing trial run of tram

End 2013: Projected commissioning of metro.

4.2.1.2. Main technical issues at Gerland Sector

The entry shaft of TBM and cut and cover trench

The back of the Gerland train station and the new tunnel are connected as is shown in Figure 4-8 by a 300 meters cut and cover trench. In 2013, the metro B will pass under Gerland Park before crossing the Rhone and reach the Oullins station.

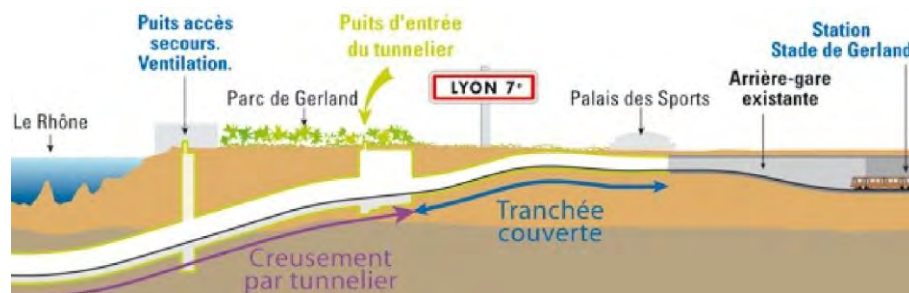


Figure 4-8. Section view of Gerland Sector

The key steps in Gerland sector

• Year 2009: Start of civil works and construction of covered trench. On June 2009, workers started to dig a covered trench about 300 meters from the rear of the train terminus to the Gerland park where the tunnel entrance shaft is placed. Also the entrance shaft of the TBM was excavated. Figure 4-9 illustrates the sequential process of the trench execution.

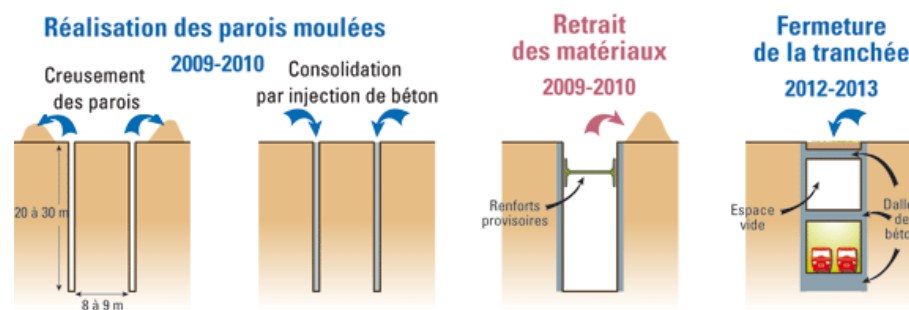


Figure 4-9. Construction of covered trench

- *Early 2010:* Workers completed the construction of diaphragm walls of the shaft. The upper slab of the shaft was sunk and earthworks can remove the land between the diaphragm walls of the shaft. Also, construction of the intermediate shaft was started. This second shaft will be used to ventilate and exhaust smoke (in the case of incident) of line B (see Figure 4-8).

- *May 2010:* The TBM arrived at Gerland, by special transport from the Herrenknecht company in Germany, in separate pieces.

- *June 2010:* The TBM was assembled in the entrance shaft. On the surface, the slurry treatment station was being assembled.

- *September 27, 2010:* The TBM began the excavation of the gallery.

- *April 2011:* The wall separating the rear of the existing terminal and cut and cover trench was demolished.

- *May-June 2011:* On the surface, with the redevelopment of Jean Jaures Avenue and the sports hall, the parking and around of the site were returned to users of sports facilities and residents.

4.2.1.3. Main technical issues at Oullins - Saulaie Sector

Oullins Gare station

It is here that in 2013 will place the new metro station (Oullins Gare). It will be part of a multimodal pole (bus station, train station and two TCL park), see Figure 4-10. This railway station is a 80 meters long hole with 20 meters depth, realized by the diaphragm wall technique.

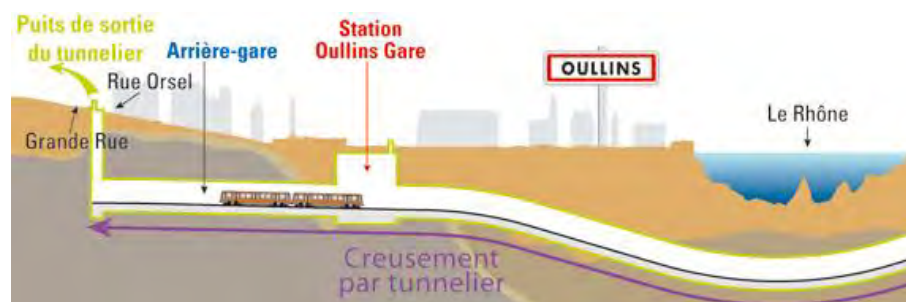


Figure 4-10. Oullins- Saulaie Sector

The framework of the station and the cover slab was completed but to build the platforms, they had to wait for the complete evacuation of the TBM. Work was continuing in the station and on the surface (2011).

The key stages of construction at the Saulaie

- *Fall 2009 -- January 2011:* Excavation and earthworks of the shaft of the station with 20 meters depth, 80 meters long and 25 meters width.

- *First quarter 2011:* The diaphragm walls of the station were raised. Drilling and installation of the rock bolts to reinforce the walls. The slab of the mezzanine was executed before molding of the coverage slab.

- *March 2, 2011:* The tunnel boring machine arrived to the Gare Oullins station. The works continued with the construction of access and the mezzanine.

- *May- June 2011*: The cover slab was executed. The TBM utilities, after excavation of the rest of tunnel to get the exit shaft in Orsel, were evacuated from the future station (Oullins Gare). The TBM elements were stored in containers and were sent to Germany to the manufacturing company of the TBM.

4.2.1.4. Main technical issues at Oullins - Orsel Sector

300 meters after the Oullins Gare station, a shaft with 30m depth was excavated, see Figure 4-10. It was used to evacuate the TBM at the end of digging. The shaft will then be used for ventilation and emergency access to the metro gallery.

Special excavation techniques of the shaft

To dig the exit shaft of TBM, 18 meters in diameter and 30 meters depth, two methods were followed according to the type of encountered soil:

- Up to 8 meters depth: the digging was done with shovels in the ground made up of soft alluvium.
- From 8 meters depth to 30m: the soil consists of granite; the digging was done by blasting, from late June to November 2010.

Key steps in the Orsel sector

- *July -- December 2009*: "solidity" diagnosis of all the buildings in the vicinity of the future metro line conducted by Apave (technical office).

- *December 2009 -- Summer 2011*: SYTRAL made a referred preventive campaign: it was a valuation of buildings in a radius of 80 meters around the exit shaft of TBM (December 2009-March 2010) and within a 25 meters on both sides of the future tunnel (from fall 2010 to 1th September 2011).

- *January 2010*: Preparation of the site.
- *February -- November 2010*: The digging of the TBM exit shaft, 18 meters diameter and 30 m depth.
- *April 23, 2011*: The tunnel boring machine arrived in the exit shaft.
- *May-June 2011*: The TBM (the cutter head and the shield) is dismantled and evacuated by the exit shaft.
- *Year 2012*: Installation of equipments in the output shaft for safety and maintenance of the tunnel in operation: creation of access firefighters, equipment rooms, smoke control system, etc.

More information about this section:

- 18 m in diameter, 30 m depth
- 2030 m³ soft soil extracted over the first 8 meters by Lutetian method.
- 125 blasting performed to dissociate the very hard granite rock.
- 4800 m³ of earth and rock excavated with explosives
- 18 sensors positioned around the shaft
- 20 people on site for digging

Focus on blasting in Oullins Orsel shaft

After five months of work, the blasting was completed in late November. The digging went well. The shaft reached a depth of 30 meters. SYTRAL and the companies took all the needed precautions to secure the excavation:

- control of the buildings near to the shaft,
- installation of 18 sensors around the shaft to monitor in real time the impact of each blasting,
- warning procedure (alarm). An audible warning procedure was set up for each blasting,
- observation of feedbacks and information of residents and public.

Preventive tests

SYTRAL conducted a series of blasting tests (low load explosion) in April 2010 to measure the impact of an explosion on surrounding buildings through the sensors placed on buildings and inside of some apartments. These tests helped to refine the modalities of implementation of the blasting that held until November. The measured vibrations showed that they have no consequence for stability of the buildings. However, the vibration sensors remained in place to control all the explosions.

A closed and secured construction site

Special precautions have been taken by SYTRAL regarding the compliance with the vibration threshold and the noise impact of the explosions. The bottom of the shaft was covered to reduce noise, avoid projections and reduce dust. Furthermore, no explosives and detonators were stored in site. They were transported to the site before each shot.

As part of an interim precautionary measure, SYTRAL asked the Administrative Court to appoint a judiciary expert to ensure the proper operation. His mission was to visit all the homes and shops within a radius of 80 meters around the Orsel square to ensure that the explosions are safe.

4.2.1.5. Tunnel boring machine (TBM)

To pass under the Rhone and join Oullins, SYTRAL chose to use a monotube slurry TBM (Figure 4-11). The TBM measures 9.50 m in diameter, 70 m long (shield with cutter head + following train) and total weight of 1300 t. Its mission was to dig a tunnel in a complex geology and link Gerland to Oullins in few months.



Figure 4-11. Tunnel Boring Machine

On 23 April 2011, the TBM was arrived in exit shaft (Figure 4-12 and 13). In just seven months, and two months ahead of General schedule of the site, 1.3 km which 300 meters is under the Rhone River was excavated. The TBM was being dismantled and evacuated before being sent back to Germany.



Figure 4-12. TBM arrival to the exit shaft

Dismantling and evacuation

Before leaving the site in beginning of summer 2011, the TBM teams involved in dismantling of machine and to implementation of the concrete slab. The cutter head and the shield were extracted via the exit shaft and the train of 60 meters long was returned to the future Oullins Gare station. Since the exit shaft was located in the urban area, the limited area of site did not allow storage of dismantled pieces of TBM. This is why the dismantling was done progressively. 18 exceptional conveyes were used during 8 nights.



Figure 4-13. TBM arrival to the exit shaft

Operation schedule of the TBM and the other project tasks are summarized in Figure 4-14. This type of representation can help to better understanding of the project tasks and their planning.

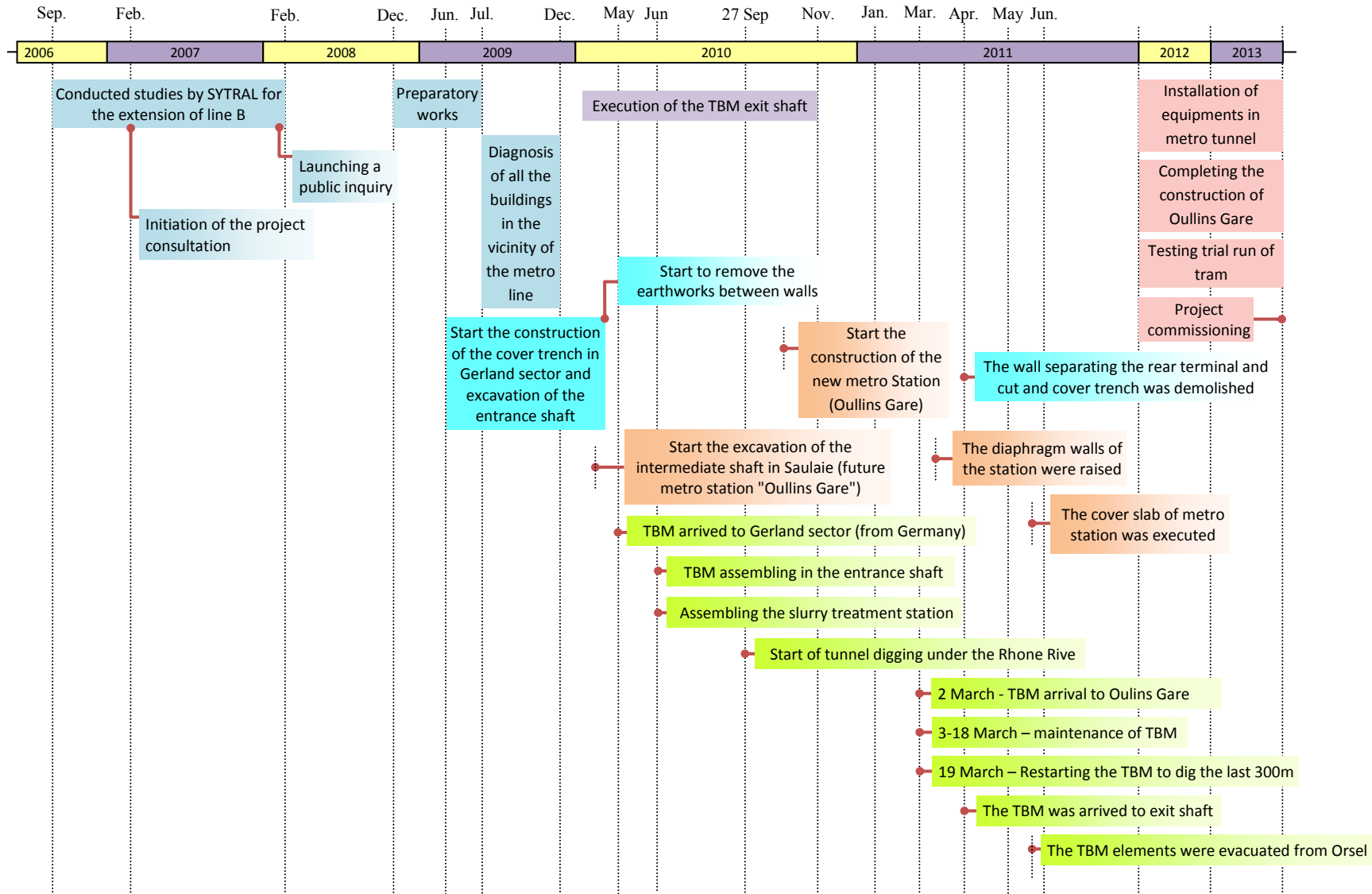


Figure 4-14. Project schedule

4.3. Lyon metro case study: dynamic risk management

It seems that construction of 1.3 km tunnel, including 300m below the Rhone river in a very complex geotechnical context is the most important part of the project which is faced with variety of risks and difficulties. In this section, we aim to focus on Lyon metro project risks regarding different perspectives of stakeholders, and their evaluation during the whole life time of the project. The main idea is to show how the risk assessment process is dynamic.

Figure 4-15 provides a schematic framework of the discussed issues in the following parts of this chapter, indicating their corresponding sections.

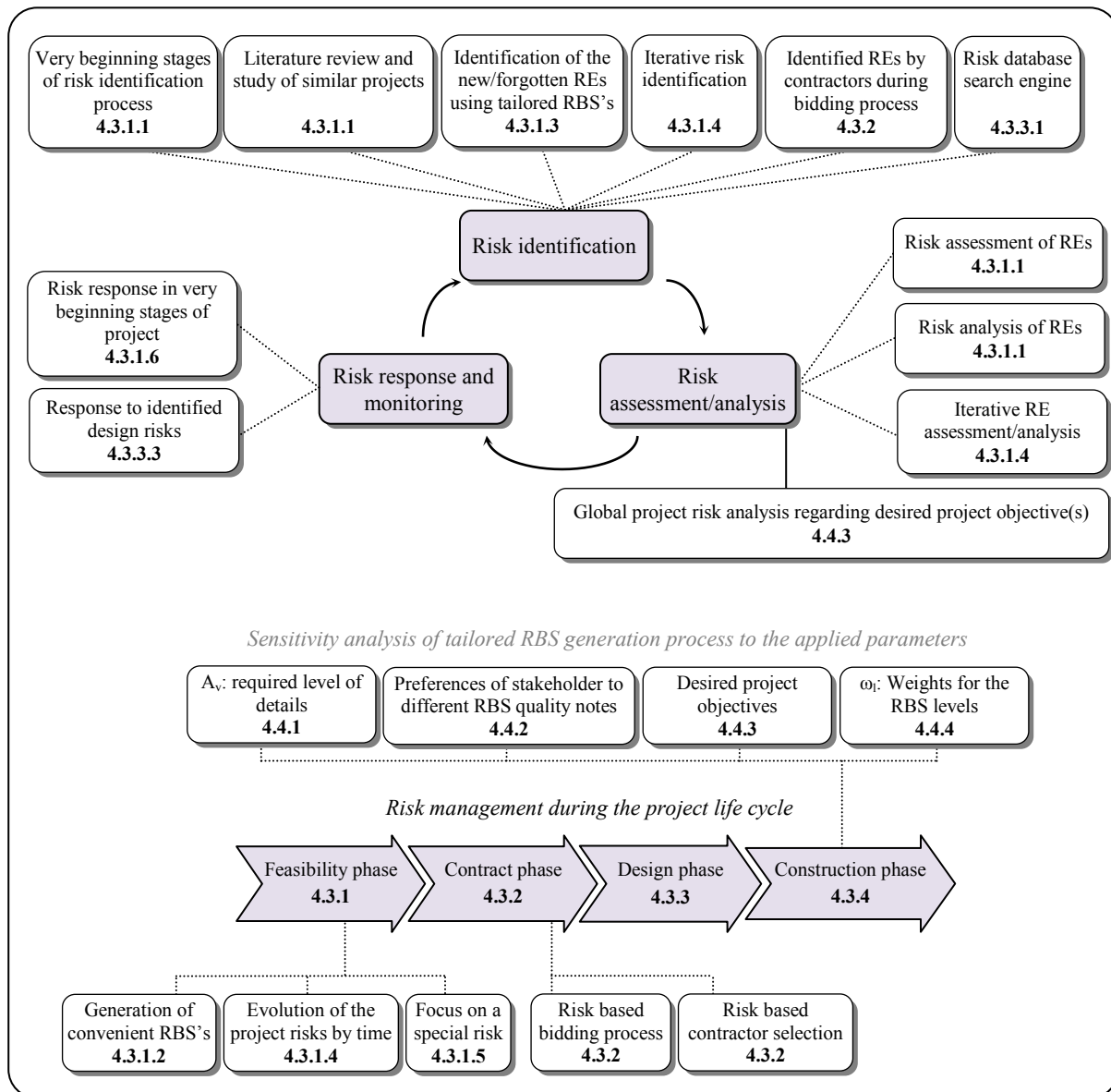


Figure 4-15. Schematic framework of the discussed issues in the following sections

To have a preliminary view on project risks and development of the initial list of probable risk events, literature review and study of construction accidents, similar projects and their difficulties can be very helpful. It has been the subject of many researches and an increasing number of studies can be found which report project failures or unfavorable project outcomes.

In order to facilitate learning from risk events, companies may construct a corporate risk memory in which the risk information is stored as well as lessons learned about effectiveness of response strategies and factors that affect the risk consequences. For instance, in 2000, HSE (Health and Safety Executive) published the investigation reports of collapse of the Heathrow Express tunnels (1994) in the United Kingdom. In 2001, Vlasov published a book (Vlasov, 2001) regarding accidents in transportation and subway tunnels, during construction and operation. The book contains data on several accidents in Russia and around the world occurring during construction and operation. In 2006, HSE issued a research report entitled "the risk to third parties from bored tunneling in soft ground" that contains a list of NATM events and a list of non-NATM Emergency events during construction and operation. Stallman (2005) analyzed a collection of 33 cases of failures during construction with details on the geological and hydrological conditions of the accident, the causes, consequences and type of collapse. SeidenfuB (2006) compiled 110 cases of problems that occurred during construction and operation, categorizing them, describing their causes and mechanisms. Sousa (2010) in her PhD thesis established a database containing 204 cases of tunnel construction accidents. The data were analyzed and the main causes and consequences of the accidents were classified.

In addition to these above listed reports and thesis, 71 incidents have been reported in 65 tunnels constructed in Japan between 1978 and 1991 at unspecified locations. These ground collapses ranged from the "quite small" through volumes of between 50 - 500 m³ of ground (15 incidents) to volumes of over 1000 m³ of ground (3 incidents) (Inokuma, 1994).

Table 4.1 represents a number of tunneling accidents, indicating the source and type of failures and applied remedial actions. It was based on the analysis of such accidents that a database of risk events of tunneling projects was developed. This database which is presented in Appendix 1 (Table 5.2) includes a variety of risk event types corresponding to different phases and stakeholders of tunneling projects. It will be used in the following steps for preliminary risk identification of the Lyon project.

Table 4.1. Some example of tunneling accidents (MEDGEO, 2009)

No.	Risk Event	Failure	Project Info.	Remedial measures
1	<ul style="list-style-type: none"> • Under-design of the strut-waler connection of the strutting system • Incorrect use of Finite Element Method • No proper design reviews • Disregard of different warnings (e.x., excessive wall deflections and surging inclinometer readings) • Poor construction quality • Ineffective instrumentation and monitoring system • Failure to implement risk management 	<ul style="list-style-type: none"> • Cracking and groaning noises heard • Collapse plan area was 100m by 130m • Settlement up to 15m • Diaphragm walls displaced • Steel struts mangled 	Singapore MRT, 20 April 2004	<ul style="list-style-type: none"> • Rescue and backfilling • All contracts to carry out checks and review of design and construction of temporary works • All professional engineers to confirm in writing the adequacy of their designs • All designs to be independently checked by the building & construction authority
2	A “hidden” vertical fault located 1m behind the sprayed concrete lining (NATM tunneling)	30m wide and 32m deep crater formed	Barcelona Metro, Spain, 27 Jan. 2005	The void was backfilled with grout of about 2000m ³
3	<ul style="list-style-type: none"> • Possible “rock slippage” • Ground investigation did not identify dyke at the tunnel intersection • Under designed rock bolts due to increased effective span at intersection of adit and tunnel 	<ul style="list-style-type: none"> • Collapse occurred during breakout for a ventilation tunnel from the running tunnel • A 10m by 10m, 25m deep crater formed in the ground 	Lane Cove Tunnel, 2 Australia Nov. 2005	<ul style="list-style-type: none"> • The void was backfilled with 1400m³ of concrete • Continual monitoring
4	<ul style="list-style-type: none"> • Failed to account for the geology of the site; fractured rock located over the excavation • The lack of sufficient supports in the roof and side walls of the excavation 	<ul style="list-style-type: none"> • Collapse of the station tunnel and partial damage to the access shaft • The rate of settlement at the tunnel crown increased rapidly and reached 15mm to 20mm two to three days before the failure 	Sao Paulo Metro, Brazil Jan. 2007	<ul style="list-style-type: none"> • Stabilized the section of tunnel with extensive reinforcement • A system of anchors extending 32m into the soil was put in place • and the excavation through the section was performed after pre-grouting
5	<ul style="list-style-type: none"> • Insufficient ground investigation • Unexpected groundwater inflow • Thin weathered rock cover and then inflow of soil and groundwater • No tunnel face stability analysis • No consideration of blasting effects closed to weathered zone with shallow cover 	<ul style="list-style-type: none"> • After blasting : daylight collapse up to ground surface, involving the embankment of a river • 20m x 15m and 4m deep crater at the ground surface • Inflow of soil and groundwater 	Seoul Metro Line 5 - Phase 2, 17 Nov. 1991, South Korea	<ul style="list-style-type: none"> • Backfilling the crater with soil followed by cement grouting and chemical grouting
6	Fluctuation of groundwater level caused by tidal effects resulting in vertical movement of the tunnel tube causing opening of joints (earth pressure balance TBM)	<ul style="list-style-type: none"> • Water and sand ingress • Tunnel subsided by 1.2m causing serious subsidence at surface 	Sewage Tunnel, Hull, 1999, UK	<ul style="list-style-type: none"> • Ground freezing • Reconstruction of tunnel using sprayed concrete

7	Groundwater flowed into the tunnel (Construction of a cross passage between two tunnel boring machine tunnels)	Collapse of the cross passage tunnel	Guangzhou Metro Line 5, China, 17 Jan. 08	Crater backfilled with concrete
8	Sudden air pressure loss through the interface between CDG/HDG and overlying marine sand during a compressed air intervention, resulting in loss of face support and subsequent formation of sinkhole (slurry TBM)	2m × 3m sinkhole reaching the ground surface	Salisbury Road, 3 June 2007, Hong Kong	Backfilling of sinkhole with granular fill
9	<ul style="list-style-type: none"> The tunnel intersected a hidden area of soft clay 	Fine soil flowed into the tunnel forming a hole in the road as the TBM went through the rock into the soft ground	Moda Collector Tunnel, Istanbul Sewerage Scheme, Turkey, 1986	
10	<ul style="list-style-type: none"> Insufficient overburden above the tunnel (earth pressure balance TBM) High pressure within tunnel causing blow out failure 	<ul style="list-style-type: none"> 2m wide and 7m deep crater formed in the grounds of George Green School, Windows up to 100m away broken by the shower of mud and stones released 	Docklands Light Rail, 23 Feb. 1998. UK	
11	<ul style="list-style-type: none"> The vibration from the TBM (Boring at a depth of 21m) may have caused the nearby wells (30m deep and 1.8m diameter) to collapse 	<ul style="list-style-type: none"> 10m diameter and 20m deep void formed in the ground behind a row of houses 	Channel Tunnel Rail Link, Feb. 2003, UK	The voids were backfilled with grout
12	<ul style="list-style-type: none"> Gap existed between the ground treatment above the station tunnel and that above the running tunnel allowing the soil to flow into the tunnel 	<ul style="list-style-type: none"> A wall section of the running tunnel under Nathan Road collapsed The subsidence did not affect the road surface 	MTR Modified Initial System, Prince Edward Station, Nathan Road, 12 Sept. 1977, Hong Kong	
13	<ul style="list-style-type: none"> Raveling of the ground seems to be due to insufficient strength in the intensely weathered and highly tectonized zones of Athenian schist Large muck openings of the TBM cutterhead which cannot adequately control muck-flow 	<ul style="list-style-type: none"> Roof collapses of appreciable size often occurred Large and occasionally uncontrollable overbreaks for TBM 	Athens Metro Greece 1991/1998	Cavities caused by the TBM overbreaks was backfilled by grout (which sometimes reached the ground surface)
14	<ul style="list-style-type: none"> Methane gas from a methane bearing fissure entered the tunnel during excavation 	<ul style="list-style-type: none"> Methane gas ignited by a blast (Fire) 	<ul style="list-style-type: none"> Orange-fish Tunnel, 1970, South Africa 	
15	<ul style="list-style-type: none"> Massive water seepage from a reservoir 	deep crater at the road surface	<ul style="list-style-type: none"> Kaohsiung Dec. 2005, Taiwan 	<ul style="list-style-type: none"> The crater was backfilled The damaged sections of the KRT tunnels needed to be reconstructed

4.3.1. Project risk management in feasibility phase

4.3.1.1. Primary risk identification and assessment

In September 2006, SYTRAL, the organizing authority of public transportation in Lyon area, started the preliminary studies of extension of line B, to connect Gerland station to Oullins Gare in the south of Lyon city center. Figure 4-16 represents the project schedule in the initial phase of the project, before launching a public inquiry in January/February 2008.

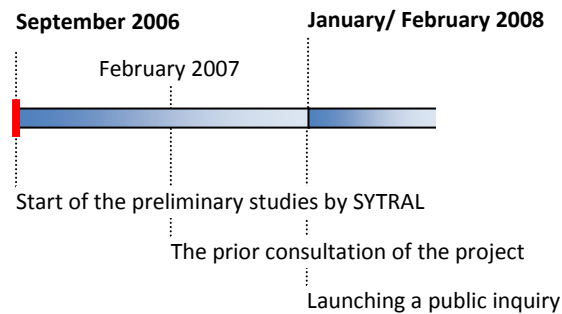


Figure 4-16. Project schedule during the feasibility phase

Performance of SYTRAL in this phase of the project has an important effect on final project success since evaluation of different tunneling methodologies, the preliminary evaluation of possible forms of contract and all the other preliminary studies have to be conducted in this phase. Integrity and accuracy of these studies is the essential basis for taking correct and reliable decisions in the following project stages. It is the phase at which the greatest degree of uncertainty about the future is encountered.

In response to such a situation, an effective Risk Management Process (RMP) can play an important role in controlling the level of risks, mitigating their effects and taking more reliable decisions. This dynamic process includes iterative risk management planning, identification, assessment and analysis of the potential project risks (considering risk interactions), risk response planning and monitoring. For each identified risk, the project experts identify the best strategy, and then design specific actions to implement that strategy, deciding whether to avoid, transfer, mitigate or accept the risk. Risk monitoring and control keeps track of the identified risks, monitors residual risks, and new risks. It also ensures the execution of risk response plans, and evaluates their effectiveness, and continues for the life of the project (WSDOT, 2010).

Risk identification should be performed as early as possible in the project lifecycle, recognizing the paradox that uncertainty is high in the initial stages of a project so there is often less information on which to base the risk identification. Early risk identification enables

key project decisions to take maximum account of risks inherent in the project, and may result in changes to the project strategy (PMI, 2008).

Implementing a RMP in the initial steps of the project life cycle is in general more difficult, because the project is more fluid, and not well defined. A more fluid project means more degrees of freedom, more alternatives to consider, including alternatives which may be eliminated as the project matures for reasons unrelated to the RMP. A less well-defined project means appropriate documentation is harder to come by, and alternative interpretations of what is involved may not be resolvable (Chapman, 1997). The high level of uncertainty and variety of alternatives in this phase of the project lead to increase the values of project risks in the very beginning stages.

Study of literature, risk management reports, check lists, risk registers and applied RBS's of similar projects can be a good start point for preliminary risk identification. Table 4.1 represented the study results of some accidents and failures of tunneling projects, pointing out the source and causes of failures. In a research by Zou et al. (2007), variation by the client, bureaucracy of government and project funding problems are some reported risk events corresponding to the feasibility phase of projects. Lack of needed codes and standards, litigation difficulties, bureaucracy, estimations and assumptions, lack of information and government improper intervention are some other reported risks (Aleshin, 2001; Long et al., 2004; Zou et al., 2007; Hillson, 2007; El-Shayegh, 2008).

During the feasibility phase and primary studies, regarding the nature and objectives of the project and synthesis of all studied similar projects and literature, a list of the most probable risk events can be prepared corresponding to the very beginning steps of the project. The events which are represented in Table 4.2 have been selected through the database of risk events and have to be evaluated and analyzed by the project experts to identify the possibility, the probability and the possible impacts on the project objectives. This list, containing a variety of risk types, is not exhaustive but a starting point to identify and evaluate the most probable risks, that have to be revised iteratively when more or new information is available.

A preliminary assessment of the selected risk events, which consider each RE individually regardless of their combined effect on the project objectives, can effectively help to prioritize and identify those which have to be further analyzed and have the most significant influence on project. Table 4.4 represents the preliminary assessment of the selected REs which is based on the quantification grid of risks, represented in Table 4.3. To get more details and see how this table is developed, refer to Chapter 3. The probability and impact factors of each RE can be expressed by the average value and Margin of Variation (M_V %) or by a qualitative investigation and selection of the scores varying between 1 and 5. In practice, in a real project, these values can be assessed by many methods (as discussed in section 2.4.1) such as brainstorming, questionnaires, interview and from the expert's knowledge of the project and also type and specific project characteristics.

Regarding the very limited available information of risks and high degree of uncertainty in the very beginning stages of the project and risk management process, it is evident that for most of the REs, the assessment is qualitative, and the scores of 1 to 5 have been used to evaluate their probability and impacts.

Table 4.2. List of the most probable risk events corresponding to the feasibility phase of the project

No.	RE Code	Risk Event
1	15	Litigation conflict with neighbor of the project during feasibility phase
2	33	Project funding difficulties during feasibility phase due to bad financial situation of financier(s)
3	35	Unavailability of needed information, code and standards in feasibility phase
4	36	Poor planning of site and ground investigation during feasibility phase by owner
5	53	National political conflict during feasibility phase
6	102	Lack of needed materials in project region or country during feasibility phase
7	141	Unavailability of needed technology to execution of owners' goal
8	158	Delay of bank in project fund allocation during feasibility phase
9	161	Poor assessment and evaluation of project options
10	163	Poor execution of preliminary investigation of site and ground
11	164	Incompetency of personnel for execution of preliminary investigation of site and ground
12	165	Poor site investigation regarding the identification of available manmade underground structures
13	166	Poor site investigation regarding the identification of natural geological/ hydrological hazards
14	167	The site preliminary investigation plan is not compatible with proposed nature and scope of the project
15	168	Poor preliminary assessment and evaluation of tunneling methodologies
16	169	Poor preliminary assessment and evaluation of different possibilities for temporary and permanent ground support systems
17	170	Poor preliminary assessment and evaluation of different possibilities of treatment measures for ground and groundwater
18	171	Poor preliminary assessment and evaluation of environmental impact of treatment measures for ground and groundwater
19	172	Poor preliminary assessment and evaluation of ground movement and settlements
20	173	Poor preliminary assessment and evaluation of environmental impacts of the project such as dust, noise, vibrations, traffic, plant movements
21	174	Poor preliminary assessment and evaluation of costs, health, safety and program implications
22	175	Poor preliminary assessment and evaluation of possible forms of contract
23	176	Poor preliminary assessment and evaluation of hazardous materials
24	177	Poor assessment and evaluation of proposed project location
25	178	Preliminary scheme design is not appropriate with the project objectives or requirements of the project
26	179	Poor preliminary risk management of different proposed options of design, contract form, contractors, etc
27	293	Not finding a bank to finance the project
28	300	Delay of authorities to issue the project permit
29	309	Delay to issue the construction permit by the environmental organization

Table 4.3. Risk Qualification grid

Note	Probability		Impact					
	Class	Range	Cost (K€)		Delay (day)		Performance	
			Class	Range	Class	Range	Class	Range
		0		0		0		0.00
1	Very low (Rare)		Very low (very mild)		Very low (very mild)		Very low (very mild)	
		1/100		1		5		0.0014
2	Low (unlikely)		Low (mild)		Low (mild)		Low (mild)	
		1/30		10		10		0.0057
3	Medium (possible)		Medium (average)		Medium (average)		Medium (average)	
		1/5		100		40		0.0778
4	High (likely)		High (strong)		High (strong)		High (strong)	
		1/2		1000		100		0.3768
5	Very high (almost certain)		Very high (very strong)		Very high (very strong)		Very high (very strong)	
		1		10000		500		1.1557

Table 4.4. The probability of occurrence and impact factors of the selected REs

RE Code	Probability of happening			Impact								
	Average	Margin of Variation	or Note	Cost (K€)				Delay (day)				Performance
				Average	Margin of Variation	or Note	Average	Margin of Variation	or Note	Note		
15			2								3	1
33			3								4	5
35			1								3	3
36	0.2	20.00%									3	4
53	0.1	15.00%									2	2
102	0.05	10.00%									4	2
141			2								3	3
158			3								2	2
161	0.25	20.00%									3	3
163			2								4	5
164			2								3	4
165			3								5	2
166			3								4	3
167			1								2	2
168	0.2	20.00%									4	3
169			2								2	3
170			3								3	4
171	0.15										2	3
172			2								3	2
173			3								2	3
174			2								3	4
175			2								2	2
176			1								2	4
177			2								3	5
178			1								1	2
179	0.15	10.00%									4	3
293			2								5	5
300			2								1	1
309			3								2	2

The parameter Margin of Variation (*MV %*) is used to measure the confidence in prediction of the average value and statistically is the equivalent of standard deviation (Figure 4-17). A low standard deviation indicates that the data points tend to be very close to the mean, whereas high standard deviation indicates that the data are spread out over a large range of values.

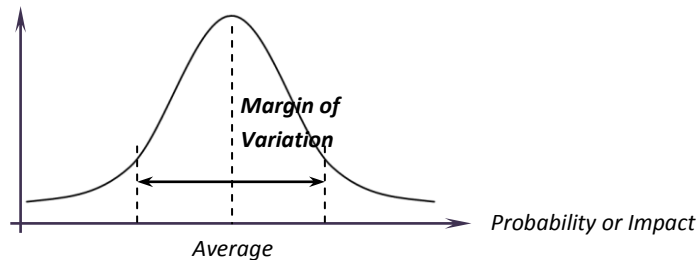


Figure 4-17. Normal distribution of the probability and impact factors of REs.

Following the method, explained in Chapter 3, the notes can be converted to values and values can be converted to notes considering the *MV* factor. Assuming $\alpha=0.7$ (uncertainty aversion factor) (Taillandier et al., 2011) the final results are represented in Table 4.5.

Table 4.5. Modified values considering uncertainties and corresponding notes

RE Code	Probability		Impact					
	Modified probability	Note	Cost (K€)		Delay (day)		Performance	
			Modified impact	Note	Modified impact	Note	Impact value	Note
15	2.63%	2	7.3	2	31	3	0.0010	1
33	15.00%	3	7.3	2	82	4	1.0000	5
35	0.70%	1	7.3	2	31	3	0.0634	3
36	21.60%	4	73	3	31	3	0.3171	4
53	10.60%	3	7.3	2	8.5	2	0.0049	2
102	5.20%	3	730	4	31	3	0.0049	2
141	2.63%	2	73	3	31	3	0.0634	3
158	15.00%	3	7.3	2	82	4	0.0049	2
161	27.00%	4	73	3	82	4	0.0634	3
163	2.63%	2	730	4	380	5	1.0000	5
164	2.63%	2	73	3	31	3	0.3171	4
165	15.00%	3	730	4	380	5	0.0049	2
166	15.00%	3	730	4	380	5	0.0634	3
167	0.70%	1	7.3	2	31	3	0.0049	2
168	21.60%	4	730	4	380	5	0.0634	3
169	2.63%	2	7.3	2	31	3	0.0634	3
170	15.00%	3	73	3	82	4	0.3171	4
171	15.00%	3	7.3	2	8.5	2	0.0634	3
172	2.63%	2	73	3	380	5	0.0049	2
173	15.00%	3	7.3	2	8.5	2	0.0634	3
174	2.63%	2	73	3	82	4	0.3171	4
175	2.63%	2	7.3	2	31	3	0.0049	2
176	0.70%	1	7.3	2	8.5	2	0.3171	4
177	2.63%	2	73	3	380	5	1.0000	5
178	0.70%	1	0.7	1	8.5	2	0.0049	2
179	15.60%	3	730	4	82	4	0.0634	3
293	2.63%	2	7.3	2	380	5	1.0000	5
300	2.63%	2	0.7	1	82	4	0.0010	1
309	15.00%	3	7.3	2	31	3	0.0049	2

It should be noted that, the values of probability and impacts on project objectives, provided in Table 4.5, are an initial estimation and they can be modified by the progress of the project. As an example, RE#161 (Poor assessment and evaluation of project options), with the assessed probability of occurrence 27%, was considered to have a strong impact on project schedule. Evidently, by the progress of the site and geology investigation and evaluation of different options to cross the Rhone river, the probability of occurrence of this risk event will decrease. However, these changes can be additive in some cases. For example, if viaduct over the Rhone is selected as the best option to cross the river, it might increase the probability and impact of RE#15 (litigation conflict with neighbor of the project during feasibility phase), knowing that this solution requires land acquisition and demolition of many buildings at the Oullins sector.

For each RE, the risk values are calculated as a function of the probability and impact values as: Risk= Probability \times Impact. So for each RE, three values of risks are calculated by multiplying the probability and the impact factors on cost, time and performance of the project. The results are provided in Table 4.6. Then, to make these values more comprehensible and comparable, they were converted to risk notes using the risk grid table (see section 3.4.6). The results are given in Table 4.7.

Table 4.6. Risk values

RE Code	Risk (Cost, K€)	Risk (Delay, day)	Risk (Performance)
15	0.1922	0.8163	0.000026
33	1.0950	12.3000	0.150000
35	0.0511	0.2170	0.000444
36	15.7680	6.6960	0.068491
53	0.7738	0.9010	0.000520
102	37.9600	1.6120	0.000255
141	1.9223	0.8163	0.001671
158	1.0950	12.3000	0.000735
161	19.7100	22.1400	0.017128
163	19.2233	10.0067	0.026333
164	1.9223	0.8163	0.008350
165	109.5000	57.0000	0.000735
166	109.5000	57.0000	0.009516
167	0.0511	0.2170	0.000034
168	157.6800	82.0800	0.013703
169	0.1922	0.8163	0.001671
170	10.9500	12.3000	0.047563
171	1.0950	1.2750	0.009516
172	1.9223	10.0067	0.000129
173	1.0950	1.2750	0.009516
174	1.9223	2.1593	0.008350
175	0.1922	0.8163	0.000129
176	0.0511	0.0595	0.002220
177	1.9223	10.0067	0.026333
178	0.0049	0.0595	0.000034
179	113.8800	12.7920	0.009896
293	0.1922	10.0067	0.026333
300	0.0184	2.1593	0.000026
309	1.0950	4.6500	0.000735

Table 4.7. Risk notes

RE Code	Risk (Cost, K€)	Risk (Delay, day)	Risk (Performance)
15	2	3	2
33	3	3	4
35	2	2	2
36	3	3	3
53	3	3	3
102	3	3	3
141	3	3	3
158	3	3	2
161	3	4	3
163	3	3	3
164	2	2	3
165	3	3	2
166	3	3	3
167	2	2	2
168	3	3	3
169	2	3	3
170	3	3	3
171	3	3	3
172	3	2	2
173	3	3	3
174	3	2	2
175	2	2	2
176	2	2	2
177	2	2	4
178	1	2	2
179	3	3	3
293	2	2	4
300	2	2	2
309	3	3	3

The results show that RE#161 (poor assessment and evaluation of project options) is the most significant RE regarding the project schedule. Regarding the three project objectives together, RE#33 and 161 are the most risky ones and have to be treated in priority. Similarly, based on the calculated risk notes, all the identified REs can be prioritized and regarding to each one of the project objectives, the most significant ones can be identified. This preliminary investigation helps to better understand the selected REs and identification of the most important ones. However, to improve this process and consideration of overall effect of the selected REs on project objectives, they have to be categorized. Thus, the next step will be the systematic generation of convenient RBS's and aggregation of values of the selected REs on corresponding categories. This process will be performed with the software which has been developed based on the methodology proposed in this research.

4.3.1.2. Generation of convenient RBS's

We are still in the very beginning stages of the project risk management of this project. The risk identification process has to be repeated iteratively and the assessed values of probability and impacts have to be revised by the progress of the projects. Furthermore, as it was discussed in section 3.3.3, generation of tailored RBS's can also be helpful in identification of new REs which may have been forgotten in the previous steps. Thus, in the following, we aim to generate convenient RBS's which may help us to identify some forgotten REs and provide a more clear vision of project risks.

As the first step, the mentioned REs in Table 4.2 should be selected in RE database. For aggregation of RE values on RBS, we will use the proposed method presented in last chapter (section 3.4). Thus, the assessed values (not scores), provided in Table 4.5, are considered as the probability and impact values of the selected REs in database. Since in this method, the impact values on cost, delay and performance of the project are not necessarily in the (0, 1) range, some small changes will be needed to make them compatible with the proposed formula, provided in section 3.3.5, for calculation of the RBS contrast note.

The applied values and parameters in *Setting tab* are shown in Figure 4-18. The objective is to have a global view to project risks to identify the most risky categories and probable forgotten REs. In this stage of the project, it would be helpful to know, which one of the project partners are encountered with the identified risks, what is the overall effect of the identified risks on project regarding each one of the project objectives and what is the global project risk value. Since RBS's with few number of levels suffice in the very beginning steps of the project and regarding the few number of selected REs, "2" was selected as the desired number of attached REs to bottom level categories ($A_v=2$). As for the five RBS quality notes, it was assumed that they have the same contribution in the final quality note of RBS's and thus, all are considered to be 0.2. For the weighting factors of different RBS levels, the default values were taken (see Figure 4-18).

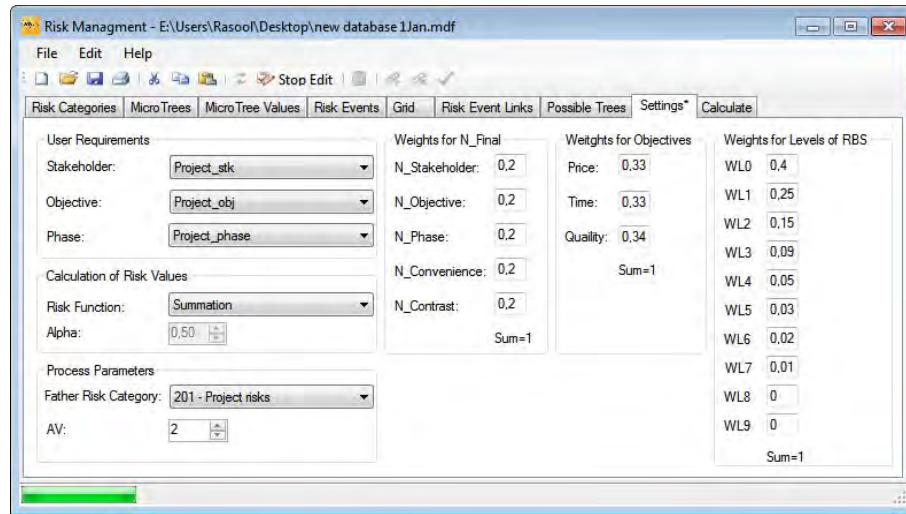


Figure 4-18. Applied values and parameters in Settings tab

Combination of 75 available MTs in the database led to generate 10047 different homogenous RBS's and for each one, 5 quality notes were calculated. Figure 4-19 provides the ranges of these notes for all the generated RBS's. It should be noted that, theoretically, the five quality notes can have values in the range of [0, 1], nevertheless, type and number of selected REs together with their probability and impact values in each special case can limit these notes to smaller ranges. For instance, in the current example, the convenience notes (N_{conv}) are varying between 0 and 0.26 and indicates that propagation of the selected REs on RBS's branches are not uniform enough to cover them homogeneously; most of them have the same type and origin and thus are concentrated in some special categories. Even if it is not a problem for the RBS generation process, being aware of these ranges can help to modify their contribution weights in calculation of the global quality notes.

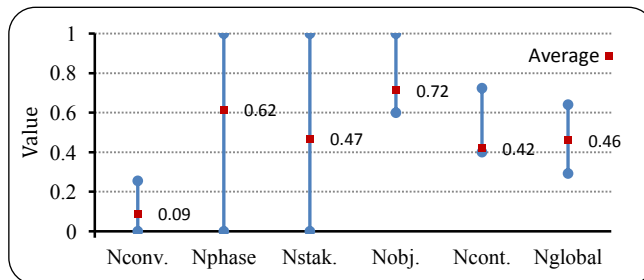


Figure 4-19. Ranges of the five quality notes, calculated for all the generated RBS's

Assuming the same preference for the five quality notes, N_{global} have been calculated for all the generated RBS's and the most convenient ones have been selected. Figure 4-20 illustrates four RBS's with the maximum global quality notes (0.641). In this process, the risk values of each category were calculated as summation of risk values of attached REs and then were

converted to risk notes of 1 to 5. Any multi-criteria method such as Analytic Hierarchy Process (Saaty, 1990) or ELECTRE TRI (Brito et al., 2010) can be applied to calculate the global risk note of each category. In this example, a simple method, being the weighted average of the three risk notes, was used with the same weighting factors of 0.33 for the three objectives of time, quality and cost.



Figure 4-20. The most convenient RBS's generated in the very beginning steps of the RM process

The four selected RBS's, with the maximum global quality notes, decompose the project risks regarding different project stakeholders and their differences are in decomposition form of "management" and "external risks" categories. Since all the generated RBS's are homogenous, it can be seen that management category also has been decomposed, even there is no selected RE corresponding to this category. In the following sections, it will be shown how the quality of these RBS's can be improved by cutting such MTs. Furthermore, sensitivity of results to the applied parameters and variables will be studied in detail.

Regarding the results provided in Figure 4-20 and assuming the same preference to the three project objectives (cost, time, quality), it seems that internal risks of the project related to the project stakeholders are the most significant ones comparing with external and project management risks. At the current stage of the project, among different project stakeholders, the owner and financiers are faced with many risks. The most significant overall consequences of risks allocated to the owner are on project schedule (with the risk note of 5) and for the project financiers, consequences on performance and quality of the project is the case (with the risk note of 4).

In RBS#2114 (Figure 4-20), external risks of the project that can affect all the project partners have been decomposed into 7 different subcategories while economic/financial and context risks are the most significant ones. In another possibility, RBS#1 regroups these two categories together with political risk to a more general category, being "country" risks with 9 attached REs. This is the reason why RBS#1 has less value of N_{conv} compared with RBS#2114.

As it was mentioned before, in the current applied method for aggregation of risk values on RBS branches, impact values of REs are not necessarily in [0, 1] range. In the other hand, the proposed formula in section 3.3.5, for calculation of RBS contrast note, has been developed assuming that all risk event values are in [0, 1] range. Thus, some small changes are required to make the formula compatible with the current aggregation method. The idea is to convert the risk values, corresponding to risk notes of 1 to 5, into normalized values in the range of [0,1] based on the existing non-linear relation between risk notes and values. Figure 4-21 provides the main principles of this process. The corresponding values of risk notes (C_i) are obtained from the risk grid (Table 3.17) and using the same function as in Equation 3-13. Knowing the C_i values and assuming $y_1=0$ and $y_5=1$, the normalized values corresponding to

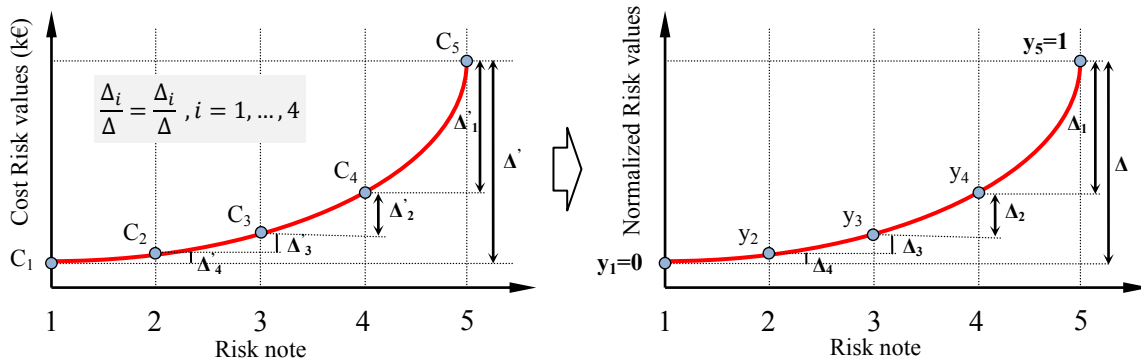


Figure 4-21. Normalization of risk values

risk notes of 2,3 and 4 can be easily calculated using the following equation:

$$\frac{\Delta_i}{\Delta} = \frac{\Delta_i}{\Delta}, i = 1, \dots, 4 \quad \text{Equation 4-1}$$

It should be noted that these normalized values are used only for calculation of contrast notes (N_{contrast}) of RBS's, and based on the defined scales of risk, these values are not meaningful as risk values.

4.3.1.3. Identification of new REs using generated tailored RBS's

As it was discussed, when suitable RBS's are constructed, they can also be helpful in identification of new REs, which may have been forgotten during the previous steps. These newly identified risk events are added to the database, and the process for the generation of the most suitable RBS is repeated.

Here in this representative example, regarding the generated RBS's in the very beginning steps of the RM process (represented in Figure 4-20), it can be seen easily that, the risks related to the project management, despite their importance, have been forgotten. It is the case for the risks which are probably related to skill deficiency of project manager, change in management strategies, poor communication, lack of information or complexity of project risk management. All the available REs in database related to these kinds of risks have to be identified, evaluated and discussed by the project experts, and those which are probable or have a notable impact on project objectives have to be added to the RE list of the current project. Table 4.8 provides 6 new probable REs which are all related to project management and were selected as probable risk events of the current project. Following the same process as in the first try, these REs were assessed (see Table 4.9) and generation of convenient RBS's was repeated. The most convenient RBS is illustrated in Figure 4-22. As is shown in this RBS, the new identified REs have been attached to the corresponding categories, the risk values have been aggregated and the five quality notes have been recalculated.

Comparing the five quality notes of this RBS with RBS#2114 in Figure 4-20 shows that the RBS quality regarding the level of details (N_{conv}) has been improved and this is due to a more equilibrated propagation of REs on bottom level categories. However, among the 35 selected REs, 19 are attached to "owner/client" category and 6 REs to "context" category and there are 8 bottom categories which don't cover any of the selected REs. This is the reason why the selected RBS has not a high value of N_{conv} . In the following sections, it will be explained how the quality of selected RBS can be improved by further decomposition of bottom level risky categories and those that cover many REs.

The results, provided in Figure 4-22, show that the risks related to owner of the project are still the most significant ones and risks related to the project management have the same criticality as the external risks.

Table 4.8. Identification of new REs related to project management

No.	RE Code	Risk Event
30	29	Complexity of project time management due to complex nature of the project
31	30	Imposed unrealistic time planning for project due to insufficient or incorrect information
32	40	Poor time Management due to change of manager or management strategies of the project
33	44	Public concerns related to health and safety of the project due to poor communication
34	89	Skill deficiency in cost management of the project
35	96	Skill deficiency of project manager(s) in environmental protection

Table 4.9. Assessment of the new identified risk events

RE Code	Impact							
	Probability		Cost (K€)		Delay (day)		Performance	
	Modified probability	Note	Modified impact	Note	Modified impact	Note	Impact value	Note
29	0.15	3	7.3	2	82	4	0.0010	1
30	0.22	4	73	3	82	4	0.0049	2
40	0.007	1	73	3	8.5	2	0.0010	1
44	0.15	3	0.7	1	8.5	2	0.0634	3
89	0.108	3	730	4	8.5	2	0.0010	1
96	0.156	3	0.7	1	3.5	1	0.3171	4

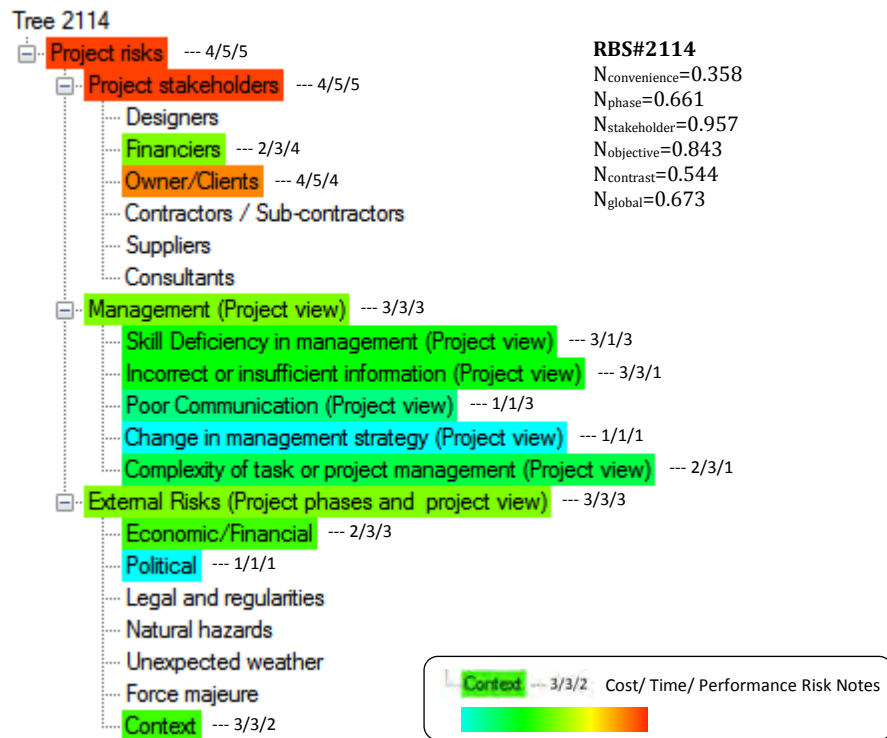


Figure 4-22. The most convenient RBS after adding new REs related to project management

4.3.1.4. Iterative risk identification based on the available information

Identification and assessment of risk events is an iterative process that has to be repeated whenever new information is available. By progress of the project preliminary studies and performing preliminary geology and geotechnical in-situ tests, it was found that crossing the two banks of Rhone River has two main geotechnical difficulties:

- high permeability of Alluvium Rhone,
- granite pier of Oullins which is known as a very hard rock.

Probable water inflows in a very permeable Alluvium can cause various degrees of difficulties during construction of shafts and trenches. Furthermore, if tunneling is the option to cross the river, water intrusion can be critical. The stability of face and walls may be compromised by the erosive power of high pressure water inflow. Such kinds of difficulties have to be taken into consideration from the very beginning steps of the project. The risk events and their probable effects on project and stakeholders have to be identified and if is needed, an effective strategy has to be applied to reduce the probable negative impacts. Moreover, such a process may convert potential pitfalls into gains.

At the current stage, study of similar projects, failures and difficulties due to the mentioned geotechnical difficulties can effectively help to identify the maximum number of corresponding probable REs. As an example, during construction of the cross passage on Shanghai's Metro Line 4 using ground-freezing method, on 1st July 2003, excessive ground loss into the excavating face occurred and some parts of the completed tunnels were damaged as a result. The collapse happened at the point where the line runs under the Huangpu river. This caused a massive ingress of water and material at the face at a depth of 35m, a six-storey building collapsed and several other buildings in the neighborhood were evacuated. As an immediate measure to limit damage to other sections of the tunnel due to unbalance load after the collapse, the twin tunnels were filled with water. Cavity filling using grout and concrete was also carried out after the collapse as part of the damage control measures. The cause of the loss was identified as being the failure of the ground-freezing unit that had been installed to protect the excavation work for the cross passage. This incident caused the completion of the metro line to be delayed for almost a year. (SeidenfuB, 2006; Yu et al. 2007).

As another example, on March 3rd 2009, during construction of the north-south-metro Line in Cologne, in the open pit of the 28m deep turn-off under construction in a river gravel context, an inrush of groundwater and ground material occurred and resulted in a total collapse of the Historical Archive of the City of Cologne consisting of five stories above ground and two stories underground (Figure 4-23). Two residents of neighboring buildings were found dead. Failure in the diaphragm-walls of the shaft and hydraulic ground seepage were reported as the probable reasons of the accident (Haack, 2009).

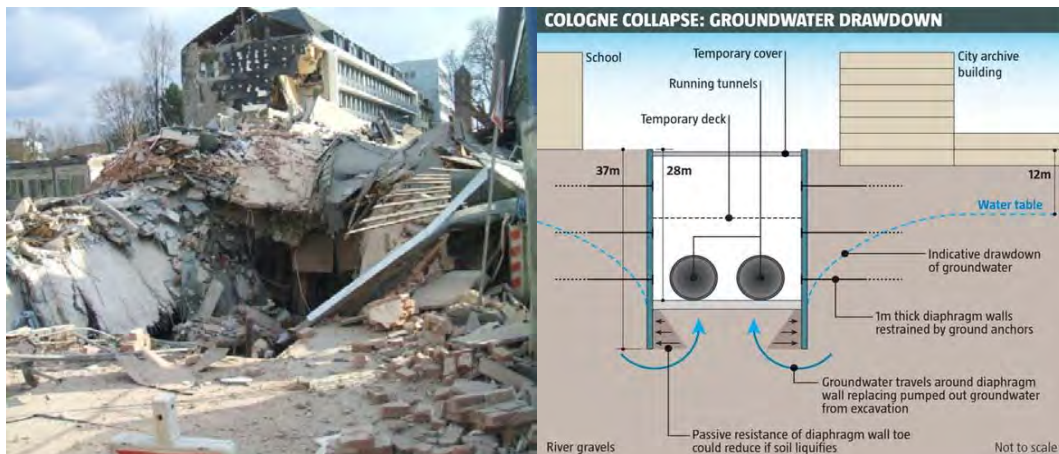


Figure 4-23. Collapse of the historical archive of Cologne-Germany, 3 March 2009 (Manderfeld, 2010).

Excavation in very hard Granite of Oullins can also cause a variety of difficulties and if using explosives is the chosen option for excavation, ejection of rock and the ground vibrations produced by inadequate use of explosives could potentially damage the shaft and tunnel structures and adjacent facilities and buildings. As an example, on 1th January 1983, during construction of MTR Island Line in Hong Kong using the drill and blast method, misinterpretation of the geology by the contractor led blasting to go so far, resulting in the tunnel penetrating the rock into soft ground. As consequence, 1500m³ of material flowed into the tunnel creating a void of an area of 100m² and 30m depth beneath the road surface (see Figure 4-24) and many of the adjacent buildings were damaged (SeidenfuB, 2006; MED, 2008).

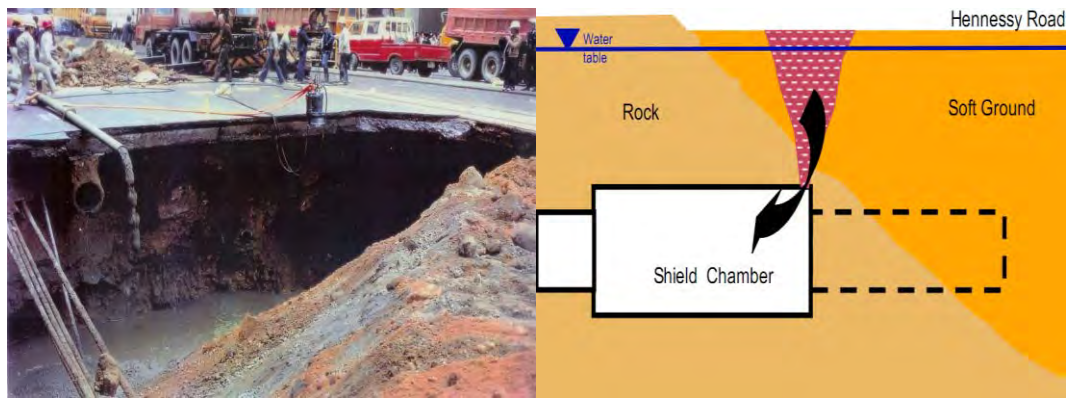


Figure 4-24. Tunneling from Admiralty to Causeway Bay for MTR Island Line using the drill and blast method, on 1th January 1983, Hong Kong (MED, 2008).

By study of such similar projects and evaluation of the criticality and the potential consequences of very complex geology of the site, it seems that another RE has to be added to the list of the probable REs: “RE#316: project has very complex geology and geotechnical

conditions”. Since it is a new RE, it should be added to the database and connected to the corresponding risk categories. Thus, in a first step, the RE is connected to the convenient bottom level categories which are: “natural constraints of site” and “external risks (feasibility phase)”. In a second step, based on the available connections between risk categories in the MT database, the software generates all the indirect links between this RE and the other convenient RCs. The database consistency criteria are controlled and if all are validated, this new RE and its links will be registered into database. Figure 4-25 illustrates all the validated direct and indirect links related to this new RE.

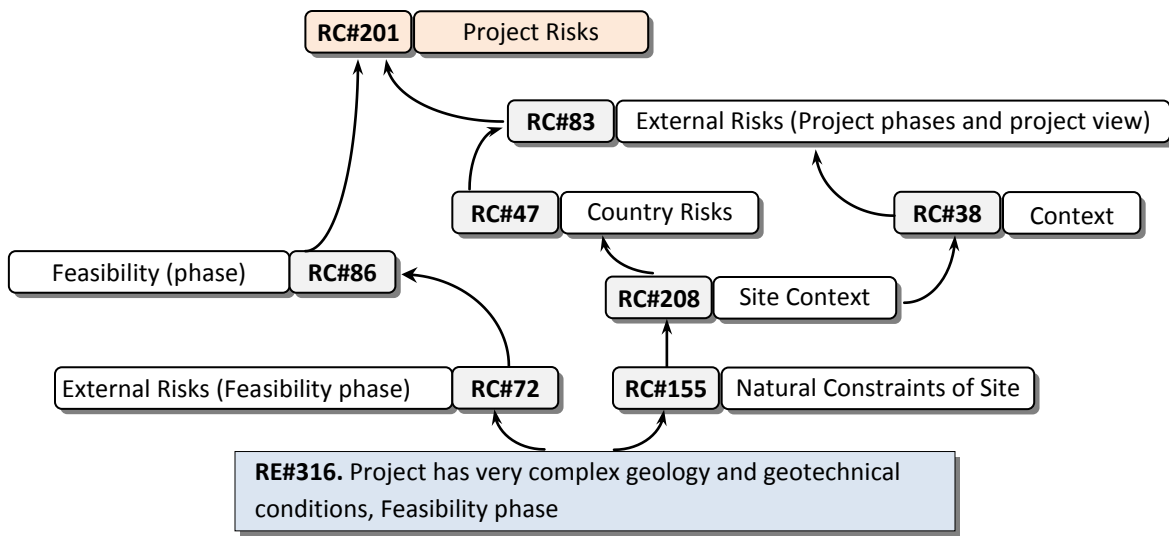


Figure 4-25. Direct and indirect links related to the new identified risk event (RE#316)

The probability and impact factors of this new identified RE are assessed based on the available information, and aggregation of all the identified REs on RBS branches is repeated again. Table 4.10 provides the preliminary assessment results which might be changed when more geological data are available and Figure 4-26 provides the recalculated risk values on RBS branches.

Table 4.10. Assessment of the new identified RE

RE Code	Probability		Impact					
			Cost (K€)		Delay (day)		Performance	
	Modified probability	Note	Modified impact	Note	Modified impact	Note	Impact value	Note
316	0.378	4	730	4	82	4	0.0049	2

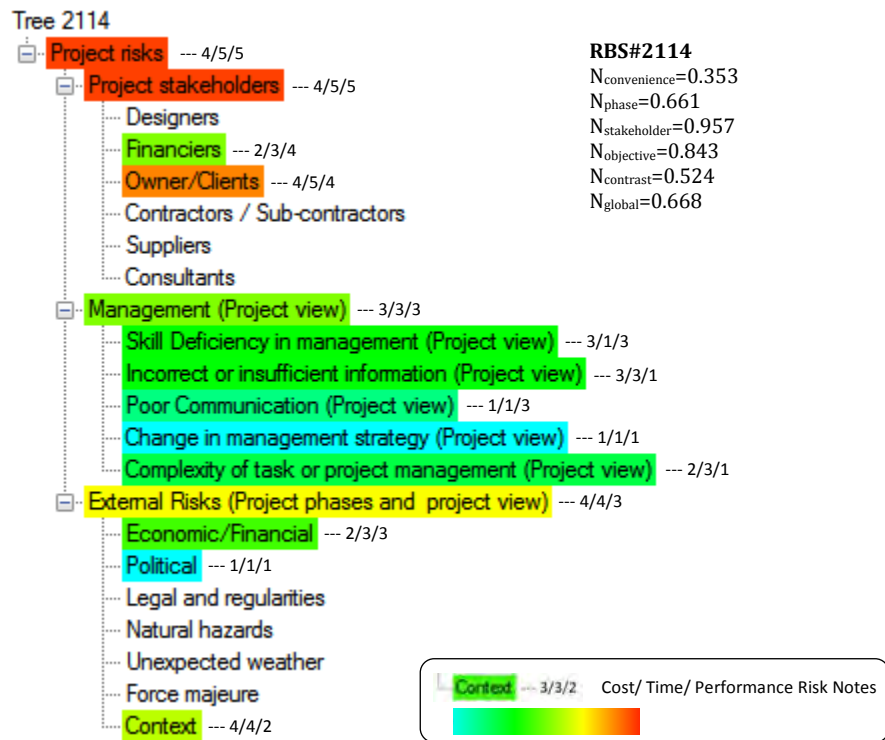


Figure 4-26. Recalculated RBS after identification of RE#316

Based on the current project information and comparing the results, before and after identification of RE#316, it seems that “external risks” of the project are going to be more risky and among the 36 identified REs, 10 of them belong to this category. Furthermore, a simple comparison of the RBS’s quality notes shows that the global quality note has a small degradation. More imbalanced distribution of the identified REs on the bottom level categories, with addition of RE#316 to “context” category, together with decrease of contrast of risk values at the first level of the RBS (contrast between “project stakeholder”, “management” and “external risks” categories) are the main reasons of this degradation. Such kind of variation in RBS quality notes is the reason why during the PRM progress, even in an special stage with fixed objectives and requirements, the RBS selected as the most convenient one may change when the input information and their level of accuracy are changed.

Again, it is noted that these results are related to the very beginning stages of the risk management process and by progress of the project, performing complementary studies, more evaluation of the identified REs and appearance of new REs, the results of the risk analysis process might be more accurate.

Identification of probable REs in the very beginning stages of the project can also affect the impacts or probability of occurrence of some other risk events related to the following phases of the project. For instance, identification of the risk event related to the very complex geology of the site (RE#316) will effectively increase the probability of having technical design defects

or accidents during the implementation phase. In such a case, performing additional in-situ tests to precise the geotechnical information of the complex terrain can be a solution to reduce the negative effect of this interaction. Consideration of these interactions in risk analysis process requires a dynamic and iterative process of identification and analysis of risks. As it was explained in section 3.4.9, to take these interactions into consideration, we modify the values of risk events regarding their interactions before aggregation through the RBS branches.

Up to here, in this representative example, a list of the most probable REs related to the very beginning stages of the project has been identified and the convenient RBS's with a global view to project risks have been generated. It was explained how the tailored RBS's are helpful in identification of new REs which may have been forgotten during the precedent analysis; it was explained how the generation of tailored RBS's and risk analysis process are iterative and how the results have to be updated whenever new information is available. The most risky categories and REs and those which regarding to risk interactions are considered as key REs (those whose occurrence can significantly affect the occurrence of other REs) have to be identified and convenient response actions must be determined to reduce their negative impacts on project objectives.

At the current example, the last obtained results (provided in Figure 4-26) show that the risks related to owner of the project (SYTRAL) with a very strong overall impact on final project cost have priority to be treated. Also the "context" risks (problems and difficulties due to available situation of site, technology, resources, social, cultural and third parties which are considered as external risks) with a significant effect on project cost and schedule have the second place. Figure 4-27 represents the risk matrixes related to REs attributed to "context" and "owner" categories. The most significant REs were selected to show how convenient response actions can minimize their negative impacts. Section 4.3.1.6 will focus on response planning to RE#161 (poor assessment and evaluation of project options) and RE#316 (project has very complex geology and geotechnical conditions).

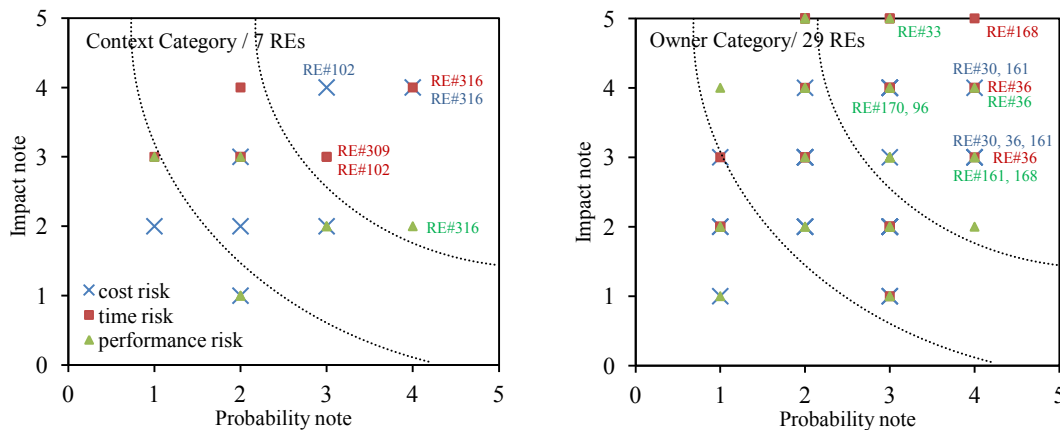


Figure 4-27. Risk matrix related to the REs attributed to the "context" and "owner" categories

4.3.1.5. Focus on special risk categories

The tailored RBS's in last sections were generated with a global view to project risks and considering all the project objectives. We will show now how the requirements of the user can change the structure of the most convenient RBS. The objective is to focus more on risks related to the project feasibility phase and to generate a convenient RBS which facilitates understanding of risks for owner of the project (SYTRAL). Thus, in setting tab, "owner/clients" is selected as the user of the RBS and "feasibility phase" as the desired project phase. The aim is to analysis the overall effect of the identified REs on schedule, final cost and performance of the project. All the other parameters and options are left without any change.

Generation of tailored RBS's and aggregation of risk values on RBS branches was performed and the most convenient one with the maximum global quality note was selected (Figure 4-28, RBS#9861). In this RBS, the project risks are decomposed into different project phases and risks related to management. It is a different view to project risks with focus of the feasibility phase. Among the 36 selected REs, 20 of them belong to feasibility phase and the rest to "management" category, and the other subcategories are null. This imbalanced distribution of REs to the bottom level categories is the reason why the RBS has a very small value of $N_{convenience}$. However, the RBS is completely compatible with the required phase and objectives of the PRM ($N_{phase}=N_{objectives}=1$). $N_{stakeholder}$ is 0.4 means that this RBS is not completely able to decompose the risks based on special perspective of the desired stakeholder (here, owner of the project).

However the selected RBS has the maximum global quality note, its quality could be further improved by more decomposition of the "feasibility" and "management" categories. The modified RBS with higher level of details, which has a new code and modified quality notes, is illustrated in Figure 4-28 (RBS#10047). For each RC, three risk notes have been calculated

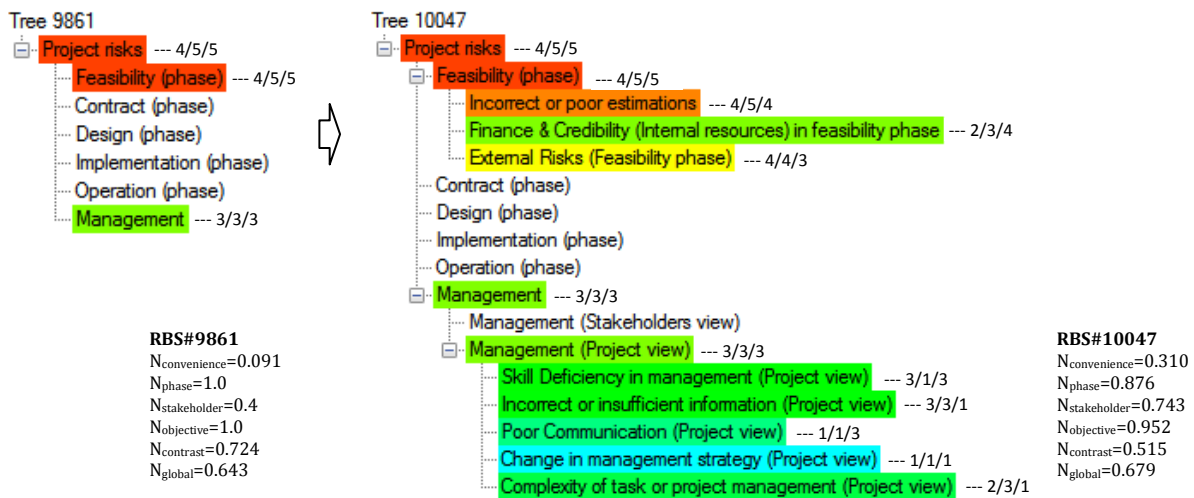


Figure 4-28. Focus on risks related to the feasibility phase

corresponding to the three project objectives. The results indicate that special attention should be given to the preliminary studies and assumption during the feasibility phase and also to the project external risks which have the second place in risk priority list.

As it can be seen, by progress of the PRM process, our knowledge about the project risks, their priorities and their target phases and stakeholders is increasing progressively. This is helpful in selection of convenient response actions and a more effective planning for management of project risks.

4.3.1.6. Actions to reduce and manage the identified risks in feasibility phase

SYTRAL as the client and financier of the project, during the feasibility phase, had to launch effective actions to reduce the probability of occurrence and the negative consequences of the identified risks.

For RE#161, SYTRAL started comprehensive studies of different options for crossing Rhone River and connections to the stations. After many studies and a long period of consultation with consultant companies, SYTRAL chose to use a slurry pressure balance Tunnel Boring Machine with crusher, and a programmed modification of the cutting tools when entering the granite. The mission of this TBM was to build a mono-tube, double-track tunnel which pass more than 15m below the riverbed (Herrenknecht, 2011). This technique allows to limit the nuisance during construction and operation phase, since everything is underground. The other studied options were:

- ***The viaduct over the Rhone:** Total cost is much higher than the other solutions (land acquisition and demolition of buildings), urban integration difficulties at the Oullins sector and impact on the flow of the Rhone in case of flooding are some disadvantages of this option. Therefore this solution was abandoned.*
- ***Immersed tunnel, laying on the riverbed:** Crossing the Rhône in submerged caissons was also the subject of exhaustive study, because it had the advantage of being able to be entirely done by local companies. COWI (Consultancy within Engineering, Environmental Science and Economics) was responsible for the study of this option. The immersed tunnel is a one-tube tunnel, 9.6m wide and 6.0m high. The two 150m long immersed tunnel elements are placed in a 3 to 8m deep trench in the river bed and connected to cut and cover tunnels at both ends. The top of the immersed tunnel is approximately 10m below the water level (see Figure 4-29).*

The process of immersion of the elements and risks related to this immersion are emphasized. The Rhône has a substantial amount of commercial navigation, and the aim is to minimize the interruption of this traffic during installation of the tunnel elements. Furthermore, the Rhône is characterized by occasional high flow rates. The impact on immersed tunnel elements during immersion from high currents has been tested by model tests. The rock protection on top of the tunnel has also been dimensioned and tested in model tests to withstand high currents (COWI, 2011). The analysis showed that the total cost is much more than the tunnel option.

As for RE#316, between 2006 and 2009, SYTRAL conducted hundreds of in-situ tests to define a precise profile of the different geological zones, between Gerland and Oullins. The soil surveys carried out by Hydro-Geotechnique Sud-Est company. They concentrated mainly on the under-river passage (with 9 vibro-cores in the Rhône, carried out from a self-elevating platform), and in particular on the granite horst at Oullins, which was considered as the hard point of the project. As a consequence, however the project has a complex geology, the geotechnical profile of the site got more clarity and sufficient information was available for contracting, technical design and taking determinant decisions.

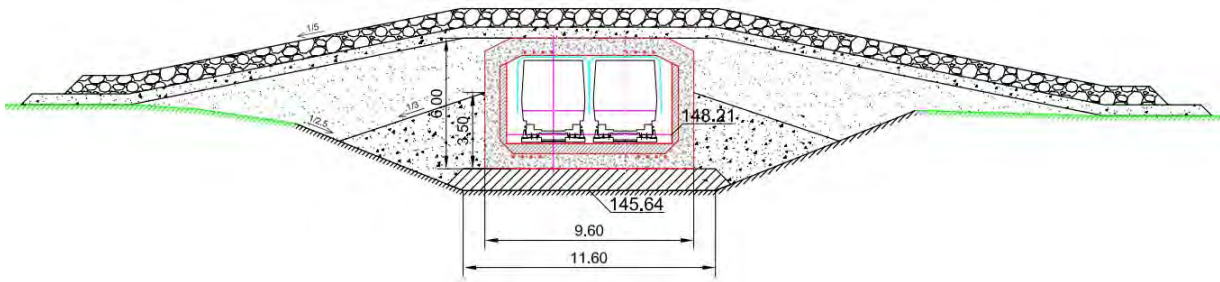


Figure 4-29. Immersed tunnel, one of the options to cross the Rhon River

Such preventive actions effectively reduce probability of occurrence and/or consequences of target REs during this stage or the following stages. For instance, considering the performed actions to control and manage the risks related to site and ground investigations and also selection of a convenient solution to cross the Rhone river, the corresponding REs can be reassessed as below:

Table 4.11. Revision of REs assessment after preventive actions

RE Code	Risk Event	Probability (%)	
		Before revision	After revision
36	Poor planning of site and ground investigation during feasibility phase by owner	21.6	5
161	Poor assessment and evaluation of project options	27	10
163	Poor execution of preliminary investigation of site and ground	2.63	1
164	Incompetency of personnel for execution of preliminary investigation of site and ground	2.63	1
165	Poor site investigation regarding the identification of available manmade underground structures	15	4
166	Poor site investigation regarding the identification of natural geological/hydrological hazards	15	2

Risk analysis process was repeated based on the revised values. Table 4.12 provides a part of the obtained results. As expected, performing the effective response actions decreased the risk values corresponding to the feasibility phase. This process has to be repeated and revised dynamically for all identified risks and whenever a new RE is identified, or new information become available, the database has to be updated and all calculations be revised.

Table 4.12. A part of the new results after reassessment of the REs mentioned in Table 4.11

Risk Category	Before Revision			After Revision		
	Risk Cost K€ (note)	Risk Delay day (note)	Risk Perf. value (note)	Risk Cost K€ (note)	Risk Delay day (note)	Risk Perf. value (note)
Incorrect or poor estimations	566.6 (4)	287.5 (5)	0.26 (4)	353.7 (4)	170.5 (5)	0.16 (4)
Feasibility (phase)	886.9 (4)	364.3 (5)	0.44 (4)	674 (4)	247 (5)	0.35 (4)

4.3.2. Contract phase

The call for tenders for the construction work was launched at the end of 2007, on the basis of an AVP which would leave the door open for the two or three variants mentioned in the last section. SYTRAL and Egis-Rail therefore undertook negotiations for a contract with four companies proposing a mono-tube. This process stretched out over 10 months and allowed the risk with each one to be gradually analyzed, in a way so as to properly identify the risks and to study in advance ways of overcoming them and paying for them. At the end of this negotiating stage, the contracting authority asked the companies to present a final bid, based on a shared and very precise definition of the risks (type and frequency) covered by the contracting authority, and those left for the contractor.

Thereby, we aim to show how such a risk based project analysis can be performed by each one of the contractors and how risk analysis process can provide different results based on different perspectives of client and contractors to project risks. Each contractor has to identify and analyze the project risks based on his own view to project risks and then, when the risk level (threat and opportunities) of the project was defined, based on his abilities and competence to overcome with identified risks, a rational bid can be proposed. However, the contractors risk management system and approaches must be compatible with the owners, thereby reducing and controlling risks both to himself, to the owner and the public (Eskesen et al., 2004).

In this procedure, representation and analysis of risks using risk breakdown structure can be useful. Using the RBS, not only the global risk level of project can be calculated but also the project risks can be broken down into smaller categories of similar risks, each one having an individual risk level. Thus, it is easier to identify these risks which contractor is able to overcome and those which have to be left for the other partners. In the following, these issues will be more clarified using a simple representative example.

Performance of the client during the project feasibility phase in identification, assessment and analysis of project risks led to obtain some preliminary information about the project risks. A part of this information was shared with the pre-selected contractors. Table 4.13 provides a list of identified REs which were communicated. However, each company has to perform complementary studies to enrich his knowledge about the project risks. In this representative

example, we will focus on two different contractors, called A and B which have different level of competence, experience, equipments and also abilities in project risk management.

Each contractor, based on the available information and his own view to project risks, evaluates the notified REs. Furthermore, complementary studies by each company and their experience in similar projects can lead to identify some more REs. The 3 other identified REs by these contractors are provided in Table 4.14 and the assessment results of all REs performed by the contractors are provided in Table 4.15. At this stage, if a probable RE is ignored by contractor it will lead to an underestimated bid and could be problematic at the later stages. Conversely, the overestimation of project risks can lead to an overestimated price and thus, losing the opportunity to win the tender. At the end of the tender negotiations, the proposed tenders may help the owner to revise his preliminary list of identified REs.

Contractor B, unlike the other contractor, has experience of working in the region and regarding his knowledge about the climate, considered a low probability of occurrence (3% with 10% Margin of Variation) for the first RE (RE#6). Also, experience of this contractor shows that a very cold weather in this region, leading to cessation of construction, can last one week maximum. As for contractor B, they have not experience of working in the project region and thus, a higher probability with a larger margin of variation (5%+20% MV) was considered for this RE. Furthermore, a quantitative note of 3 was assumed for the impact of this RE on project schedule.

Damage to person or property or materials during construction (RE#150) is a case that contractor B has experienced several times. Conversely, effective safety and health management and respecting labor regulations by contractor A are the reasons why this case is not considered as a RE with a high probability of occurrence. As for RE#316, contractor B has experience on projects with similar difficulties. Their experience, competence and being equipped with all the needed equipments, skilled workers, experts and a good financial background have made this contractor capable to overcome with such difficulties. Their successes in last similar projects prove this issue. Thus, impact assessment of RE#316 on project objectives is much lower than the values proposed by the client.

Based on the assessed REs, and selecting “contractor” as user of the RBS and “contract” as the desired project phase, the convenient RBS’s were generated and the values were aggregated on RBS branches. Figure 4-30 illustrates the two best RBS’s for each contractor, together with the risk analysis results. Comparing the obtained results indicates that contractor A has evaluated the project more risky than contractor B and this is due to different perceptions and different views on project risks. These different views are due to the difference of risk attitude (Wang and Yuan, 2011), competence, experiences, abilities and knowledge of these contractors about the project risks.

Table 4.13. List of the identified REs, shared with contractors for bidding process

No.	RE Code	Risk Event
1	6	Unwanted cold weather during construction phase
2	29	Complexity of project time management due to complex nature of the project
3	43	Strike during implementation phase
4	44	Public concerns related to health and safety of the project due to poor communication
5	54	Litigation conflict with other projects during implementation phase
6	55	Improper intervention of government during implementation phase
7	101	Unpredicted increase of power price during implementation phase
8	150	Damage to persons or property or materials due to poor safety and health management of the project
9	290	Poor communication between different subcontractors
10	316	Project has very complex geology and geotechnical conditions

Table 4.14. Some of the probable risk events, identified by the contractors

No.	RE Code	Risk Event
1 ^{A,B}	103	Lack of needed equipments in project region or country during implementation phase
2 ^A	148	Environmental pollution during implementation phase due to poor inspection of site
3 ^B	300	Delay of government to issue the project permission

^A identified by contractor A

Table 4.15. Risk assessment, prepared by contractor A and B (A/B)

RE Code	Impact							
	Probability		Cost (K€)		Delay (day)		Performance	
	Modified probability	Note	Modified impact	Note	Modified impact	Note	Impact value	Note
6	0.054 / 0.031*	3 / 2	73 / 7.3	3 / 2	31 / 7	3 / 2	0.0049 / 0.0049	2 / 2
29	0.25 / 0.05	4 / 3	7.3 / 7.3	2 / 2	82 / 82	4 / 4	0.0634 / 0.0634	3 / 3
43	0.15 / 0.15	3 / 3	7.3 / 7.3	2 / 2	31 / 31	3 / 3	0.0010 / 0.0010	1 / 1
44	0.05 / 0.02	3 / 2	0.7 / 0.7	1 / 1	8.5 / 8.5	2 / 2	0.0634 / 0.0634	3 / 3
54	0.1 / 0.026	3 / 2	7.3 / 7.3	2 / 2	31 / 31	3 / 3	0.0010 / 0.0010	1 / 1
55	0.02 / 0.02	2 / 2	7.3 / 7.3	2 / 2	82 / 82	4 / 4	0.0010 / 0.0010	1 / 1
101	0.026 / 0.15	2 / 3	73 / 73	3 / 3	8.5 / 8.5	2 / 2	0.0049 / 0.0049	2 / 2
150	0.106 / 0.031	3 / 2	73 / 7.3	3 / 2	31 / 7	3 / 2	0.0049 / 0.0049	2 / 2
290	0.07 / 0.02	3 / 2	7.3 / 7.3	2 / 2	8.5 / 31	2 / 3	0.0049 / 0.0049	2 / 2
316	0.378 / 0.378	4 / 4	730 / 250	4 / 4	82 / 50	4 / 4	0.0049 / 0.0049	2 / 2
103	0.35 / 0.15	4 / 3	300 / 300	4 / 4	30 / 20	3 / 3	0.0049 / 0.0049	2 / 2
148	0.20 / -	3 / -	7.3 / -	2 / -	31 / -	3 / -	0.3171 / -	4 / -
300	- / 0.1	- / 3	- / 7.3	- / 2	- / 60	- / 4	- / 0.0010	- / 1

* The first number is related to contractor A, and the second one for contractor B

- The bold numbers are the notes/values assessed directly by the contractors, and the others are the equivalent notes/values. As an example, 0.054 is the assessed probability of RE#6 by contractor A. The equivalent note of this probability value is 3.



Figure 4-30. Risk analysis results related to contractor A and B

The next step will be the detailed analysis of obtained results based on the risk attitude, constraints and main strategies of each company, to distinguish those risks which are accepted by the contractor and those which have to be shared or transferred to the other parties. Risks should be allocated to the party who has the best means for controlling them (Eskesen et al., 2004). Contractor A has not the capacity and ability to face with all the consequences of RE#316, so they prefer to share the probable consequences of this risk with the owner of the project. Conversely, contractor B has experience of dealing with such REs and thus, he prefers to accept all the probable consequences of this RE. But of course, such a decision will increase the final price, proposed by the contractor.

Dealing with some external risks such as litigation conflict with other projects, delay of government in issue of the project permission or improper intervention of government are much more effective and faster if they are transferred to the client as the organizing authority of public transportation in Lyon area. This is why both contractors have decided to put all responsibilities of such REs on the owner of the project. As for RE#6, contractor B has all the needed equipments and also the experience of working in cold weather. He is capable to deal with such special conditions and thus he decided to accept all responsibilities of this RE. In fact, such a risk event is going to be an opportunity for this contractor since the other one (contractor A) has not the capacity and experience to deal with it.

The other REs are also evaluated and convenient decisions are taken based on the values of REs, their capacity and abilities to deal with risks and the main strategies of the company. The graphical representation of all these decisions, illustrated in Table 4.16, and indicating risk values of each RE (considering different project objectives) and representation of their global risk values (here, a simple average of the three risk notes) using color spectrum, make their understanding and interpretation much more easier.

Table 4.16. Response of contractors to the identified REs

RE Code	Contractor A			Contractor B		
	Accept	Share	Transfer	Accept	Share	Transfer
6		3/3/3		3/2/2		
29		3/4/4			3/3/3	
43	3/3/2			3/3/2		
44			2/3/3			2/2/3
54			3/3/2			3/3/2
55			2/3/2			2/3/2
101			3/2/2		3/2/2	
150	3/3/3			3/2/2		
290	3/3/3			2/2/2		
316		4/4/3		4/4/3		
103		4/4/3		4/3/3		
148	3/3/4			-	-	-
300	-	-	-			3/3/2

2/3/4: Risk on cost/time/quality

Having this information and taking the risks and their allocation into consideration, each contractor can evaluate the final project cost and then bid the project out. The owner of the project has to evaluate all this information in detail and based on the proposed schedules and prices, experience and competence of the contractors, the evaluated risks, their allocations and the proposed solutions, and using a multi-criteria decision making method (ex. AHP, ELECTRE) select the best contractor for the project (Holt, 1998; Eskesen, 2004; Darvish et al., 2009; Jaskowski et al., 2010).

When a contractor has been chosen, negotiations between the owner and the contractor may lead to a detailed contractual description of the risk management system to be implemented on the project. This may be based on a combination of the intentions of the owner and the suggested procedures of the contractor with the purpose of improving the co-operation between the parties. Alternative technical solutions will also be negotiated on the basis of risk assessments carried out and stated in the contract (Eskesen et al., 2004).

It was the bid from the consortium steered by Chantiers Modernes Rhône Alpes which was accepted in November 2008. The Engineers then drew up a detailed plan, in compliance with the final bid accepted, in consultation with the consortium.

Before starting the contracting process, identification of probable risks related to contract documents and contracting procedure can help to prevent future difficulties of stakeholders with contract. Probable risks related to the contract documents were identified through the long list of risk events available in the database (see Table 4.17). Then, after their assessment (from the client perspective) the values were aggregated on RBS branches and the convenient RBS's were generated (setting "owner" as the desired user of the RBS and "contract" as the desired project phase). At this stage, we aim to focus on risks related to the contract phase and thus, all the other REs identified during the feasibility phase were disregarded during this

procedure. But of course, all these ignored REs and their values were effectively taken into consideration during the assessment of the new REs. For instance, RE#33 and 158 which are related to project funding difficulties (delay in project fund allocation and financial situation of financier) have been identified and treated during the feasibility phase. Obviously, all these actions have influence on assessment of RE#294 which has been identified in contract phase. As for RE#181, it was identified in the very beginning stages of the contracting procedure and was assessed as a significant RE. But the adopted strategy of the client in asking all the companies to present a final bid, based on a shared and very precise definition of the risks and their allocation, made this RE less likely.

As expected, regarding the few number of selected REs (only 8), a one-level RBS was selected as the most convenient one which decompose the project risks into different project stakeholders, management risks and also to external risks of the project. The “quality” of the RBS was improved by more decomposition of risky categories and focusing on contracting risks. The result is illustrated in Figure 4-31.

The results indicate that the client has to pay special attention to prevent probable conflicts with contract documents. Some external risks also affect the contracting procedure but regarding the performed preventive actions and defined strategies during the feasibility phase, they are not considered as significant.

Table 4.17. Preliminary list of the most probable risk events related to the contracting procedure

No.	RE Code	Risk Event
1	17	Improper intervention of government during contract phase
2	78	Conflict of laws related to one of contract clauses (laws are not consistent)
3	87	Inconsistency of contract clauses
4	92	Delay in contract issue by owner of the project
5	93	Type of contract between owner and contractor is not allowed by laws regarding special type of the project
6	180	Inappropriate form or type of the contract
7	181	Allocation of risks to the parties is not mentioned or is not clear in the contract
8	294	Changing of mind of bank before finalizing the contract

Table 4.18. Modified values considering uncertainties and corresponding notes

RE Code	Impact							
	Probability		Cost (K€)		Delay (day)		Performance	
	Modified probability	Note	Modified impact	Note	Modified impact	Note	Impact value	Note
17	0.03	2	0.7	1	31	3	0.0010	1
78	0.052	3	7.3	2	31	3	0.0049	2
87	0.11	3	7.3	2	31	3	0.0049	2
92	0.151	3	0.7	1	66	4	0.0010	1
93	0.03	2	7.3	2	8.5	2	0.0049	2
180	0.055	3	7.3	2	8.5	2	0.0049	2
181	0.053	3	730	4	82	4	0.0634	3
294	0.021	2	7.3	2	99	4	0.0049	2

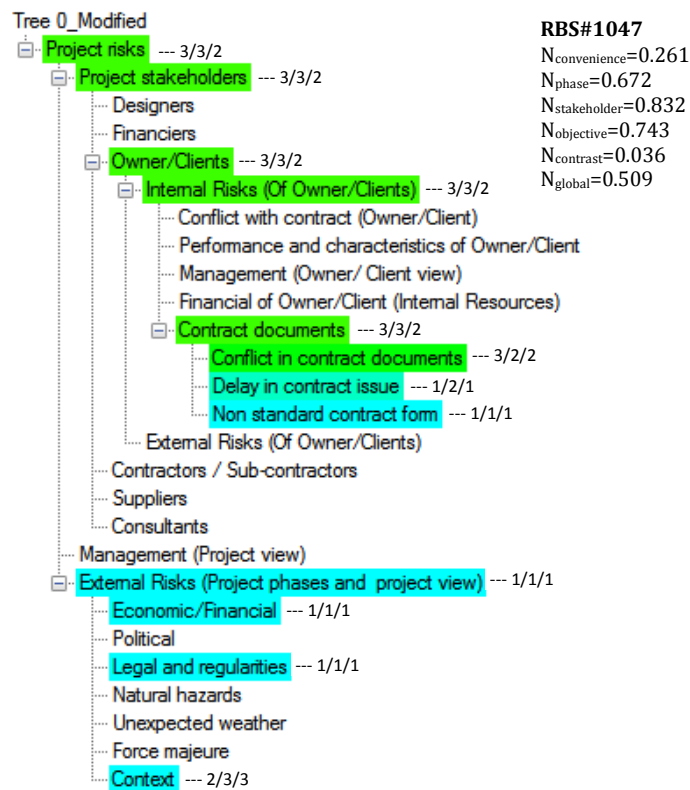


Figure 4-31. Focus on risks related to contracting procedure

4.3.3. Identification and assessment of risks related to design phase

4.3.3.1. Risk identification using the database search engine

In this section we aim to identify and analyze the probable risks related to design and designers of the project and also the external risks which may disrupt this process. Furthermore it will be shown how the user can focus more on risky categories and how the quality of the selected RBS can be improved.

The first step is to find the probable risk events and we would like to show how the developed software can be helpful in this process. The database is equipped with a search engine which facilitates identification of REs, RCs or even the MTs based on their ID code or the desired keywords (to get more information, see Appendix 3 at the end of this manuscript). To start, “design” (as a keyword) was searched in the database of risk categories to find all corresponding categories. As is illustrated in Figure 4-32, it seems that *RC#56: Design (phase)* is the most general category, since it is the subcategory of MT#3 and usually appears in the first level of generated RBS’s. The list of REs corresponding to this category is represented at the right side of the window. All of them have to be evaluated and discussed one by one to select the probable ones for the current project. Among the 87 corresponding REs, 67 ones

were considered as probable. Then, by a more precise evaluation and following the same procedure as for the feasibility and contract phases, the probability and impact values were evaluated for each one and their individual risk values were calculated. Table 4.19 is a list of the most risky identified REs and Table 4.20 provides a part of the risk assessment results.

During development of our database, all the identified REs and RCs were ranked based on their criticality and frequency of occurrence in studied projects and literature. Furthermore, using the developed software, the data related to identified and assessed REs for each special project are registered in a data file which can be shared and compared with other projects. Having such information can effectively help in identification and assessment of probable REs in future projects.

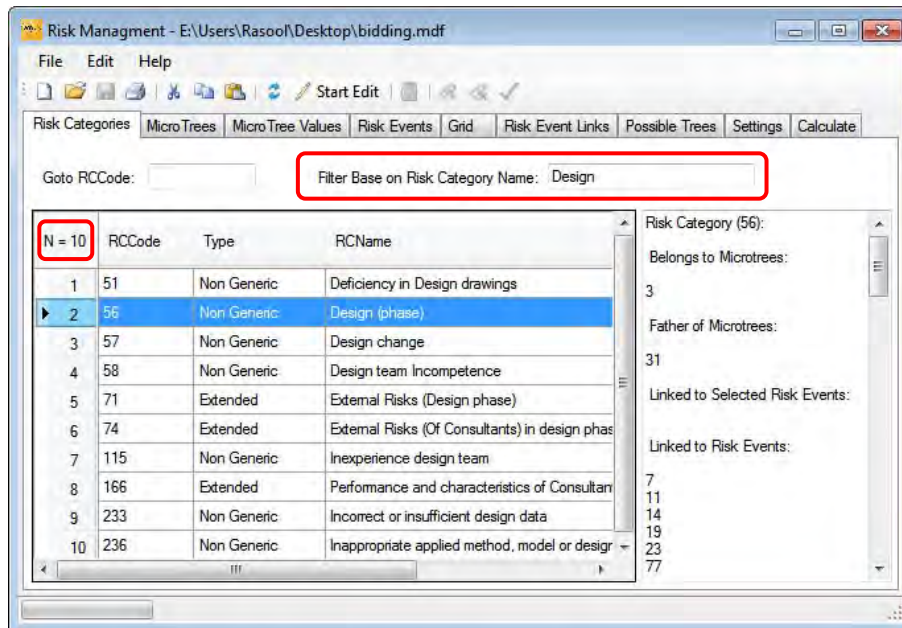


Figure 4-32. Searching a keyword in the risk category database

Considering the selected REs and assuming “design” and “designers” as the desired phase and the user of RBS’s, respectively, all the possible homogenous RBS’s were generated, ranked and the most convenient one with the maximum global quality note was selected. Figure 4-33-a illustrates the selected RBS together with the obtained results of risk analysis and also the number of attached REs to each risk category. As the results indicate, at the current stage, most of the identified risks are related to designers and project consultants. However, some of the identified risks are affecting the design process from the external environment of the project (external risks). Furthermore, some of the RBS categories are not affected by any RE, such as management category, but as it was discussed in section 4.3.1.3, they can be helpful in identification of new REs which may have been forgotten during the previous identification steps.

Table 4.19. A partial list of the riskiest REs related to design phase

No.	RE Code	Risk Event
1	10	Mistake in design
2	190	Design process doesn't include impact assessment of the construction on third party structures and infrastructures.
3	186	Inappropriate method used by designer for design risk assessment
4	189	Design process doesn't include sensitivity study to assess the impact of natural hazards
5	233	Poor or defective design due to using inappropriate design parameters
6	202	Poor design due to disregarding to the possibility of flooding from surface run-off, tidal water, rivers, etc.
7	191	Poor design check by consultant regarding the level of complexity and type of construction of the Tunnel Works
8	192	Poor design check by consultant regarding the level of risks for tunnel works and/or third party
9	218	Defective or inconvenient design of TBM or excavation machine (Type of machine, structure)
10	219	Defective or inconvenient design of TBM operation parameters (Speed, balance pressure in face, ...)
11	196	Design process doesn't take account of the impact of staged or sequential excavations
12	228	Mistake of designer in remedial action planning and design
13	296	Poor or defective design due to disregarding to environmental effect of the project (poor environmental analysis)
14	223	Inadequate method (model) used for blasting design (type, quantity,...)
15	26	Change of design because of poor understanding of customer needs

Table 4.20. Risk assessment of the riskiest REs related to the design phase

RE Code	Probability		Impact						Risk notes		
	Modified probability	Note	Cost (K€)		Delay (day)		Performance		Cost (K€)	Delay (day)	Performance
			Modified impact	Note	Modified impact	Note	Impact value	Note			
10	0.15	3	730	4	82	4	0.0634	3	4	4	4
190	0.10	3	730	4	82	4	0.3171	4	4	4	4
186	0.08	3	730	4	82	4	0.3171	4	4	3	4
189	0.05	3	730	4	82	4	0.3171	4	4	3	4
233	0.05	3	730	4	82	4	0.3171	4	4	3	4
202	0.10	3	730	4	82	4	0.0634	3	4	4	3
191	0.05	3	73	3	8.5	2	0.3171	4	3	3	4
192	0.05	3	73	3	8.5	2	0.3171	4	3	3	4
218	0.07	3	73	3	82	4	0.3171	4	3	3	4
219	0.09	3	73	3	82	4	0.3171	4	3	3	4
196	0.07	3	73	3	82	4	0.3171	4	3	3	4
228	0.06	3	73	3	31	3	0.3171	4	3	3	4
296	0.05	3	7.3	2	8.5	2	0.3171	4	3	3	4
223	0.04	3	730	4	31	3	0.0049	2	4	3	3
26	0.02	2	730	4	82	4	0.0634	3	3	3	3

4.3.3.2. Quality improvement of the selected RBS

Selection of the most convenient RBS is a multi-criteria question and at the current example, despite the very non-homogeneous distribution of the selected REs to the bottom level categories, the selected 2-level RBS (Figure 4-33-a) has the maximum global quality note and is considered as the most convenient one. Of course, it is not the “best” RBS but the most adapted one to the current case. Its quality can be further improved by more decomposition of the risky bottom level categories and removing the negligible micro trees.

As is illustrated in Figure 4-33-b, we have focused more on “designer” category, with 59 corresponding REs, and it was decomposed into 4 subcategories of conflict with contract, performance and characteristics of designers, resource definition and design team incompetence. The first one was the most significant one with 55 corresponding REs and a critical impact on project schedule, thus, it was decomposed again to a lower level. Each bottom level category, regarding the level of criticality and the number of attached REs, was further decomposed if the corresponding MT was available in the database. Furthermore, at the current stage, none of REs are attributed to the subcategories of “management” category, thus, this MT can be removed. The final result is a 7-level RBS with focus on risks related to designers of the project. The significant increase of $N_{convenience}$ (from 0.088 to 0.404) and the global quality note prove this quality improvement. Nevertheless, it can be seen that “disregarding to the effective parameters and standards” which is a bottom level category is connected to 23 REs. Development of new MTs to decompose this category can further increase the quality of the RBS.



Figure 4-33. a) Tailored RBS for the project designers b) Focus on risks related to designers

In this representative example we considered only the probable REs related to design phase, but such analysis can be performed even during the feasibility and contract phase with a more plenary and prospective view to project risks. In this case, the overall project risks have to be evaluated considering all the identified REs related to different project phases.

4.3.3.3. Actions to reduce and manage the identified design risks

Incorrect or insufficient design data which is mostly related to geology and geotechnical data is one of the main risks faced by designers. The complementary geological investigations, performed during the feasibility phase which refined the geological profile, have provided all needed information for technical design and thus, reduced effectively the corresponding risks attributed to designers. Table 4.21 represents some of these REs which were influenced by the performed actions and some of them, such as RE#201 and 209, were assessed as improbable.

Table 4.21. A partial list of REs which their assessment is influenced by the performed complementary geological and geotechnical investigations

RE Code	Risk Event
201	Defective design due to incorrect evaluation of the water table level
209	Poor design due to disregarding to the existing chemical contamination of soil and ground water
210	Poor design due to disregarding to the presence of methane, or other hazardous gases
231	Insufficient information is available for selection of the tunneling method
235	Poor or defective design due to poor or insufficient geotechnical investigation
236	Poor or defective design due to mistake in evaluation and analysis of available geotechnical information (Soil static/dynamic strength and hydro-geological parameters)

As for digging the TBM exit shaft (18 meters in diameter and 30 meters depth) two methods were designed according to the type of encountered soil. Up to 8 meters depth, the digging was done with shovels in the ground made up of soft alluvium. From 8 meters depth to 30m, the soil consists of granite; the digging was done by blasting, from late June to November 2010. Table 4.22 illustrates some identified risk events related to blasting design. Regarding these REs, the client made a referred preventive campaign which was evaluation of buildings in a radius of 80 meters around the exit shaft of TBM and within 25 meters on both sides of the future tunnel. Furthermore, he conducted a series of blasting tests (low load explosion) in April 2010 to measure the impact of an explosion on surrounding buildings through the sensors placed on buildings and inside of some apartments. These actions provided all the needed information for design of blasting process and effectively reduced the risk values of mentioned identified REs.

Table 4.22. Identified risk events related to blasting design

No.	RE Code	Risk Event
1	190	Design process doesn't include an assessment of the impact of construction on third party structures and infrastructures.
2	212	Poor design due to disregarding to ground vibrations, overpressures from blasting and fly rock
3	213	Poor design due to disregarding to the effect of explosion on surrounding strata and tunnel stability
4	223	Inadequate method (model) used for blasting design (type, quantity,...)

4.3.4. A more comprehensive risk analysis of the project – construction phase

During the construction phase, most of the partners are involved in project. An effective dynamic process of identification, assessment and controlling of project risks has to be applied to reduce the probable troubles faced by project and project partners. Furthermore, management of relationships and interfaces between stakeholders is an important key to project success and has to be taken into consideration. Thus, a more comprehensive risk analysis of the project is needed, considering different perspectives of stakeholders to project risks.

Through the 169 identified REs related to construction phase, 115 ones were selected as probable, 18 of them are concerning the project and stakeholder management. Following the same process as for preceding phases, the selected REs were evaluated and probability and impact values were assessed. Table 4.23 provides a list of the most significant identified REs by the preliminary investigation.

It should be noted again that, evidently, the list of selected REs is not comprehensive, but a start point to generate convenient RBS's and identification of new/forgotten REs. However, understanding, evaluation and dealing with such a long list of identified REs is not easy. Generation of tailored RBS's which are adapted to requirements of user, their special perspective to project risks and the level of available information can effectively be helpful in synthesizing all these data and facilitate discussing about the project risks. In the following, we aim to show how design of tailored RBS's and risk analysis results are sensitive to the user requirements, applied parameters and different perspectives of stakeholders to project risks.

Table 4.23. List of the most significant REs related to implementation phase

No.	RE Code	Risk Event
1	268	Fracturing of the ground or damage to nearby services, buildings or structures due to Inappropriate pressure of grouting, applied by operator
2	155	Technical mistakes during construction stage by contractor
3	146	Consultant is not informed about the changes in project during implementation phase
4	2	Failure of equipments and mechanical systems due to irregular mechanical control by contractor
5	4	Incident or construction accidents during implementation phase due to poor workmanship
6	27	Poor communication between stakeholders of the project to manage the project schedule
7	48	Economic slowdown, economic crisis during implementation phase
8	126	Poor exchange of information between contractors/ subcontractors
9	240	Poor communication of designer and contractor to control of suitability and constructability of employed construction method by contractor
10	251	Accident due to falling objects
11	260	Inadequate storage, transport and use of explosives (inexperience contractor)
12	276	Disregarding to sequential and staged activities of remedial action by contractor
13	278	Disregard to different warning signs (excessive deformation, crack...) by contractor
14	156	Irregular or inadequacy of site inspection by consultant during implementation phase
15	43	Strike during implementation phase

4.4. Lyon metro case study: Sensitivity of results to the applied parameters in construction phase

Up to here, generation of tailored RBS's and analysis of risk values were performed without discussing about the involved parameters (ex. A_v , desired number of attached REs to each bottom level category; Φ_i , the weighting factors of the five quality notes; risk analysis function, etc.). In this section, based on the identified REs during the construction phase, we will explain how the RBS design or risk analysis results can be affected by the values of the involved parameters.

4.4.1. Adequacy of the decomposition level

The desired number of associated REs to each bottom level category (A_v) is one of the parameters involved in generation of tailored RBS's. To evaluate the effect of this parameter in extracting RBS's with the desired level of detail, the RBS generation was repeated for different values of A_v . In the first try, regarding the considerable number of selected REs related to the construction phase (115), "6" was selected as the A_v value. Considering the three project objectives, all the project stakeholders and focusing on the construction phase as the requirements of the user and taking the default values for the other parameters, all the homogenous RBS's were generated and the five quality notes were calculated. Considering only the first quality criteria (adequacy of the decomposition level), all the generated RBS's were ranked and the most convenient one with the maximum value of $N_{conv.}$ was selected. Figure 4-34-a represents this 2-level RBS together with the number of attached REs to each bottom level category. However the "contractor/subcontractor" category has 60 attributed REs but considering $A_v=6$, this homogenous RBS is the most convenient one regarding the required level of details.

In a second try, only A_v was changed to be 5 and the RBS generation process was repeated. The result was a 3-level RBS which decomposes the "contractor/subcontractor" category into 5 subcategories at the third level.

As it was explained in section 3.3.5.1, smaller values of A_v should be taken if more level of details of RBS (RBS with larger number of levels) is desired and the obtained results illustrated in Figure 4-34 and Figure 4-35 confirm this issue.

An important point here is that, all the generated RBS's are homogenous and even RBS#4631 (in Figure 4-35 with $A_v=3$) has the maximum value of $N_{conv.}$, but it does not mean that this RBS is the "best one" regarding the required level of details. It can be seen that 49 REs are attached to "performance of the contractors/subcontractors" category which is much different from the required number ($A_v=3$) and also the subcategories of "Designers" are not connected to any RE. In fact, this RBS has the most convenient level of details among all the generated homogenous RBS's, but its quality can be further improved manually by further

decomposition of risky bottom level categories and removing negligible MTs. Figure 4-35.b illustrates a modified form of RBS#2114 with a greater value of N_{conv} .

Taking decision to select the most convenient RBS for a special case is a multi-criteria question and regarding the preferences of the user, the most convenient one has not necessarily the maximum note of N_{conv} . This is why the variation effect of A_v has to be studied, not only on the RBS's with the maximum values of N_{conv} , but also on all the generated RBS's.

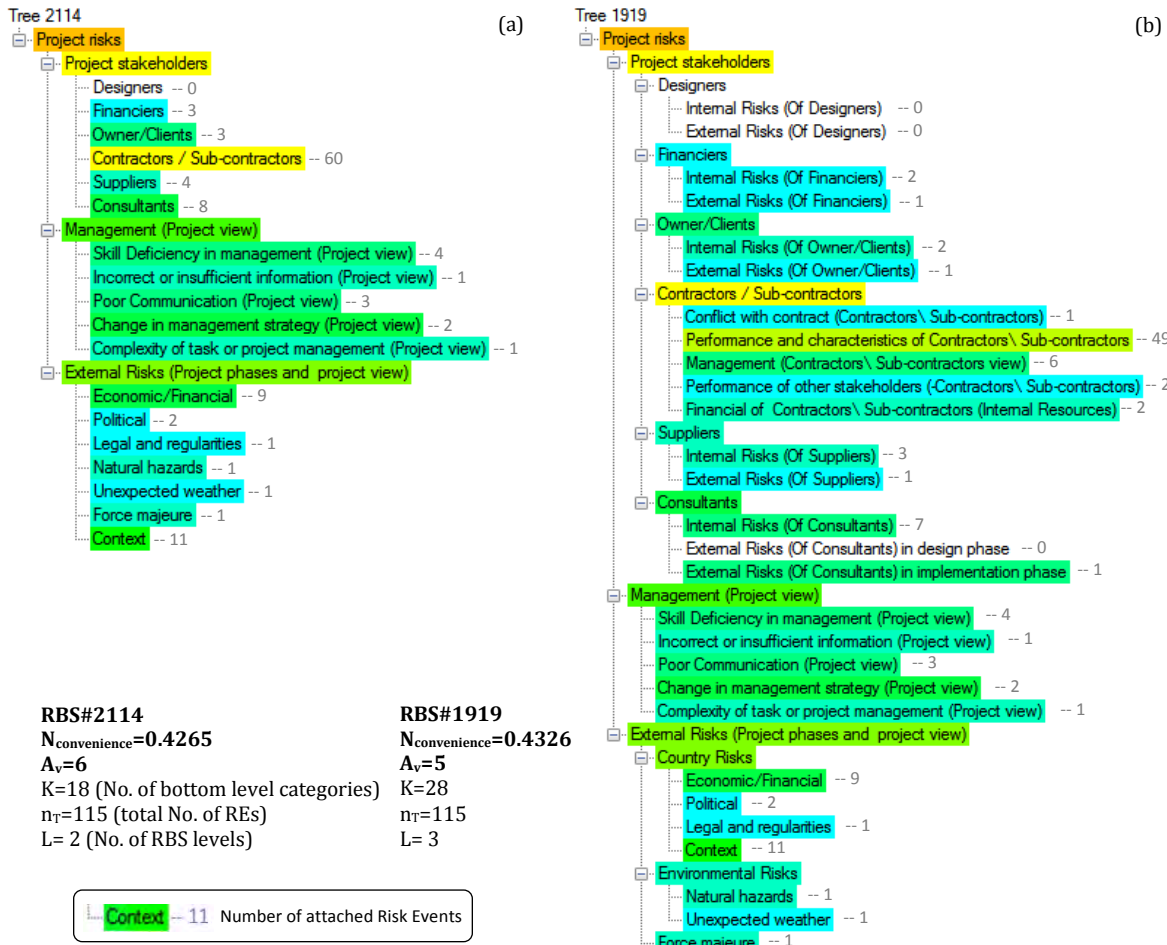
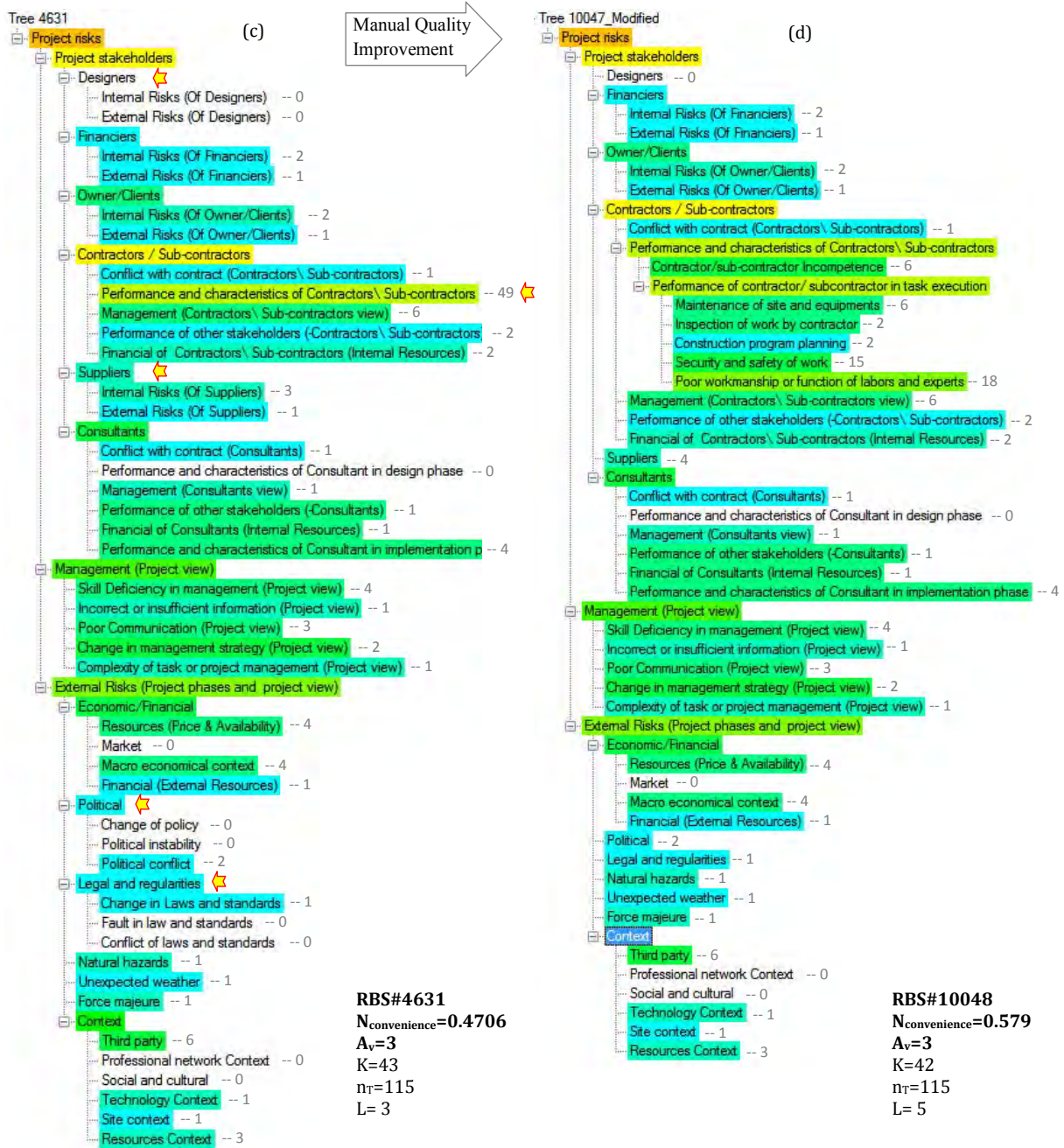


Figure 4-34. RBS with the maximum value of N_{conv} ($A_v=6$ and $A_v=5$)



RBS#4631
 $N_{convenience}=0.4706$
 $A_v=3$
 $K=43$
 $n_r=115$
 $L=3$



RBS#10048
 $N_{convenience}=0.579$
 $A_v=3$
 $K=42$
 $n_r=115$
 $L=5$

Figure 4-35. RBS with the maximum value of N_{conv} ($A_v=3$) and manual further quality improvement

Figure 4-36 illustrates the frequency of N_{conv} notes of all the generated RBS's for different values of A_v . However the maximum value of N_{conv} corresponding to different values of A_v has not notable changes, but for the larger values of A_v , most of the RBS's have very small values of N_{conv} . In other words, by increase of A_v , the values of N_{conv} are decreasing, indicating that the contribution of N_{conv} in final global notes of the RBS's is decreasing as well. However, this is not a general rule since the number and distribution of the selected risk events on RBS branches can change this result.

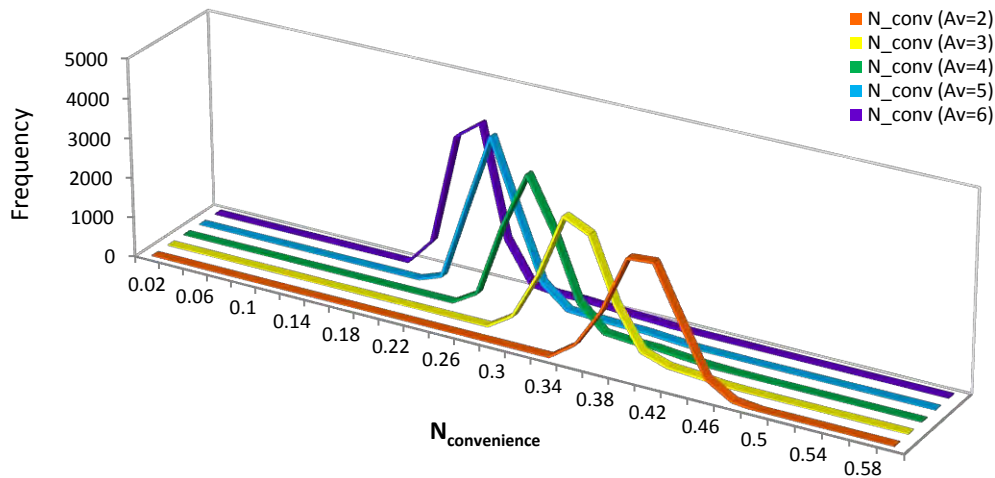


Figure 4-36. Variation of N_{conv} for different values of A_v

The most convenient RBS corresponding to $A_v=3$ was a 3-level tree with 43 bottom level categories. The three RBS's, illustrated in Figure 4-37 are the most inconvenient ones since the number of REs attributed to the bottom level categories are extremely different from the desired number A_v . These RBS's decompose the project risks based on different logics but not with a convenient level of details. Concentration of 97 REs to the implementation category and 18 REs to the management category, while the other subcategories are null, is the reason why RBS#9861 has the minimum quality note of N_{conv} . However in the second and third RBS's, the distribution of selected REs is much more equilibrated, but still much far from the desired number to each bottom level category ($A_v=3$).

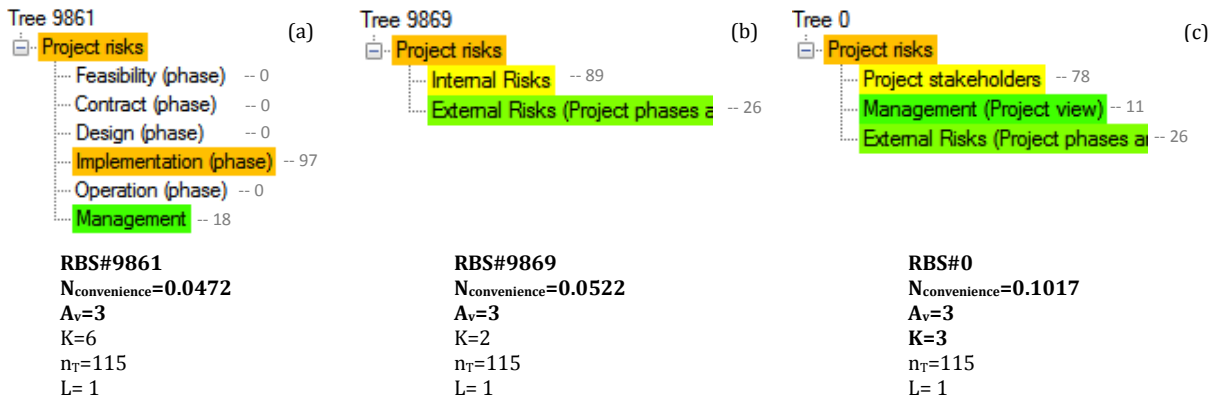


Figure 4-37. The three most inconvenient RBS's regarding adequacy of the decomposition level ($A_v=3$)

4.4.2. Preference notes of the five quality notes

As it was discussed in section 3.3.6, any multi-criteria decision method can be used to select the most convenient RBS based on the five quality notes. Also, a simple method being the weighted average of the five quality notes was proposed to facilitate this process. Each

user has different preference to the five RBS quality notes, and in this section we aim to show the sensibility of results to these preference notes.

Considering the identified risk events during the construction phase, the three project objectives, all the project stakeholders and focusing on the construction phase as the requirements of the user, $A_v=3$ and taking the default values for the other parameters, all the homogenous RBS's were generated and the five quality notes were calculated.

If one of the project stakeholders prefer to have an RBS only with a significant contrast of risk values regardless of the other criteria, the RBS illustrated in Figure 4-37-a would be the best option. This RBS among the 10047 generated RBS has the maximum contrast note. When important decisions have to be taken, such an RBS which clearly distinguish the risky and non risky domains of the project would be so useful. Furthermore, this RBS is the best option when a temporal view to project risks is desired. The interesting point is that this RBS, as was explained in last section, with concentration of 97 REs to the implementation category, 18 REs to the management category and 4 null categories has the minimum quality note of N_{conv} and is the most inconvenient one regarding the required level of details. Based on this criterion (level of details), the 5-level RBS represented in Figure 4-35-d with 42 bottom level categories is the best option. To facilitate discussing about risks, if a shared RBS which clearly distinguishes the risks allocated to different project stakeholders is desired, the RBS represented in Figure 4-37-c would be the best option. However, this RBS is not convenient at all regarding the required level of details.

As it can be seen, different RBS's can be proposed regarding different preferences of the user and the preference notes (Φ_i) have been adopted to take these preferences into account during the selection of the most convenient RBS. At the current example, assuming the same preference notes for the five quality criteria ($\Phi_i=0.2$, $i= 1$ to 5), the most convenient RBS would be RBS#2114 represented in Figure 4-34-a. However, its quality can be further improved by further decomposition of the “contractors/subcontractors” category. Figure 4-38 provides the five quality notes of this RBS together with the range of these notes for all the generated RBS's. The results provided in Figure 4-38 indicates that the selected RBS is not the best one regarding each one of the criterion but an RBS which has the maximum global note considering the same preferences to the five quality criteria.

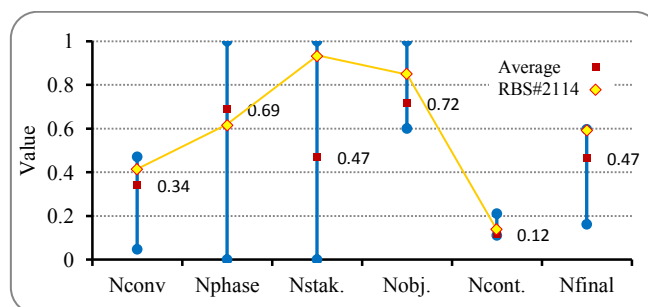


Figure 4-38. Range of the five quality notes for all the generated RBS's

4.4.3. Preferences to the project objectives

As it was explained in section 3.4.8, any multi-criteria decision making method (AHP, ELECTRE, etc.) can be used to transfer the three risk notes of each RC or RE (notes of 1 to 5), corresponding to three project objectives, to a global risk note. The risk analysis results of all presented RBS's in last sections were based on a simple calculation of the global risk note of each category with the same preference for the three main objectives of cost, delay and quality of the project. However, changing the desired project object as one of the effective parameters in generation of tailored RBS's can affect the final results.

To show how the desired objective can affect the generation of tailored RBS's, assuming all the parameters the same as in the last section and considering all the REs identified during the construction phase (115 REs), generation of tailored RBS's was repeated for different objectives. Figure 4-39 provides a part of the obtained results. The first RBS (a) is the most convenient one considering the same preferences to the three project objectives. The results indicate that at the current stage of the project, the risks attributed to the contractors and the context risks are the most significant ones.

In a second try, management of project cost was selected as the desired objective and the most convenient RBS regarding the global quality notes was selected. Figure 4-39-b illustrates this RBS together with the cost risk values and notes of categories. The results indicate that the risks attributed to the contractors and also economic/financial risks have significant consequences on final cost of the project. Furthermore, it can be seen that by change of the desired objective not only the risk analysis results but also the structure of the tree has changed. In fact, if management of the final cost is desired, this RBS with an explicit decomposition of management category based on different management objectives (cost, time, quality, etc.) is the most convenient one. This is while the last RBS (a) decomposes the management category according to the possible causes of management risks.

This process was repeated for “delay” and “quality” as the desired project objectives. At the present stage of the project, the risks attributed to the contractors and project time management, together with context and economic risks have significant effect of project schedule. As for quality/performance of the project, contractors and consultants are the main sources of risks. Furthermore, the context risks have an important effect on quality of the project from the external environment of the projects.

As the results show, change of the desired objective affect the final quality notes of the RBS's not only through the objective quality note ($N_{\text{objective}}$) but also through the risk values of categories and thus the contrast quality note (N_{contrast}). As consequence, different preferences to the project objectives can lead to different RBS's with different structures and risk values.



Figure 4-39. Effect of the desired project objective on generation of tailored RBS's

4.4.4. Weights for the RBS levels

As it was explained in section 3.3.5.2, the weighting factors (ω_i) were defined so as to give more importance to higher levels of the RBS. In this section, we show how changing of these factors can affect the generation of tailored RBS's.

In a first try, assuming “contractors”, “time management”, “implementation phase” and $A_v=3$ as requirements of the user, and taking the default values for the other parameters, all homogenous RBS's were generated and the most convenient one was selected (RBS#7044 in Figure 4-40). The RBS level weighting factors (ω_i) applied in this try are given in Figure 4-40, and Table 4.24 provides the calculated RBS quality notes.

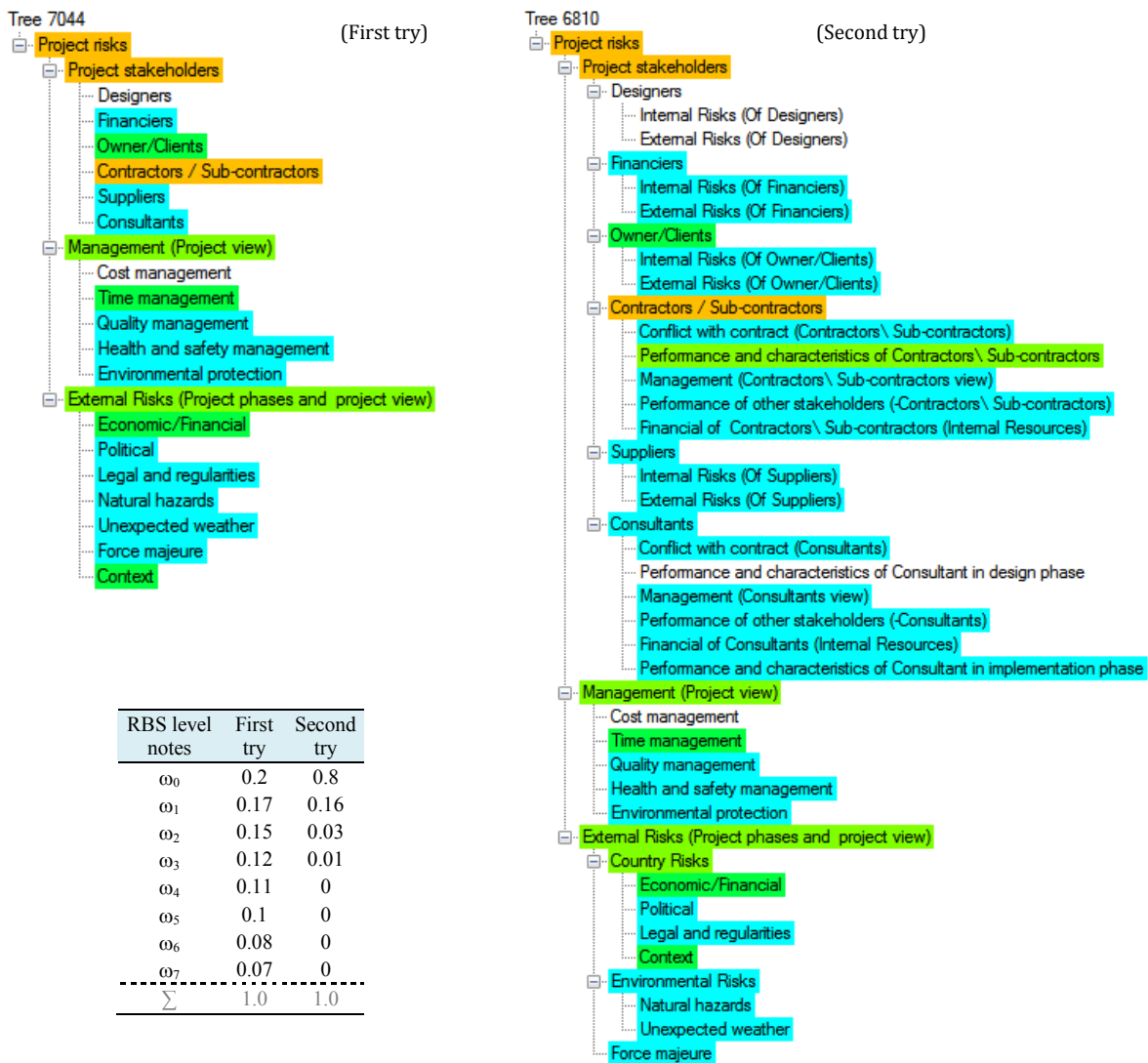


Figure 4-40. Effect of the RBS level notes (ω_i) on tailored RBS generation

Table 4.24. Effect of the RBS level notes (ω_i) on RBS quality notes

	First try		Second try	
	RBS#7044	RBS#6810	RBS#7044	RBS#6810
$N_{\text{convenience}}$	0.393	0.446	0.393	0.446
N_{phase}	0.639	0.772	0.525	0.576
$N_{\text{stakeholder}}$	0.761	0.471	0.875	0.784
$N_{\text{objective}}$	0.792	0.781	0.700	0.712
N_{contrast}	0.158	0.126	0.184	0.183
N_{global}	0.548	0.519	0.535	0.540
The most convenient RBS	√		√	

In a second try, only the ω_i values were changed to deviate the RBS level weighting factors to the higher levels of the RBS, and all the RBS's with new quality notes were regenerated. The applied ω_i values are given in Figure 4-40. By this change, the user gives much more importance to the properties of MTs at the higher levels of the RBS. As result, RBS#6810 with the maximum global quality note of 0.540 was selected as the most convenient one.

To see how changing of RBS level notes (ω_i) can affect the generation process of tailored RBS's, the quality notes of the 2 selected RBS's, corresponding to the two last tries, have been compared in Table 4.24. As the results show, variation of the RBS level weighting factors affects all the RBS quality notes except N_{conv} . In other words, even the two selected RBS's have different number of levels, but this difference is not due N_{conv} note.

The results provided in Table 4.24 show that, in the first try by a smooth distribution of weighting factors on different RBS levels, RBS#7044 has the maximum global quality note while RBS#8610 with the global quality note of 0.519 has the 6th position between the high ranked RBS's. By the adopted changes and a sharp deviation of weighting factors to the higher levels of the RBS, RBS#7044 got the 11th place while RBS#6810 with the global quality note of 0.540 is the most convenient one.

This representative example shows the influence of the RBS level weighting factors on tailored RBS generation process and as was explained in the last chapter, the greater the values of ω_i , the more important are the MTs at the higher levels of RBS. Furthermore, the user has always the possibility to change these notes to better fit his own purpose.

4.5. Summary and conclusions

In this chapter we tried to show a practical application of the proposed method represented in chapter 2. To do that, a complex construction project was selected as an illustrative support. The choice was the extension project of Lyon metro; a complex project to extend the public transport network in Lyon. We emphasize again that we had not involved in this project and we have just used the available project information to show the capacity of our methodology.

The chapter began with a brief introduction of the software which has been developed for an easy application of the proposed methodology in real projects. The software integrates all the concepts and algorithms of the method with a user friendly interface. More extensive information is provided in Appendix 3. Then, after a general introduction to extension project of Lyon Metro, the focus was on a dynamic and multi-perspective risk management of the project. The PRM process was started with a primary risk identification and assessment of the probable REs related to the feasibility phase and it was explained how study of literature, risk management reports, check lists, risk registers and applied RBS's of similar projects can be helpful in this stage. Then it was shown how the identified REs can be individually analyzed regardless of their overall effects on project objectives.

To analyze the overall effect of the identified REs, the convenient RBS's were generated and it was explained how they can be useful in identification of new REs which may have been forgotten during the first analysis. Furthermore, it was shown how the quality of the selected RBS's can be further improved, how the risk identification process, generation of tailored RBS's and risk analysis process is iterative and how the results have to be updated whenever new information is available.

During the bidding process, it was explained how a risk based project analysis can be performed by each one of the contractors and how risk analysis process can provide different results based on different perspectives of client and contractors to project risks. As it was explained, these different views are due to the difference of risk attitude, competence, experiences, abilities and knowledge and information of contractors about the project risks.

The last sections focused on some parts of the user requirements, explaining how they can affect the generation process of the tailored RBS's. It was shown, how different requirements of the user (such as the required level of details, preferences to the project objectives and different quality notes of the RBS, etc.) can lead to generate different tailored RBS's, while the same REs are selected in the database. It was shown, how the desired objective(s) of the user can affect the risk analysis results and also the decomposition form of categories in RBS. Furthermore, it was explained that different partners, based on their competence, risk attitude and experiences may identify some special risk events which are not considerable for the others. All these differences can be summarized in one word, being different perspectives of stakeholders to project risks.

Chapter 5

GENERAL CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORKS

5. General Conclusion and recommendations

5.1. General summary and conclusions

Construction projects, like all complex activities, involve many partners with different objectives, who are subjected to many risks in an uncertain environment. In practice, different project stakeholders have different understanding and perception of project risks. Each one identifies and analyzes the project risks regarding his objectives, risk attitude and special perspective to project risks without relying on a common and shared methodology. This is why in most of construction projects, discussing the project risks and making risk based decisions are of common difficulties which may also cause to disputes between project parties. Improving the risk management process is therefore a key challenge.

In this research, we have developed a methodology for a dynamic, multi-scale and multi-perspective risk management of construction projects. This method is based on the application of tailor-made risk breakdown structures which are well adapted to the stage and degree of development of project, specific requirements and objectives of project stakeholders, and required level of details. Using this method, each of the project stakeholders, at each stage of the project and regarding his special view to project risks can build his own specific RBS. However, the RBS can also be tailored as a shared support for all the project stakeholders in order to facilitate understanding and discussing project risks. Using these tailored RBS's which are all generated using a unique procedure and knowledge base, each of project stakeholders can identify, analyze and represent the project risks regarding his point of view and requirements. The method ensures the consistency of all these perspectives.

The first difficulty encountered was to develop a common language as the underlying basis for risk description with which the project risks can be described and discussed. Thus, a thorough analysis of literature, accidents, technical reports, codes and standards related to construction projects led to the development a comprehensive knowledge base of risks which contains three interactive components: risk events, risk categories and micro trees. The idea is that each risk category can be further decomposed when more level of details is required and for decomposition of each category, different options can be proposed, each of them being more convenient for some special cases (special phase, stakeholder or project objective). The development process was mostly empirical and iterative since the risk categories and their relative organization within micro-trees had to be identified together.

This knowledge base is sufficiently general to cover all construction projects, and sufficiently specific to be adapted to any particular project. The general version of the database was extended to cover the most common risk events of two specific cases: tunneling projects and temporary structures. However, by following the proposed procedure and criteria, the user can build his own original database of risks if he has different preferences.

In addition to the academic development of the database, it was important to ensure the consistency of the knowledgebase with professional practices. This is the reason why engineers and consultants involved in the GERMA project, belonging to one main contractor and several consultant companies, contributed to this study. Regular discussions were held in order to validate the content of the databases.

In parallel, efforts were devoted to the automatic rebuilding process of tailored RBS's that must be scalable, adaptable to the project development and able to represent different perspectives of stakeholders to project risks. The process begins with rebuilding of all "possible" homogeneous RBS's with combination of available micro trees in the database. The constraint of being homogenous (RBS with the same number of level on all branches) was adopted in order to reduce the number of possible RBS's which could exceed to several billions. Then, all the identified REs by the user are propagated through the RBS's branches to calculate the risk values of risk categories. The rebuilt RBS's are then compared with regard to a set of five notes, enabling one to have, at the same time, different "convenient RBS's" for different project partners and making communication between partners easier. It is on the basis of these five notes that all RBS's can be compared and the best ones selected, using a final multi-criteria decision process.

The quality of the final selected RBS with the highest ranking can be further improved by extending the bottom level categories with high-risk value and/or considerable number of attached REs and removing the negligible MTs regarding the level of details and criticality. Moreover, the user can focus on some specific risks by further decomposition of relevant categories. This method allows identifying and managing the construction project risks in a more formal, efficient and systematic way.

A specific method was developed in order to calculate the risk values of REs regarding different project objectives, aggregate the risk values through the RBS branches and also to calculate global risk value of project. The method combines consistently the quantitative and qualitative approaches, allowing the user to choose the best one for risk assessment at any level, based on the available information and required accuracy. In this method, at the first step, the probability and impact factors of risk events are assessed quantitatively or qualitatively. Two concomitant scales are used: a continuous cardinal scale and a discrete ordinal scale ranging from 1 to 5. Each scale has its own advantage. Continuous scale is closer to physical reality and has a more concrete meaning while discrete scale has a strong symbolic value. The assessments based on each of these scales can be converted to the other one following a defined process. At the second step, the risk values of REs are calculated and then aggregated through the RBS branches in order to calculate the risk values of risk categories. Finally, application of a multi-criteria decision method allows calculating the global risk note of each category. This method provides a more consistent approach to get more realistic results without suffering from the usual weaknesses of available methods cited in literature.

We have developed a specific software for the straightforward application of the proposed methodology to real projects. This integrates all of the concepts and algorithms described in the present study, with a user-friendly interface. First, it generates all possible homogeneous RBS's, aggregates the RE values through the RBS branches and automatically computes their quality scores. Second, it ranks these RBS's, enabling the user to select the "best" one, before applying (if appropriate) any further improvements. Then, it provides a graphical representation of the RBS's, indicating the risk values/notes of categories and distribution of project risk events on different categories.

As for practical application of this innovated method, it was adopted for a dynamic, multi-scale and multi-perspective risk management of a tunneling project in France. It was explained how the individual and overall effect of identified risk events on project objectives can be analyzed, how the risk identification process, generation of tailored RBS's and risk analysis process is iterative and how the results have to be updated whenever new information is available. It was explained how during the bidding process a risk based project analysis can be performed by each of the contractors and how risk analysis process can provide different results based on different perspectives of client and contractors to project risks. An illustration on how the desired objective(s) of the user can affect the risk analysis results and also the decomposition form of categories in RBS was explained. Furthermore, it was shown that different partners, based on their expertise, risk attitude and experiences may identify some special risk events which may be not considerable for the others. All these differences can be summarized in one phrase, being "different perspectives of stakeholders to project risks".

5.2. Recommendation for future works

The work described in this thesis deals with the development of a methodology for design of tailor-made risk breakdown structures in order to manage risks in a more formal, efficient and rational way. The proposed methodology and tools allow establishing a dynamic, multi-scale and multi-perspective project risk management which facilitates the communication and discussion of partners about the project risks.

Based on the works performed in this research, the following recommendations for the future works can be made:

- a) The initial version of the construction project risk database was extended to cover two special fields: tunneling and temporary structures. It can be extended for some other specific construction fields (e.g. bridge, dam,...) and/or specific type of projects such as public-private-partnership projects. Our methodology is compatible with any database which is generated following the defined criteria and development procedures of a consistent database.

- b) An online version of the developed database and software would help to enrich the database and also let the risk practitioners to share their experience with other experts. Each user could use the available information in database or develop his own specific database while the consistency of data is controlled automatically. Furthermore, registration of identified REs, applied RBS's, analysis results and the adopted response actions in each project stage, together with some additional context information (such as economic, financial, political context situation and even the weather condition) during its lifecycle would provide a rich database of practical information. These data could be then analyzed and lessons learned be used in order to predict probable risks and difficulties of future projects. Such a shared risk based platform would be a powerful support for all risk practitioners and project managers.
- c) Development of a database including possible response actions to construction project risks. This database can be developed based on a thorough analysis of literature, accidents, construction failures and experience of experts and risk practitioners.
- d) The developed prototype software is able to provide a report of calculation process and corresponding information about selected RBS's. Furthermore, the analysis results in each project stage can be saved with in a separate file which can be retrieved again in later stages. It would be useful to add possibility of registration of risk analysis history and also generation of a risk register as a part of the risk analysis report. This report would provide all relevant information about selected tailored RBS's, risk analysis results, list of identified REs, their probable consequences on project objectives, their priority to be treated and also some propositions as relevant response actions.
- e) Work Breakdown Structures is the hierarchical decomposition structure of project tasks and can be set at different levels of detail (project/ phases/ tasks/ subtasks), each one attached to corresponding stakeholder(s) and resources. The designed tailored RBS's for each special case can be combined with relevant WBS's. This interaction is a useful technique which allows risks to be considered in project risk management process. Thus, based on the required level of details, strategies, objectives and special view to project risks, convenient RBS's and WBS's are designed and the two pictures are combined so as to offer a "hierarchical matrix". This helps to better understand, interpret and discuss risks, especially in complex and strategic projects.
- f) In available methods and techniques, project interdependent risks are indeed often managed as if they were independent. In our research, consideration of risk interactions in risk analysis and generation process of tailored RBS's was briefly discussed and some examples were provided. The choice was to modify the values

of risk events regarding their interactions before aggregation through the RBS branches. This kind of interaction between project REs can be explained by a cause-effect relation, where a first risk event, when it happens, influences the occurrence, severity or criticality of another risk event in project. Further development of this method can be the subject of future works. We propose to develop a database of RE interactions including all interaction vectors and also to develop a more formalized method to apply the interaction effects on each target RE.

- g) Application of the proposed methodology and tools during the life time of some real construction projects in order to extend and enrich the risk database.
- h) Making a link between this methodology which aims to identify and analyze the project risks and the systematic simulation of project tasks, actors and their interactions (i.e. structural, temporal and functional simulation of project). This allows performing a risk based project management.
- i) Practical application of the proposed method for a dynamic management of risks related to subsoil and underground projects in the frame of a future national research project of France called “10D - City, City of Idea¹” (meaning in French: various dimensions for a sustainable and desirable urban development, declined in a dynamic up-and-under process). This project aims to develop an applied research on contribution of subsoil to sustainable urban development by a better consideration of positive interactions between the surface and underground. It aims to improve the knowledge about the underground resource and to show that there is a credible alternative to only develop the surface.

¹ Différentes Dimensions pour un Développement Urbain Durable et Désirable Décliné Dans une Dynamique Dessus-Dessous

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Appendix 1

Database (risk events, risk categories, micro trees)

Table 5.1. List of Risk Events in database

No.	RE Code	Risk Event
1	1	Delay payment to contractor during project implementation phase
2	2	Failure of equipments and mechanical systems due to irregular mechanical control by contractor
3	3	lack of qualified staff, working for contractors (incompetent staff)
4	4	Incident or construction accidents during implementation phase due to poor workmanship
5	5	Financial difficulties of contractor
6	6	Unwanted cold weather during construction phase
7	7	Change in design standard during design process
8	8	Finding the historical objects during excavation process
9	9	Change in management system or manager of owner of the project
10	10	Mistake in design drawings
11	11	Fault in design standards
12	12	War or revolution happening during construction phase
13	13	skill deficiency in health and safety management of project
14	14	lack of skilled designers in project region
15	15	litigation conflict with neighbor of the project during feasibility phase
16	16	Unpredicted increase of needed material price in implementation phase
17	17	Improper intervention of government during contract phase
18	18	Instability of national politics during operation phase
19	19	Poor performance of consultant during design phase
20	20	Difficulty to find suitable plant due to special geotechnical conditions of region
21	21	Lack of experienced contractor in project region
22	22	Design team is unfamiliar with new technology
23	23	Available technical design solutions are not sufficiently proved or reliable
24	24	Design team has not enough experience
25	25	Contractor/ Subcontractor has not enough experience or good performance on previous relevant projects.
26	26	Change of design because of poor understanding of customer needs
27	27	Poor communication between stakeholders of the project to manage the project schedule
28	28	Change of laws during implementation phase
29	29	Complexity of project time management due to complex nature of the project
30	30	Imposed unrealistic time planning for project due to insufficient or incorrect information
31	31	Delay access to plant of the project in feasibility phase
32	32	Poor or incomplete exchange of information between designers (in different stages of design)
33	33	Project funding difficulties during feasibility phase due to bad financial situation of financier(s)
34	34	Poor performance of contractor in health and safety of work
35	35	Unavailability of needed information, code and standards in feasibility phase
36	36	Poor planning of site and ground investigation during feasibility phase by owner
37	37	Delay in approving the contractor work by consultant or owner of the project during implementation phase
38	38	Contractual failure (bankruptcy)
39	39	Incorrect definition of type and quantity of needed materials by designer(s)
40	40	Poor time Management due to change of manager or management strategies of the project
41	41	Social, racial or cultural conflicts during implementation phase
42	42	Inadequate monitoring of tasks by contractor manager(s)
43	43	Strike during implementation phase
44	44	Public concerns related to health and safety of the project due to poor communication
45	45	Earthquake, flood, land slid, fire or wind damage during implementation phase
46	46	Restriction of public funding, budgetary cuts, delay during implementation phase
47	47	Changes in exchange rates, convertibility during implementation phase

- 48 48 Economic slowdown, economic crisis during implementation phase
- 49 49 Lack of needed infrastructures during implementation phase (Telephone, ...)
- 50 50 Power context during operation phase
- 51 51 Power context during implementation
- 52 52 Poor performance of supplier(s) during implementation phase (long distance between production place and project)
- 53 53 National political conflict during feasibility phase
- 54 54 Litigation conflict with other projects during implementation phase
- 55 55 Improper intervention of government during implementation phase
- 56 56 Delay of other projects (third party, which have interaction with the project) during implementation phase
- 57 57 Delay of neighbor of the project during implementation phase
- 58 58 Change in management system or manager of the consultant
- 59 59 Change in management system or manager of the contractor(s)/ subcontractor(s)
- 60 60 Change in management system or manager of the designer(s)
- 61 61 Change in management system or manager of the financier(s)
- 62 62 Change in management system or manager of the supplier(s)
- 63 63 Change of construction techniques during implementation phase (available technologies are not convenient)
- 64 64 Instability of macro politics during operation phase
- 65 65 Macro political conflict during implementation phase
- 66 66 Change of macro politics during implementation phase
- 67 67 Low competition in internal market during feasibility phase
- 68 68 Complexity of internal management of consultant(s)
- 69 69 Complexity of internal management of Contractor(s)/ subcontractor(s)
- 70 70 Complexity of internal management of designers
- 71 71 Complexity of internal management of financiers
- 72 72 Complexity of internal management of owner of the project
- 73 73 Complexity of internal management of suppliers
- 74 74 Type and number of needed equipments (analyzed by designers) are not convenient with project scale
- 75 75 Contractor(s) are not able to use the equipments defined by designers
- 76 76 Defined equipments by designer(s) are not compatible with natural conditions of the project
- 77 77 Design standards are not consistent
- 78 78 Conflict of laws related to one of contract clauses (laws are not consistent)
- 79 79 Conflict of designer(s)with contract
- 80 80 Conflict of consultant(s) with contract
- 81 81 Conflict of financier(s) with contract
- 82 82 Conflict of supplier(s) with contract
- 83 83 Conflict of contractor(s)/ subcontractor(s) with contract
- 84 84 Conflict of owner(s) with contract
- 85 85 Disturbance of other projects' operation during operation phase of the project due to poor performance of owner of the project
- 86 86 Environmental pollution during operation phase of the project due to poor performance of owner of the project
- 87 87 Inconsistency of contact clauses
- 88 88 Contractor with lack of requirement equipments
- 89 89 Skill deficiency in cost management of the project
- 90 91 Delay in presenting design results by designers
- 91 92 Delay in contract issue by owner of the project
- 92 93 Type of contract between owner and contractor is not allowed by laws regarding special type of the project
- 93 94 Decrease of demand in future external market during implementation phase
- 94 95 Increase of supply in current internal construction market during implementation phase
- 95 96 Skill deficiency of project manager(s) in environmental protection
- 96 97 Poor quality management of the project due to frequent change of management strategies
- 97 98 Unpredicted increase of needed equipment price in implementation phase
- 98 99 Difficulty in manpower supply due to unpredicted increase of salaries during implementation phase
- 99 100 Difficulty to find suitable plant, because of high prices
- 100 101 Unpredicted increase of power price during implementation phase

101	102	Lack of needed materials in project region or country during feasibility phase
102	103	Lack of needed equipments in project region or country during implementation phase
103	104	Consultant receive the technical design plans with delay
104	105	Financial difficulties of designer(s)
105	106	Financial difficulties of owner of the project during implementation phase
106	107	Financial difficulties of supplier(s) during implementation phase
107	108	Financial difficulties of consultant(s) during implementation phase
108	109	Poor internal management of designers due to incorrect or insufficient information
109	110	Poor internal management of financiers due to incorrect or insufficient information
110	111	Poor internal management of clients due to incorrect or insufficient information
111	112	Poor internal management of consultants due to incorrect or insufficient information
112	113	Poor internal management of suppliers due to incorrect or insufficient information
113	114	Unpredicted change of interest rate during implementation phase
114	115	Unpredicted change of inflation rate during implementation phase
115	116	Local political conflict during implementation phase
116	117	Material handling solution (designed by designers) is not convenient with specific conditions of the site
117	118	Material storage solution (designed by designers) is not convenient with specific conditions of the site
118	119	Concrete type is not compatible with specific conditions of soil
119	120	Mistake in calculation of quantity of needed materials
120	121	Difficulties of access and work on site due to specific geographical constraint of region
121	122	Designed elements are not executable (including health and safety consideration)
122	123	Poor quality of operation process due to financial problems of financier
123	124	Poor performance of owner of the project in operation phase
124	125	Poor performance of financier during implementation phase
125	126	Poor exchange of information between contractors/ subcontractors
126	127	Poor internal communication of consultants
127	128	Poor exchange of information between financiers
128	129	Poor internal communication of clients
129	130	Poor internal communication of suppliers
130	131	Intervention of pressure group during implementation phase
131	132	Poor project maintenance due to financial problems of owner
132	133	Mistake of designer in calculation of quantity of needed manpower
133	134	Skill deficiency of consultant in internal time management
134	135	Skill deficiency of designers in internal management
135	136	Skill deficiency of financier in internal management
136	137	Internal management difficulties of inexperience owner
137	138	Skill deficiency of suppliers in internal management
138	139	Poor performance of consultant during implementation phase
139	140	Terms and qualification of needed experts in project are not defined clearly by designers
140	141	Unavailability of needed technology to execution of owners' goal
141	142	Designers receive the order by delay
142	143	Delay payment to suppliers during project implementation phase
143	144	Delay in delivery of the project by clients due to poor performance of other stakeholders during implementation phase
144	145	Financier difficulties due to delay of owner in documents approval during implementation phase
145	146	Consultant is not informed about the changes in project during implementation phase
146	147	Change of design because of change of order or scope vagueness by owner of the project
147	148	Environmental pollution during implementation phase due to poor inspection of site
148	149	Executed elements are not consistent with design plans due to poor performance of contractor
149	150	Damage to persons or property or materials due to poor safety and health management of the project
150	151	Project design does not comply with building regulations standards and criteria
151	152	Unproven design solutions accepted by consultant
152	153	Consultant lacks in adequate number of staff (insufficient human resources) during implementation phase
153	154	Delay of contractor in final billing presentation due to poor performance of personnel
154	155	Technical mistakes during construction stage by contractor
155	156	Irregular or inadequacy of site inspection by consultant during implementation phase

156	157	Inconsistency in time schedule of different stakeholders due to poor communication management
157	158	Delay of bank in project fund allocation during feasibility phase
158	293	Not finding a bank to finance the project
159	294	Changing of mind of bank before finalizing the contract
160	295	Interruption of project funding by bank during the project execution
161	296	Poor or defective design due to disregarding to environmental effect of the project (poor environmental analysis)
162	297	Project schedule is not respected by contractor
163	298	Need to change the design, demanded by public or neighbor of the project
164	299	Change of design demanded by architect
165	300	Delay of government to issue the project permission
166	301	Poor performance of contractor in security of site (theft of equipments and materials)
167	302	Contractor doesn't respect the labor regulations on site
168	303	Poor performance of contractor in hazardous waste disposal
169	304	Skill deficiency of contractor in time management of work
170	305	Unpredicted increase of power price during operation phase
171	306	Landowners do not want to sell their land
172	307	Objection of local authorities with project due to local political conflict during operation phase
173	308	Change of environmental laws during the implementation phase
174	309	Delay to issue permission because the environmental organization requires the examinations more than usual
175	310	Designer with Lack of specialized staff
176	311	Delay in internal procedures and decision making by inexperienced owner of the project
177	312	The new priorities are applied to the project schedule
178	313	The authorities try to change the existing execution program of project
179	314	Applied schedule by inexperienced manager is not consistent with the desired cost and quality of the project
180	315	Pressure to deliver project by an accelerated schedule (modified schedule)
181	316	Very Complex geology and geotechnical conditions of site – feasibility phase

Table 5.2. Additional list of Risk Events in database (tunneling projects)

No.	RE Code	Risk Event
1	160	Poor preliminary site and ground investigation
2	161	Poor assessment and evaluation of project options
3	163	Poor execution of Preliminary investigation of site and ground
4	164	Incompetency of personnel for execution of Preliminary investigation of site and ground
5	165	Poor site investigation regarding the identification of available manmade underground structures
6	166	Poor site investigation regarding the identification of natural geological/ hydrological hazards
7	167	The site Preliminary investigation plan is not compatible with proposed nature and scope of the project
8	168	Poor preliminary assessment and evaluation of tunneling methodologies
9	169	Poor preliminary assessment and evaluation of different possibilities for temporary and permanent ground support systems
10	170	Poor preliminary assessment and evaluation of different possibilities of treatment measures for ground and groundwater
11	171	Poor preliminary assessment and evaluation of environmental impact of treatment measures for ground and groundwater
12	172	Poor preliminary assessment and evaluation of ground movement and settlements
13	173	Poor preliminary assessment and evaluation of environmental impacts of the project such as dust, noise, vibrations, traffic, plant movements
14	174	Poor preliminary assessment and evaluation of costs, health, safety and program implications
15	175	Poor preliminary assessment and evaluation of possible forms of contract

16	176	Poor preliminary assessment and evaluation of hazardous materials
17	177	Poor assessment and evaluation of proposed project location
18	178	Preliminary scheme design is not appropriate with the project objectives or requirements of the project
19	179	Poor preliminary risk management of different proposed options of design, contract form, contractors, etc
20	180	Inappropriate form or type of the contract
21	181	Allocation of risks to the parties is not mentioned or is not clear in the contract
22	182	Short time for tendering determined by clients due to skill deficiency in time management
23	183	Design is not appropriate with the project objectives or requirements of the project
24	184	Incorrect design due to incorrect or insufficient available information (geological/ geotechnical)
25	185	Inappropriate or mistake in method(s) of analysis, used for design
26	186	Inappropriate method used by designer for design risk assessment
27	187	Calculations, analyses and assessments don't consider intermediate stages of construction
28	188	Design process doesn't include sensitivity study to assess the impact of changes and unwanted variation of design parameters
29	189	Design process doesn't include sensitivity study to assess the impact of natural hazards
30	190	Design process doesn't include an assessment of the impact of construction on third party structures and infrastructures.
31	191	Poor design check by consultant regarding the level of complexity, degree of difficulty and type of construction of the Tunnel Works
32	192	Poor design check by consultant regarding the level of risks for tunnel works and/ or third party
33	193	No proper design review and checking by consultant
34	194	Poor design check by consultant regarding any statutory or the requirements of client or a third party
35	195	Insufficient time for appropriate level of design control due to poor communication of consultants with designers
36	196	Design process doesn't take account of the impact of staged or sequential excavations
37	197	Inappropriate monitoring measures by consultants (Ground, groundwater, tunnel work' structures, adjacent structures affected by the tunnel works) during the works to control the robustness of Design
38	198	Mistake of designer in calculations for design of tunnel including the dimensions, shape, excavation tolerance of the excavation, and the tunnel support and lining design
39	199	Inadequate definition of timeframes for excavation work
40	200	Defective design due to incorrect evaluation of the nature of ground
41	201	Defective design due to incorrect evaluation of the water table level
42	202	Poor design due to disregarding to the possibility of flooding from surface run-off, tidal water, rivers, dams, reservoirs, lakes or swamps
43	203	Poor design due to disregarding to the possibility of flooding from leaking storm water drains, water mains or flooded communications conduits
44	204	Poor design due to disregarding to the possibility of flooding from intersection of old flooded workings or an underground water-bearing structure, such as a fault, cast or perched water table
45	205	Poor design due to disregarding to the proximity of existing underground services, such as water mains, sewerage drainage, electricity, gas and telephone
46	206	Poor design due to disregarding to the soil nails, rock anchors, basement underpinning, or other pre-existing ground supports
47	207	Poor design due to disregarding to the adjacent excavations (e.g. shafts, tunnels or trenches) ground support
48	208	Poor design due to disregarding to the heavy loadings, above or adjacent to the tunnel (e.g. roadways, railway lines, buildings)
49	209	Poor design due to disregarding to the existing chemical contamination of soil and ground water
50	210	Poor design due to disregarding to the presence of methane, or other hazardous gases
51	211	Poor design due to disregarding to the dynamic loads or ground vibration near an excavation due to traffic (highway or rail), excavation equipments (TBM,...) or explosives.
52	212	Poor design due to disregarding to ground vibrations, overpressures from blasting and fly rock
53	213	Poor design due to disregarding to the effect of explosion on surrounding strata and tunnel stability
54	214	Using inadequate software for design of entrance portal of the tunnel
55	215	Excavation and spoil-removal equipments of contractor are not adopted for cold operation
56	216	Inappropriate software used for design of support system (lining, temporary or permanent shield)

- 57 217 Inappropriate model used for stability analysis of tunnel (tunnel face)
- 58 218 Defective or inconvenient design of TBM or excavation machine (Type of machine, structure)
- 59 219 Defective or inconvenient design of TBM operation parameters (Speed, balance pressure in face, ...)
- 60 220 Disregarding to the ground water level fluctuation on design of diaphragm wall, tunnel, or other structures
- 61 221 Defective design of ground freezing system
- 62 222 mistake of designer in back analysis
- 63 223 Inadequate method (model) used for blasting design (type, quantity,...)
- 64 224 Defective design due to calculation or numerical analysis error
- 65 225 Poor or defective design due to disregarding to considering the ground pressure water
- 66 226 Poor or defective design due to not considering earthquake in design
- 67 227 Application of inappropriate method for design of anti fire system
- 68 228 Mistake of designer in remedial action planning and design
- 69 229 Mistake of designer in analysis for definition of stages and sequential activities of remedial action
- 70 230 Poor or defective design of ventilation system due to incorrect information
- 71 231 Insufficient information is available for selection of the tunneling method
- 72 232 Disregard to considering the 3D effects in design (such as the effect of existing tunnels)
- 73 233 Poor or defective design due to using inappropriate design parameters
- 74 234 Defective or inappropriate selection of needed equipments by designers (they are not usable in the project)
- 75 235 Poor or defective design due to poor or insufficient geotechnical investigation
- 76 236 Poor or defective design due to mistake in evaluation and analysis of available geotechnical information (Soil static/ dynamic strength and hydrogeological parameters)
- 77 237 Poor definition of organization chart of contractors' staff (inexperience contractor)
- 78 238 The Site Organization chart has not sufficient detail to identify the key personnel and their role and responsibilities (inexperience contractor)
- 79 240 Poor communication of designer and contractor to control of suitability and constructability of employed construction method by contractor
- 80 242 Poor definition of roles and responsibilities and contingency actions in the case of probable collapse and accidents by the inexperience manager of the project
- 81 243 Changes of design or construction methods are not reported by designer
- 82 244 Impact of pre-excavation grouting on existing wells (effect on ground water) due to poor performance of labors
- 83 245 Air contamination or oxygen depletion due to inconvenient design of ventilation system of the tunnel
- 84 246 Poor traffic management in tunnel during construction phase
- 85 247 Close proximity to electrical supplies and circuits due to poor performance of contractor
- 86 248 Accident due to use of compressed air and high pressure hydraulics by inexperienced contractor
- 87 249 Accident due to uneven surfaces in tunnel
- 88 250 Accident due to wet or other slippery surfaces
- 89 251 Accident due to falling objects
- 90 252 Accident due to reduced visibility
- 91 253 Loss of power, including lighting and ventilation due to poor electrical system of the site
- 92 254 The necessary measures in the case of loss of power, including lighting and ventilation, is not planned by contractor
- 93 255 High level of noise in tunnel, and workers without safety equipments
- 94 256 Falling of the workers from heights due to poor performance of contractor in safety of site
Vibration effects on the body from the use of hand tools, falling objects, noise, dust, heat stress and
- 95 257 crush injuries from small mobile plant due to poor performance of contractor related to safety of workers
- 96 258 Fire of excavation machine due to irregular mechanical control
- 97 259 Inadequate work condition of operator of excavation machine such as visibility, seat belts, hand rails, seating, vibration controls, stairs, manual tasks, communication
- 98 260 Inadequate storage, transport and use of explosives (inexperience contractor)
- 99 261 Inadequate ground support requirements for drill and blast method used by contractor
- 100 262 Incompetency of explosives contractors and operators
- 101 263 Inadequate firing times and preventing access to firing areas
- 102 264 Disregard to clearance of blasting fumes and dust.

103	265	Poor inspection of the tunnel works by contractor
104	266	Inappropriate permanent ground support used by contractor
105	267	Disregard to the effect of cold on people and equipment
106	268	Fracturing of the ground or damage to nearby services, buildings or structures due to Inappropriate pressure of grouting, applied by operator
107	269	Incompetency of personnel, working with excavation machines
108	270	Inappropriate or unsafe fuelling system in tunnel, prepared by contractor
109	271	Inappropriate or unsafe Personnel-riding vehicles
110	272	Inappropriate or unsafe Rolling stock-locomotives and rail cars are used by contractor
111	273	Inadequate lighting system in tunnel
112	274	Poor electrical safety (electric cables, electrical articles, portable generators) by contractor
113	275	Inappropriate personnel protective equipment used by contractor
114	276	Disregarding to sequential and staged activities of remedial action by contractor
115	277	Poor workmanship and construction errors
116	278	Disregard to different warning signs (excessive deformation, crack...) by contractor
117	279	Poor construction quality due to poor performance of labors
118	280	Construction errors due to poor performance of experts and labors
119	281	Damage to installed lining during the work due to poor performance of workers
120	282	error in reading or collection of monitoring data by contractor
121	283	Poor execution of remedial actions by contractor
122	284	lack of allocation of responsibilities of workers due to poor management by inexperience contractor
123	285	Using inappropriate equipments by contractor
124	287	failure of ground freezing system due to poor inspection of the site
125	288	Poor planning of contractor for emergency measures
126	289	Contractor has inexperience project manager
127	290	Poor communication between different subcontractors
128	291	Mistake in analysis for design of instrumentation and monitoring system
129	292	Error in processing the monitoring data (Not fast enough) by contractor

Table 5.3. Risk Category database

No.	RC Code	Risk Category
1	1	Advanced technology
2	2	Archaeology
3	3	Change in Laws and standards
4	4	Change in management strategy (Consultants view)
5	5	Change in management strategy (Contractors\ Sub-contractors view)
6	6	Change in management strategy (Designers view)
7	7	Change in management strategy (Financiers view)
8	8	Change in management strategy (Owner/ Client view)
9	10	Change in management strategy (Project view)
10	11	Change in management strategy (Suppliers view)
11	12	Change in technology
12	13	Change of policy
13	14	Competition
14	15	Complexity of task or project management (Consultants view)
15	16	Complexity of task or project management (Contractors\ Sub-contractors view)
16	17	Complexity of task or project management (Designers view)
17	18	Complexity of task or project management (Financiers view)
18	19	Complexity of task or project management (Owner/ Client view)
19	21	Complexity of task or project management (Project view)
20	22	Complexity of task or project management (Suppliers view)
21	23	Condition of equipment
22	24	Conflict in contract documents
23	25	Conflict of laws and standards
24	27	Conflict with contract (Consultants)
25	28	Conflict with contract (Contractors\ Sub-contractors)
26	29	Conflict with contract (Designers)
27	30	Conflict with contract (Financiers)
28	31	Conflict with contract (Owner/Client)
29	32	Conflict with contract (stakeholder)
30	33	Conflict with contract (stakeholders- Designers)
31	34	Conflict with contract (Suppliers)
32	35	Consistency with Environment
33	36	Consistency with Other projects
34	37	Consultants
35	38	Context
36	39	Contract (phase)
37	40	Contract documents
38	41	Contractor/ subcontractor with lack of equipment
39	42	Contractor/ subcontractor with lack of labor and expert
40	43	Contractor/sub-contractor Incompetence
41	44	Contractors / Sub-contractors
42	45	Contractual
43	46	Cost management
44	47	Country Risks
45	48	Currency exchange rate
46	49	Current market
47	50	Poor or defective design
48	51	Deficiency in Design drawings
49	52	Delay in contract issue
50	53	Delay in design
51	54	Delay to plant access

52	55	Demand
53	56	Design (phase)
54	57	Design change
55	58	Design team Incompetence
56	59	Designers
57	62	Economic slowdown
58	63	Economic/Financial
59	64	Environmental protection
60	65	Environmental Risks
61	66	Equipment (Price & Availability)
62	67	Equipments context
63	68	Equipments definition
64	69	External Market
65	70	External Risks (Contract phase)
66	71	External Risks (Design phase)
67	72	External Risks (Feasibility phase)
68	73	External Risks (Implementation phase)
69	74	External Risks (Of Consultants) in design phase
70	75	External Risks (Of Consultants) in implementation phase
71	76	External Risks (Of Contractors\ Sub-contractors)
72	77	External Risks (Of Designers)
73	78	External Risks (Of Financiers)
74	79	External Risks (Of Owner/Clients)
75	81	External Risks (Of Suppliers)
76	82	External Risks (Operation phase)
77	83	External Risks (Project phases and project view)
78	84	External risks of stakeholders (Implementation phase)
79	85	Fault in law and standards
80	86	Feasibility (phase)
81	89	Finance & Credibility (Internal resources) in feasibility phase
82	90	Finance & Credibility (Internal resources) in implementation phase
83	91	Financial (External Resources)
84	93	Financial of Contractors\ Sub-contractors (Internal Resources)
85	94	Financial of Consultants (Internal Resources)
86	95	Financial of Designers (Internal Resources)
87	96	Financial of Financiers (Internal Resources)
88	97	Financial of Owner/Client (Internal Resources)
89	98	Financial of stakeholders (Internal Resources)
90	99	Financial of Suppliers (Internal Resources)
91	100	Financiers
92	101	Force majeure
93	102	Future market
94	103	Government (Improper Intervention)
95	104	Health and safety of work
96	105	Implementation (phase)
97	106	Incorrect or poor estimations
98	108	Incorrect or insufficient information (Consultants view)
99	109	Incorrect or insufficient information (Contractors\ Sub-contractors view)
100	110	Incorrect or insufficient information (Designers view)
101	111	Incorrect or insufficient information (Financiers view)
102	112	Incorrect or insufficient information (Owner/ Client view)
103	113	Incorrect or insufficient information (Project view)
104	114	Incorrect or insufficient information (Suppliers view)
105	115	Inexperience design team
106	116	Inexperienced contractor/ subcontractor
107	117	Inflation Rate

108	118	Information/Codes& Standard context
109	119	Infrastructures context
110	120	Interest Rate
111	121	Internal Market
112	122	Internal Risks
113	123	Internal Risks (Of Consultants)
114	124	Internal Risks (Of Contractors\ Sub-contractors)
115	125	Internal Risks (Of Designers)
116	126	Internal Risks (Of Financiers)
117	127	Internal Risks (Of Owner/Clients)
118	129	Internal Risks (Of Suppliers)
119	130	Labor and experts context
120	131	Legal and regularities
121	132	Litigation conflict with third party
122	133	Local politics
123	134	Macro economical context
124	135	Macro politics
125	136	Management
126	137	Management (Consultants view)
127	138	Management (Contractors\ Sub-contractors view)
128	139	Management (Designers view)
129	140	Management (Financiers view)
130	141	Management (Owner/ Client view)
131	143	Management (Project view)
132	144	Management (Stakeholders view)
133	145	Management (Suppliers view)
134	146	Manpower (Price & Availability)
135	147	Manpower and experts definition
136	148	Market
137	149	Material (Price & Availability)
138	150	Material context
139	151	Material Handling
140	152	Material Storage
141	153	Materials definition
142	154	National politics
143	155	Natural Constraints of site
144	156	Natural hazards
145	157	Neighbors
146	158	Non standard contract form
147	159	Operability of design
148	160	Operation (phase)
149	161	Operation consistency
150	162	Operation performance
151	163	Operation quality
152	164	Other projects
153	165	Owner/Clients
154	166	Performance and characteristics of Consultant in design phase
155	167	Performance and characteristics of Consultant in implementation phase
156	168	Performance and characteristics of Contractors\ Sub-contractors
157	169	Performance and characteristics of Designers
158	170	Performance and characteristics of Financiers
159	171	Performance and characteristics of Owner/Client
160	172	Performance and characteristics of stakeholder
161	173	Performance and characteristics of stakeholders
162	174	Performance and characteristics of Suppliers
163	175	Performance of contractor/ subcontractor in task execution

164	176	Performance of other stakeholders
165	177	Performance of other stakeholders (-Consultants)
166	178	Performance of other stakeholders (-Contractors\ Sub-contractors)
167	179	Performance of other stakeholders (-Designers)
168	180	Performance of other stakeholders (-Financiers)
169	181	Performance of other stakeholders (-Owner/ Client)
170	182	Performance of other stakeholders (-Suppliers)
171	183	Plant (price & availability)
172	184	Plant context
173	185	Political
174	186	Political conflict
175	187	Political instability
176	188	Poor Communication (Consultants view)
177	189	Poor Communication (Contractors\ Sub-contractors view)
178	190	Poor Communication (Designers view)
179	191	Poor Communication (Financiers view)
180	192	Poor Communication (Owner/ Client view)
181	194	Poor Communication (Project view)
182	195	Poor Communication (Suppliers view)
183	196	Power (Price & availability)
184	197	Power context
185	198	Pressure Group
186	199	Professional network Context
187	200	Project maintenance
188	201	Project risks
189	202	Project stakeholders
190	203	Quality management
191	204	Quantity of manpower
192	205	Resource definition
193	206	Resources (Price & Availability)
194	207	Resources Context
195	208	Site context
196	210	Skill Deficiency in management (Consultants view)
197	211	Skill Deficiency in management (Contractors\ Sub-contractors view)
198	212	Skill Deficiency in management (Designers view)
199	213	Skill Deficiency in management (Financiers view)
200	214	Skill Deficiency in management (Owner/ Client view)
201	215	Skill Deficiency in management (Project view)
202	216	Skill Deficiency in management (Suppliers view)
203	217	Social and cultural
204	218	Suitability of equipment
205	219	Suppliers
206	220	Supply
207	221	Technical Design
208	222	Technology Availability
209	223	Technology Context
210	224	Terms & Qualification of manpower
211	225	Third party
212	226	Third party Delay
213	227	Third Party Interference
214	228	Time management
215	229	Type and quantity of materials
216	230	Unexpected weather
217	231	Unfamiliar with new technology
218	232	Usability of equipment

Table 5.4. Additional Risk Category database (tunneling projects)

No.	RC Code	Risk Category
219	233	Incorrect or insufficient design data
220	234	Disregarding to the effective parameters and standards
221	235	Mistake of designer in calculations and analysis
222	236	Inappropriate applied method, model or design tool
223	237	Maintenance of site and equipments
224	238	Inspection of work by contractor
225	239	Construction program planning
226	240	Security and safety of work
227	241	Poor workmanship or function of labors and experts

Table 5.5. Risk Category Description

No.	RC Code	Description
1	1	Available technologies for execution of task or project are so advanced and complicated
2	2	Archaeological finds that can make problems for working on site or access to plant of the project
3	3	Unwanted changes in laws and standards
4	4	Any change in management strategies, principles or change of chief of consultant
5	5	Any change in management strategies, principles or change of chief of contractors/ subcontractors
6	6	Any change in management strategies, principles or change of chief of designers
7	7	Any change in management strategies, principles or change of chief of financiers
8	8	Any change in management strategies, principles or change of chief of owner/clients
9	10	Any change in management strategies, principles or change of manager(s) of project
10	11	Any change in management strategies, principles or change of chief of suppliers
11	12	Change of technology during design, implementation or operation phase
12	13	Any change in political situations
13	14	Level of competition in market
14	15	Complexity of internal management of consultant
15	16	Complexity of internal management of contractor/ subcontractors
16	17	Complexity of internal management of designers
17	18	Complexity of internal management of financiers
18	19	Complexity of internal management of owner/ client
19	21	Complexity of project management, it's a general view to project management
20	22	Complexity of internal management of suppliers
21	23	Definition of type, quantity and conditions of requirement equipments
22	24	Conflict, inconsistency or mistake in contract documents
23	25	Any conflict or inconsistency in laws and standards
24	27	Any problem or conflict of consultants with contract
25	28	Any problem or conflict of contractors/ subcontractors with contract
26	29	Any problem or conflict of designers with contract
27	30	Any problem or conflict of financiers with contract
28	31	Any problem or conflict of owner/ client with contract
29	32	Any problem or conflict of stakeholders with contract
30	33	This category is not a real decomposition of risks, just to make a link between conflict of stakeholders with contract (-designers) and implementation phase
31	34	Any problem or conflict of suppliers with contract
32	35	Inconsistency of operation process with environment that can be pollution or any disturbance in natural environment
33	36	Inconsistency of operation process with other projects that can disturb their process
34	37	Project risks allocated to consultant(s) as one of project stakeholders

35	38	Problems and difficulties due to available situation of site, technology, resources, social, cultural and third parties. They are considered as external risks of the project
36	39	The risks that can happen during contract phase of the project
37	40	Any problem related to contract documents such as conflict in documents, or delay in issue
38	41	Contractor/ subcontractor with not enough/ suitable equipments
39	42	Contractor/ subcontractor with not enough/ qualified labor and expert
40	43	Incompetency of contractor/ subcontractor due to lack of experience, equipments or not enough expert and labor
41	44	Project risks allocated to contractor(s)/ subcontractor(s) as one of project stakeholders
42	45	Any problem related to contract documents or conflict of stakeholders with contract
43	46	Any problem related to poor or incorrect cost management of the project
44	47	Some parts of external risks of the project which are related to destination country, such as economical, legal and political of the country
45	48	Unwanted change of currency exchange rate
46	49	Present situation of market
47	50	Poor or incorrect technical design by designer(s)
48	51	Mistake in design drawings or incompatibility of design and design drawings
49	52	Delay in contract issue by owner of the project
50	53	Delay in presenting design results or design drawings
51	54	Delay in access to plant of the project
52	55	Situation of demand in market
53	56	The risks that can happen during design phase of the project
54	57	Change of design by designer(s)
55	58	Incompetence designer(s) due to lack of experience or unfamiliar with new technology
56	59	Project risks allocated to designer(s) as one of project stakeholders
57	62	Is related to macro economical situation
58	63	Is a part of external risks of the project, related to economic situation and external financial resources of project
59	64	Control, monitoring of compatibility of project execution with natural environment, it's a part of project management process
60	65	Is related to natural hazards and unexpected weather as external risks
61	66	Unavailability or high price of needed equipments due to economical conditions
62	67	Unavailability or lack of needed equipments in project region or country
63	68	Definition of type, quantity and conditions of needed equipments regarding special conditions of the project and users
64	69	External market of the project, in other countries
65	70	The risks related to external environment of the project which are relatively uncontrollable and can happen in contract phase of the project
66	71	The risks related to external environment of the project which are relatively uncontrollable and can happen in design phase of the project
67	72	The risks related to external environment of the project which are relatively uncontrollable and can happen in feasibility phase of the project
68	73	The risks related to external environment of the project which are relatively uncontrollable and can happen in implementation phase of the project
69	74	The risks related to external environment of consultants during design phase, which are related to performance and characteristics of other stakeholders, but it doesn't include the external risks of the project
70	75	The risks related to external environment of consultants during implementation phase, which are related to performance and characteristics of other stakeholders, but it doesn't include the external risks of the project
71	76	The risks related to external environment of contractors/ subcontractors which are related to performance and characteristics of other stakeholders, but it doesn't include the external risks of the project
72	77	The risks related to external environment of designers which are related to performance and characteristics of other stakeholders, but it doesn't include the external risks of the project
73	78	The risks related to external environment of financiers which are related to performance and characteristics of other stakeholders, but it doesn't include the external risks of the project
74	79	The risks related to external environment of owner/ clients which are related to performance and characteristics of other stakeholders, but it doesn't include the external risks of the project
75	81	The risks related to external environment of suppliers which are related to performance and characteristics of other stakeholders, but it doesn't include the external risks of the project
76	82	The risks related to external environment of the project which are relatively uncontrollable and can happen in operation phase of the project

- 77 83 The risks related to external environment of the project which are relatively uncontrollable and can happen in different phases of the project
- 78 84 This category is not a real decomposition of risks, just to make a link between external risks of the stakeholders (-designers) and implementation phase
- 79 85 Error or mistake in laws and standards
- 80 86 The risks that can happen during feasibility phase of the project
- 81 89 It's related to internal financial situation of stakeholders during feasibility phase.
- 82 90 It's related to internal financial situation of stakeholders during implementation phase.
- 83 91 Situation of external financial resources of the project.
- 84 93 Internal situation of finance and credibility of contractor(s)/ subcontractor(s)
- 85 94 Internal situation of finance and credibility of consultant(s)
- 86 95 Internal situation of finance and credibility of designer(s)
- 87 96 Internal situation of finance and credibility of financier(s)
- 88 97 Internal situation of finance and credibility of owner of the project
- 89 98 Internal situation of finance and credibility of stakeholders
- 90 99 Internal situation of finance and credibility of suppliers(s)
- 91 100 Project risks allocated to financier(s) as one of project stakeholders
- 92 101 An extraordinary event or circumstance beyond the control of the parties, such as a war, strike, riot, crime. This category exclude the natural hazards
- 93 102 Future situation of market
- 94 103 Improper intervention of government, as a third party, in internal issues of the project or stakeholders
- 95 104 Control and monitoring of safety and health of the project, specially during implementation phase. It's a part of project management process
- 96 105 The risks that can happen during implementation phase of the project
- 97 106 Incorrect or poor prediction and estimations during feasibility phase
- 98 108 Incorrect or insufficient information available for internal risk management of consultants
- 99 109 Incorrect or insufficient information available for internal risk management of contractors and subcontractors
- 100 110 Incorrect or insufficient information available for internal risk management of designers
- 101 111 Incorrect or insufficient information available for internal risk management of financiers
- 102 112 Incorrect or insufficient information available for internal risk management of owner and clients
- 103 113 Incorrect or insufficient information available for global project management
- 104 114 Incorrect or insufficient information available for internal risk management of suppliers
- 105 115 Design team with not enough experience
- 106 116 Contractor/ subcontractor with not enough experience
- 107 117 Change of inflation rate (increase or unwanted change) as an external risk of the project
- 108 118 Unavailability of needed information, code or standards as external risks
- 109 119 Unavailability of needed infrastructures in project region or country as an external risk
- 110 120 Unwanted change of interest rate
- 111 121 Internal market situation, inside the country
- 112 122 The risks related to internal environment of the project which are relatively controllable
- 113 123 The risks related to internal environment of consultants which are relatively controllable
- 114 124 The risks related to internal environment of contractor(s)/ subcontractor(s) which are relatively controllable
- 115 125 The risks related to internal environment of designer(s) which are relatively controllable
- 116 126 The risks related to internal environment of financier(s) which are relatively controllable
- 117 127 The risks related to internal environment of owner/ client(s) which are relatively controllable
- 118 129 The risks related to internal environment of supplier(s) which are relatively controllable
- 119 130 Unavailability or lack of needed experts or labor in project region or country
- 120 131 Any change, conflict or fault in laws and standards.
- 121 132 litigation conflict and difficulties with third party (not with project stakeholders)
- 122 133 Conflict, change or instability of local politics
- 123 134 Any unwanted change or difficulties in macro economical situations
- 124 135 Conflict, change or instability of macro politics
- 125 136 A general category that contains the internal management of stakeholders in a local view and also global project management
- 126 137 Internal management of consultants
- 127 138 Internal management of contractors and subcontractors

128	139	Internal management of designers
129	140	Internal management of financiers
130	141	Internal management of owner/ clients
131	143	Project management in a global view
132	144	Internal management of each stakeholder
133	145	Internal management of suppliers
134	146	Unavailability or high price of manpower due to economical conditions
135	147	Any problem related to poor or incorrect definition of terms, qualification and quantity of needed manpower by designer(s)
136	148	Any problem related to market
137	149	Unavailability or high price of materials due to economical conditions
138	150	Unavailability of needed materials in project region or country
139	151	Any problem related to poor or incorrect definition of material handling process by designer(s)
140	152	Any problem related to poor or incorrect design of material storage by designer(s)
141	153	Any problem related to poor or incorrect definition of needed materials by designer(s)
142	154	Conflict, change or instability of national politics
143	155	Natural constraints and difficulties of site that can make problem to access or work on site
144	156	Natural disasters such as earthquake, flood, land slid, fire or wind damage
145	157	Any problem related to neighbors of the project site as third parties
146	158	Type or from of the contract is not standard or compatible with laws
147	159	Design is not executable
148	160	The risks that can happen during operation phase of the project
149	161	Inconsistency of operation process with other projects or natural environment
150	162	Performance of operation process
151	163	Quality of operation process
152	164	Other projects that can affect the project as third parties
153	165	Project risks allocated to owner/ client(s) as one of project stakeholders
154	166	This category contains two parameters of performance and characteristics of consultant during design phase
155	167	This category contains two parameters of performance and characteristics of consultant during implementation phase
156	168	This category contains two parameters of performance and characteristics of contractors\ sub-contractors
157	169	This category contains two parameters of performance and characteristics of designers
158	170	This category contains two parameters of performance and characteristics of financiers
159	171	This category contains two parameters of performance and characteristics of owner/ client except contractual issues
160	172	This category contains two parameters of performance and characteristics of each stakeholder
161	173	This category contains two parameters of performance and characteristics of all the stakeholders
162	174	This category contains two parameters of performance and characteristics of suppliers
163	175	Performance of contractor/ subcontractor in task execution during implementation phase
164	176	This category present the external risks of each stakeholder that are related to performance of other stakeholders
165	177	This category present the external risks of the consultants which are related to performance of other stakeholders
166	178	This category present the external risks of the contractors / sub-contractors which are related to performance of other stakeholders
167	179	This category present the external risks of the designers which are related to performance of other stakeholders
168	180	This category present the external risks of the financiers which are related to performance of other stakeholders
169	181	This category present the external risks of the owner/ clients which are related to performance of other stakeholders
170	182	This category present the external risks of the suppliers which are related to performance of other stakeholders
171	183	Unavailability or high price of plant due to economical conditions
172	184	Unavailability of or lack of plant in project region or country
173	185	Political problems in local, national or macro scale
174	186	Political conflict between different political groups
175	187	Instability of political situations
176	188	Poor internal communication of consultants, it's related to internal management
177	189	Poor internal communication of contractors and subcontractors, it's related to internal management
178	190	Poor internal communication of designers, it's related to internal management

- 179 191 Poor internal communication of financiers, it's related to internal management
180 192 Poor internal communication of owner and client, it's related to internal management
181 194 Poor communication in project between different stakeholders, its related to project management.
182 195 Poor internal communication of suppliers, it's related to internal management
183 196 Unavailability or high price of power due to economical conditions
184 197 Unavailability of or lack of power in project region or country
185 198 Pressure groups that can affect on project as third parties
186 199 Unavailability or lack of professional network (contractor, designer, consultant, financier, supplier)in project region or country
187 200 Problems related to maintenance of the project
188 201 Possible risks that can happen for project
189 202 Project risks can be allocated to different partners of the project
190 203 Control and monitoring the quality of tasks execution in project
191 204 Any problem related to poor or incorrect definition of quantity of required manpower by designer(s)
192 205 Definition of quantity and properties of needed material, manpower, experts and equipments by designer(s)
193 206 Unavailability or high price of resources due to economical conditions
194 207 Unavailability of needed resources in country or project region.
195 208 Any external problem related to project plant
196 210 Skill deficiency of consultants in internal management
197 211 Skill deficiency of contractors and subcontractors in internal management
198 212 Skill deficiency of designers in internal management
199 213 Skill deficiency of financiers in internal management
200 214 Skill deficiency of owner/clients in internal management
201 215 Skill deficiency of project manager(s)
202 216 Skill deficiency of suppliers in internal management
203 217 Social and cultural situations that can affect the project
204 218 Defined equipments by designer(s) should be suitable and compatible with special conditions of the project
205 219 Project risks allocated to supplier(s) as one of project stakeholders
206 220 level and quality of supply of demands, related to market as an external risk
207 221 Any problem related to technical design done by designer(s)
208 222 The required technology is not available or developed enough in project region or country
209 223 Any problem related to availability, change or complexity of required technology
210 224 Any problem related to poor or incorrect definition of terms and qualification of manpower by designer(s)
211 225 Any problem related to third party (not project stakeholders)
212 226 Delay of third party (not project stakeholders)
213 227 Interference of third party in internal issues of the project or stakeholders. It's considered as an external risk.
214 228 Any problem related to poor or incorrect time management of the project
215 229 The problems related to incorrect definition of type and quantity of needed materials by designer(s)
216 230 Any unwanted weather conditions, such as very cold, very hot, windy or rainy weather
217 231 Design team is unfamiliar with new technology
218 232 Contractor(s) or other partners should be able to use defined equipments by designer(s)
219 233 The risks related to the design information and data
220 234 Disregarding to the parameters, codes, standards and concepts which have to be considered for technical design
221 235 It's the human error. Mistake of designer in calculations, analysis and evaluations
222 236 Mistake in selection of a convenient model, method or software for technical analysis and design
223 237 It is related to performance of contractor in implementation phase
224 238 Any problem due to poor inspection of work by contractor.
225 239 Any problem related to poor or defective planning of construction activities in site by contractor
226 240 Any problem due to poor or defective respecting of safety of workers, equipments and security of site
227 241 Poor performance of labor and experts of contractor
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Figure 5-1. MT database

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|---|---|
| <p>1 201 - Project risks</p> <ul style="list-style-type: none"> 122 - Internal Risks 83 - External Risks (Project phases and project view) <p>2 201 - Project risks</p> <ul style="list-style-type: none"> 202 - Project stakeholders 143 - Management (Project view) 83 - External Risks (Project phases and project view) <p>3 201 - Project risks</p> <ul style="list-style-type: none"> 86 - Feasibility (phase) 39 - Contract (phase) 56 - Design (phase) 105 - Implementation (phase) 160 - Operation (phase) 136 - Management <p>4 83 - External Risks (Project phases and project view)</p> <ul style="list-style-type: none"> 63 - Economic/Financial 185 - Political 131 - Legal and regularities 156 - Natural hazards 230 - Unexpected weather 101 - Force majeure 38 - Context <p>5 83 - External Risks (Project phases and project view)</p> <ul style="list-style-type: none"> 47 - Country Risks 65 - Environmental Risks 101 - Force majeure <p>6 65 - Environmental Risks</p> <ul style="list-style-type: none"> 156 - Natural hazards 230 - Unexpected weather <p>7 47 - Country Risks</p> <ul style="list-style-type: none"> 63 - Economic/Financial 185 - Political 131 - Legal and regularities 38 - Context <p>8 202 - Project stakeholders</p> <ul style="list-style-type: none"> 59 - Designers 100 - Financiers 165 - Owner/Clients 44 - Contractors / Sub-contractors 219 - Suppliers 37 - Consultants <p>10 143 - Management (Project view)</p> <ul style="list-style-type: none"> 46 - Cost management 228 - Time management 203 - Quality management 104 - Health and safety of work 64 - Environmental protection <p>11 63 - Economic/Financial</p> <ul style="list-style-type: none"> 206 - Resources (Price & Availability) 148 - Market 134 - Macro economical context 91 - Financial (External Resources) <p>12 134 - Macro economical context</p> <ul style="list-style-type: none"> 117 - Inflation Rate 48 - Currency exchange rate 120 - Interest Rate 62 - Economic slowdown | <p>13 206 - Resources (Price & Availability)</p> <ul style="list-style-type: none"> 66 - Equipment (Price & Availability) 146 - Manpower (Price & Availability) 149 - Material (Price & Availability) 183 - Plant (price & availability) 196 - Power (Price & availability) <p>14 185 - Political</p> <ul style="list-style-type: none"> 135 - Macro politics 154 - National politics 133 - Local politics <p>15 185 - Political</p> <ul style="list-style-type: none"> 13 - Change of policy 187 - Political instability 186 - Political conflict <p>16 131 - Legal and regularities</p> <ul style="list-style-type: none"> 3 - Change in Laws and standards 85 - Fault in law and standards 25 - Conflict of laws and standards <p>17 148 - Market</p> <ul style="list-style-type: none"> 121 - Internal Market 69 - External Market <p>18 148 - Market</p> <ul style="list-style-type: none"> 49 - Current market 102 - Future market <p>19 148 - Market</p> <ul style="list-style-type: none"> 220 - Supply 14 - Competition 55 - Demand <p>20 38 - Context</p> <ul style="list-style-type: none"> 225 - Third party 199 - Professional network Context 217 - Social and cultural 223 - Technology Context 208 - Site context 207 - Resources Context <p>21 225 - Third party</p> <ul style="list-style-type: none"> 157 - Neighbors 103 - Government (Improper Intervention) 198 - Pressure Group 164 - Other projects <p>22 225 - Third party</p> <ul style="list-style-type: none"> 226 - Third party Delay 227 - Third Party Interference 132 - Litigation conflict with third party <p>23 223 - Technology Context</p> <ul style="list-style-type: none"> 12 - Change in technology 222 - Technology Availability 1 - Advanced technology <p>24 208 - Site context</p> <ul style="list-style-type: none"> 155 - Natural Constraints of site 2 - Archaeology 54 - Delay to plant access |
|---|---|

<p>25 207 - Resources Context</p> <ul style="list-style-type: none"> 150 - Material context 197 - Power context 118 - Information/Codes& Standard context 184 - Plant context 130 - Labor and experts context 119 - Infrastructures context 67 - Equipments context <p>28 43 - Contractor/sub-contractor Incompetence</p> <ul style="list-style-type: none"> 41 - Contractor/ subcontractor with lack of equipme 42 - Contractor/ subcontractor with lack of labor an 116 - Inexperienced contractor/ subcontractor <p>29 86 - Feasibility (phase)</p> <ul style="list-style-type: none"> 106 - Incorrect or poor estimations 89 - Finance & Credibility (Internal resources) in feas 72 - External Risks (Feasibility phase) <p>30 39 - Contract (phase)</p> <ul style="list-style-type: none"> 40 - Contract documents 70 - External Risks (Contract phase) <p>31 56 - Design (phase)</p> <ul style="list-style-type: none"> 169 - Performance and characteristics of Designers 166 - Performance and characteristics of Consultant 29 - Conflict with contract (Designers) 95 - Financial of Designers (Internal Resources) 74 - External Risks (Of Consultants) in design phase 77 - External Risks (Of Designers) 71 - External Risks (Design phase) <p>32 105 - Implementation (phase)</p> <ul style="list-style-type: none"> 90 - Finance & Credibility (Internal resources) in implk 168 - Performance and characteristics of Contractor 174 - Performance and characteristics of Suppliers 33 - Conflict with contract (stakeholders- Designers) 167 - Performance and characteristics of Consultant 84 - External risks of stakeholders (Implementation p 73 - External Risks (Implementation phase) <p>33 160 - Operation (phase)</p> <ul style="list-style-type: none"> 200 - Project maintenance 162 - Operation performance 163 - Operation quality 161 - Operation consistency 82 - External Risks (Operation phase) <p>34 161 - Operation consistency</p> <ul style="list-style-type: none"> 36 - Consistency with Other projects 35 - Consistency with Environment <p>35 122 - Internal Risks</p> <ul style="list-style-type: none"> 98 - Financial of stakeholders (Internal Resources) 136 - Management 45 - Contractual 173 - Performance and characteristics of stakehold 	<p>36 221 - Technical Design</p> <ul style="list-style-type: none"> 53 - Delay in design 57 - Design change 50 - Poor or defective design 159 - Operability of design 51 - Deficiency in Design drawings <p>37 205 - Resource definition</p> <ul style="list-style-type: none"> 153 - Materials definition 68 - Equipments definition 147 - Manpower and experts definition <p>38 68 - Equipments definition</p> <ul style="list-style-type: none"> 218 - Suitability of equipment 232 - Usability of equipment 23 - Condition of equipment <p>39 153 - Materials definition</p> <ul style="list-style-type: none"> 151 - Material Handling 229 - Type and quantity of materials 152 - Material Storage <p>40 147 - Manpower and experts definition</p> <ul style="list-style-type: none"> 224 - Terms & Qualification of manpower 204 - Quantity of manpower <p>41 40 - Contract documents</p> <ul style="list-style-type: none"> 24 - Conflict in contract documents 52 - Delay in contract issue 158 - Non standard contract fom <p>42 59 - Designers</p> <ul style="list-style-type: none"> 125 - Internal Risks (Of Designers) 77 - External Risks (Of Designers) <p>43 59 - Designers</p> <ul style="list-style-type: none"> 29 - Conflict with contract (Designers) 169 - Performance and characteristics of Designers 139 - Management (Designers view) 179 - Performance of other stakeholders (-Designers 95 - Financial of Designers (Internal Resources) <p>44 100 - Financiers</p> <ul style="list-style-type: none"> 126 - Internal Risks (Of Financiers) 78 - External Risks (Of Financiers) <p>45 100 - Financiers</p> <ul style="list-style-type: none"> 30 - Conflict with contract (Financiers) 170 - Performance and characteristics of Financiers 140 - Management (Financiers view) 180 - Performance of other stakeholders (-Financier 96 - Financial of Financiers (Internal Resources) <p>46 165 - Owner/Clients</p> <ul style="list-style-type: none"> 127 - Internal Risks (Of Owner/Clients) 79 - External Risks (Of Owner/Clients)
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- 47 165 - Owner/Clients
 31 - Conflict with contract (Owner/Client)
 171 - Performance and characteristics of Owner/Cli
 141 - Management (Owner/ Client view)
 181 - Performance of other stakeholders (-Owner/ C
 97 - Financial of Owner/Client (Internal Resources)
 40 - Contract documents
- 48 44 - Contractors / Sub-contractors
 124 - Internal Risks (Of Contractors\ Sub-contractor
 76 - External Risks (Of Contractors\ Sub-contractors
- 49 44 - Contractors / Sub-contractors
 28 - Conflict with contract (Contractors\ Sub-contrac
 168 - Performance and characteristics of Contractor
 138 - Management (Contractors\ Sub-contractors vi
 178 - Performance of other stakeholders (-Contract
 93 - Financial of Contractors\ Sub-contractors (Inte
- 50 219 - Suppliers
 129 - Internal Risks (Of Suppliers)
 81 - External Risks (Of Suppliers)
- 51 219 - Suppliers
 34 - Conflict with contract (Suppliers)
 174 - Performance and characteristics of Suppliers
 145 - Management (Suppliers view)
 182 - Performance of other stakeholders (-Suppliers'
 99 - Financial of Suppliers (Internal Resources)
- 52 37 - Consultants
 123 - Internal Risks (Of Consultants)
 74 - External Risks (Of Consultants) in design phase
 75 - External Risks (Of Consultants) in implementatic
- 53 37 - Consultants
 27 - Conflict with contract (Consultants)
 166 - Performance and characteristics of Consultant
 137 - Management (Consultants view)
 177 - Performance of other stakeholders (-Consular
 94 - Financial of Consultants (Internal Resources)
 167 - Performance and characteristics of Consultant
- 54 143 - Management (Project view)
 215 - Skill Deficiency in management (Project view)
 113 - Incorrect or insufficient information (Project vie
 194 - Poor Communication (Project view)
 10 - Change in management strategy (Project view)
 21 - Complexity of task or project management (Proj
- 55 139 - Management (Designers view)
 212 - Skill Deficiency in management (Designers vie
 110 - Incorrect or insufficient information (Designers
 190 - Poor Communication (Designers view)
 6 - Change in management strategy (Designers view
 17 - Complexity of task or project management (Des
- 56 140 - Management (Financiers view)
 213 - Skill Deficiency in management (Financiers vie
 111 - Incorrect or insufficient information (Financiers
 191 - Poor Communication (Financiers view)
 7 - Change in management strategy (Financiers view
 18 - Complexity of task or project management (Fina
- 57 141 - Management (Owner/ Client view)
 214 - Skill Deficiency in management (Owner/ Client
 112 - Incorrect or insufficient information (Owner/ Cli
 192 - Poor Communication (Owner/ Client view)
 8 - Change in management strategy (Owner/ Client v
 19 - Complexity of task or project management (Owr
- 58 138 - Management (Contractors\ Sub-contractors view)
 211 - Skill Deficiency in management (Contractors\
 109 - Incorrect or insufficient information (Contractor
 189 - Poor Communication (Contractors\ Sub-contr
 5 - Change in management strategy (Contractors\ Si
 16 - Complexity of task or project management (Cont
- 59 145 - Management (Suppliers view)
 216 - Skill Deficiency in management (Suppliers view
 114 - Incorrect or insufficient information (Suppliers \
 195 - Poor Communication (Suppliers view)
 11 - Change in management strategy (Suppliers view
 22 - Complexity of task or project management (Supj
- 60 137 - Management (Consultants view)
 210 - Skill Deficiency in management (Consultants v
 108 - Incorrect or insufficient information (Consultant
 188 - Poor Communication (Consultants view)
 4 - Change in management strategy (Consultants vie
 15 - Complexity of task or project management (Con:
- 61 168 - Performance and characteristics of Contractors\ S
 43 - Contractor/sub-contractor Incompetence
 175 - Performance of contractor/ subcontractor in ta
- 62 98 - Financial of stakeholders (Internal Resources)
 97 - Financial of Owner/Client (Internal Resources)
 96 - Financial of Financiers (Internal Resources)
 95 - Financial of Designers (Internal Resources)
 93 - Financial of Contractors\ Sub-contractors (Inter
 94 - Financial of Consultants (Internal Resources)
 99 - Financial of Suppliers (Internal Resources)
- 63 136 - Management
 144 - Management (Stakeholders view)
 143 - Management (Project view)
- 64 144 - Management (Stakeholders view)
 141 - Management (Owner/ Client view)
 140 - Management (Financiers view)
 139 - Management (Designers view)
 138 - Management (Contractors\ Sub-contractors vi
 137 - Management (Consultants view)
 145 - Management (Suppliers view)

65	172 - Performance and characteristics of stakeholder
	..... 171 - Performance and characteristics of Owner/Client
	..... 170 - Performance and characteristics of Financiers
	..... 169 - Performance and characteristics of Designers
	..... 168 - Performance and characteristics of Contractor
	..... 166 - Performance and characteristics of Consultant
	..... 174 - Performance and characteristics of Suppliers
	..... 167 - Performance and characteristics of Consultant
66	45 - Contractual
	..... 40 - Contract documents
	..... 32 - Conflict with contract (stakeholder)
67	32 - Conflict with contract (stakeholder)
	..... 31 - Conflict with contract (Owner/Client)
	..... 30 - Conflict with contract (Financiers)
	..... 29 - Conflict with contract (Designers)
	..... 28 - Conflict with contract (Contractors\ Sub-contractors)
	..... 34 - Conflict with contract (Suppliers)
	..... 27 - Conflict with contract (Consultants)
68	169 - Performance and characteristics of Designers
	..... 221 - Technical Design
	..... 205 - Resource definition
	..... 58 - Design team Incompetence
69	58 - Design team Incompetence
	..... 115 - Inexperience design team
	..... 231 - Unfamiliar with new technology
70	173 - Performance and characteristics of stakeholders
	..... 172 - Performance and characteristics of stakeholder
	..... 176 - Performance of other stakeholders
71	33 - Conflict with contract (stakeholders- Designers)
	..... 27 - Conflict with contract (Consultants)
	..... 28 - Conflict with contract (Contractors\ Sub-contractors)
	..... 30 - Conflict with contract (Financiers)
	..... 31 - Conflict with contract (Owner/Client)
	..... 34 - Conflict with contract (Suppliers)
72	84 - External risks of stakeholders (Implementation phase)
	..... 76 - External Risks (Of Contractors\ Sub-contractors)
	..... 81 - External Risks (Of Suppliers)
	..... 75 - External Risks (Of Consultants) in implementation
	..... 79 - External Risks (Of Owner/Clients)
	..... 78 - External Risks (Of Financiers)
73	176 - Performance of other stakeholders
	..... 181 - Performance of other stakeholders (-Owner/ Client)
	..... 180 - Performance of other stakeholders (-Financiers)
	..... 179 - Performance of other stakeholders (-Designers)
	..... 178 - Performance of other stakeholders (-Contractors)
	..... 177 - Performance of other stakeholders (-Consultants)
	..... 182 - Performance of other stakeholders (-Suppliers)

Figure 5-2. Additional MT database (tunneling projects)

-
- 74 127 - Internal Risks (Of Owner/Clients)
 - 31 - Conflict with contract (Owner/Client)
 - 171 - Performance and characteristics of Owner/Client
 - 141 - Management (Owner/ Client view)
 - 97 - Financial of Owner/Client (Internal Resources)
 - 40 - Contract documents
 - 75 175 - Performance of contractor/ subcontractor in task execution
 - 237 - Maintenance of site and equipments
 - 238 - Inspection of work by contractor
 - 239 - Construction program planning
 - 240 - Security and safety of work
 - 241 - Poor workmanship or function of labors and experts
 - 76 124 - Internal Risks (Of Contractors\ Sub-contractors)
 - 28 - Conflict with contract (Contractors\ Sub-contractors)
 - 168 - Performance and characteristics of Contractors\ Sub-contractors
 - 138 - Management (Contractors\ Sub-contractors view)
 - 93 - Financial of Contractors\ Sub-contractors (Internal Resources)
 - 77 125 - Internal Risks (Of Designers)
 - 29 - Conflict with contract (Designers)
 - 169 - Performance and characteristics of Designers
 - 139 - Management (Designers view)
 - 95 - Financial of Designers (Internal Resources)
 - 78 50 - Poor or defective design
 - 233 - Incorrect or insufficient design data
 - 234 - Disregarding to the effective parameters and standards
 - 235 - Mistake of designer in calculations and analysis
 - 236 - Inappropriate applied method, model or design tool

Table 5.6. Database of Micro Trees notes

MT Code	Project Stakeholders							Objective of project risk management				Project Phases					
	Designers	Financiers	Owner/ Clients	Contractors	Suppliers	Consultants	All the St.	Price	Time	Quality	All the objectives	Feasibility	Contract	Design	Implementation	operation	All the phases
1	0	0	0	0	0	0	0	0.4	0.4	0.6	0.6	0	0	0	0	0	0
2	1	1	1	1	1	1	1	1	0.6	1	0.8	0.4	0.4	0.4	0.4	0.4	0.4
3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.8	1	1	1	1	1	1	1	1	1
4	0.2	0.2	0.2	0.2	0.2	0.2	0.8	1	1	0.4	0.8	1	1	1	1	1	1
5	0.2	0.2	0.2	0.2	0.2	0.2	0.8	1	1	0.4	0.8	1	1	1	1	1	1
6	0.6	0.2	0.6	0.8	0.2	0.4	0.4	1	1	0.6	0.8	1	1	1	1	1	1
7	0.6	0.8	0.8	0.6	0.8	0.6	0.6	1	1	0.4	0.8	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	0.6	1	0.8	0.4	0.4	0.4	0.4	0.4	0.4
10	0.8	0.8	0.8	0.8	0.8	0.8	1	1	1	1	1	0.8	0.8	0.8	0.8	0.8	1
54	0.8	0.8	0.8	0.8	0.8	0.8	1	0.8	0.8	0.8	1	0.8	0.8	0.8	0.8	0.8	1
11	0.6	1	1	0.8	1	0.6	0.8	1	0.8	0.6	0.8	1	1	1	1	1	1
12	0.4	1	1	0.8	1	0.6	0.8	1	0.8	0.6	0.8	1	1	0.8	1	0.8	0.8
13	0.4	0.4	0.6	0.8	1	0.4	0.4	1	0.8	1	0.8	0.6	0.8	0.8	1	0.6	0.6
14	0.6	0.8	1	0.6	0.6	0.4	0.8	0.8	0.8	0.6	0.8	1	0.8	0.6	0.4	0.6	0.8
15	0.6	0.8	0.8	0.6	0.6	0.4	0.8	0.8	0.8	0.6	0.8	1	0.8	0.6	0.4	0.6	0.8
16	0.8	0.6	0.8	0.4	0.4	0.4	0.4	0.4	0.4	0.2	0.4	1	1	0.8	0.6	0.6	0.6
17	0.2	0.6	1	0.4	0.8	0.2	0.6	0.4	0	0	0.2	0.8	0.6	0.2	0.2	0.4	0.6
18	0.2	0.6	1	0.4	0.8	0.2	0.6	0.4	0	0	0.2	0.8	0.6	0.4	0.4	0.6	0.6
19	0.2	0.6	1	0.4	0.8	0.2	0.6	0.6	0	0	0.4	0.8	0.8	0.2	0.2	0.4	0.6
20	0.4	0.4	0.8	0.8	0.8	0.2	0.6	0.8	0.6	0.4	0.6	1	0.6	0.6	0.8	0.6	0.6
21	0.2	0.4	0.6	0.6	0.4	0.2	0.6	0.4	0.8	0.4	0.6	0.6	0.6	0.4	0.6	0.6	0.6
22	0.2	0.4	0.6	0.6	0.4	0.2	0.6	0.4	0.8	0.4	0.6	0.6	0.6	0.4	0.6	0.6	0.6
23	1	0	0	0.8	0	0.6	0.4	0.6	0.6	0.6	0.6	0	0.2	0.8	0.8	0.6	0.4
24	0.4	0	0.4	0.8	0.6	0.2	0.4	0.6	0.6	0.4	0.6	0.6	0.2	0.4	0.8	0.6	0.4
25	0.6	0	0.6	1	0.8	0	0.8	0.8	0.8	0.6	0.8	0.4	0.4	0.6	1	1	0.6
28	0.4	0	0.4	1	0.2	0.4	0.4	0.6	0.6	0.8	0.8	0	0.4	0.4	1	0	0.4
29	0	0.6	1	0.4	0	0	0.4	0.8	0.8	0.6	0.8	1	0	0	0	0	0
30	0	0.2	0.8	0.6	0.4	0.4	0.4	0.6	0.4	0.4	0.4	0	1	0	0	0	0
31	1	0	0.4	0.4	0	0.8	0.4	0.8	0.8	0.4	0.6	0	0	1	0	0	0
32	0.4	0.6	0.4	1	0.8	0.6	0.6	0.8	0.8	0.8	0.8	0	0	0	1	0	0
33	0	0.4	0.8	0	0.4	0.4	0.4	0.6	0.4	0.2	0.4	0	0	0	0	1	0
34	0	0	0.8	0	0.2	0.4	0.4	0.4	0.2	0.6	0.4	0	0	0	0	1	0
35	0	0	0	0	0	0	0.4	0.8	0.6	0.8	0.8	0	0	0	0.4	0	0.4
36	1	0	0.4	0.4	0	0.6	0.4	0.6	0.6	0.4	0.6	0	0	1	0.4	0	0.4
37	1	0	0	0.4	0.4	0.8	0.4	0.6	0.6	0.8	0.6	0.4	0	1	0.4	0	0.4
38	1	0	0	0.4	0.4	0.8	0.4	0.6	0.6	0.8	0.6	0.4	0	1	0.4	0	0.4
39	1	0	0	0.4	0.4	0.8	0.4	0.6	0.6	0.8	0.6	0.4	0	1	0.4	0	0.4
40	1	0	0	0.4	0	0.8	0.4	0.4	0.8	0.8	0.8	0.4	0	1	0.4	0.2	0.4
41	0	0	1	0.4	0	0	0.6	0.4	0.4	0	0.4	0	1	0	0	0	0
42	1	0	0	0	0	0	0	0.6	0.4	0.4	0.6	0	0	1	0.6	0	0.4
43	1	0	0	0	0	0	0	0.6	0.4	0.4	0.6	0	0	1	0.6	0	0.4
44	0	1	0	0	0	0	0	0.4	0.8	0.4	0.8	0.6	0.4	0.4	1	0.8	0.8
45	0	1	0	0	0	0	0	0.4	0.8	0.4	0.8	0.6	0.4	0.4	1	0.8	0.8

46	0	0	1	0	0	0	0	0.4	0.8	0.4	0.6	0.8	1	0.4	0.4	0.8	0.8
47	0	0	1	0	0	0	0	0.4	0.8	0.4	0.6	0.8	1	0.4	0.4	0.8	0.8
48	0	0	0	1	0	0	0	1	0.8	1	0.8	0	0.8	0.4	1	0	0.8
49	0	0	0	1	0	0	0	1	0.8	1	0.8	0	0.8	0.4	1	0	0.8
50	0	0	0	0	1	0	0	1	0.8	0.6	0.6	0	0	0	1	0.4	0.6
51	0	0	0	0	1	0	0	1	0.8	0.6	0.6	0	0	0	1	0.4	0.6
52	0	0	0	0	0	1	0	0.6	0.6	0.6	0.6	0.4	0.2	0.8	0.8	0.6	0.6
53	0	0	0	0	0	1	0	0.6	0.6	0.6	0.6	0.4	0.2	0.8	0.8	0.6	0.6
55	1	0	0	0	0	0	0	0.4	0.6	0.4	0.4	0	0	1	0	0	0
56	0	1	0	0	0	0	0	0.4	0.8	0.4	0.6	0	0	0	1	0.8	0.6
57	0	0	1	0	0	0	0	0.6	0.8	0.4	0.8	0.6	1	0.6	0.6	0.8	0.8
58	0	0	0	1	0	0	0	0.8	0.8	0.8	0.8	0	0	0.2	0.8	0	0.6
59	0	0	0	0	1	0	0	0.8	0.8	0.6	0.6	0	0	0	1	0.8	0.6
60	0	0	0	0	0	1	0	0.6	0.8	0.8	0.6	0.2	0.2	0.8	0.8	0.4	0.6
61	0	0	0	1	0	0	0	1	0.8	1	1	0	0	0	1	0	0
62	1	1	1	1	1	1	1	0.6	0.8	0.8	0.8	0.6	0.6	0.6	0.8	0.6	0.6
63	1	1	1	1	1	1	1	1	1	1	1	0.6	0.6	0.6	0.6	0.6	1
64	1	1	1	1	1	1	1	0.8	1	0.8	1	0.2	0.2	0.2	0.4	0.2	0.6
65	1	1	1	1	1	1	1	0.8	0.8	0.8	0.8	0.2	0.2	0.2	0.2	0.2	0.4
66	0.4	0.4	0.8	0.4	0.4	0.4	0.6	0.4	0.6	0.4	0.4	0	1	0.4	0.4	0.4	0.4
67	1	1	1	1	1	1	1	0.4	0.6	0.4	0.4	0	0.2	0.4	0.4	0.4	0.4
68	1	0	0	0	0	0	0	0.6	0.6	0.4	0.6	0	0	1	0	0	0
69	1	0	0	0	0	0	0	0.4	0.4	0.2	0.4	0	0	1	0	0	0
70	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1	1	1	1	0.4	0.4	0.4	0.6	0.4	0.6
71	0	1	1	1	1	1	0.8	0.4	0.6	0.4	0.4	0.2	0.2	0.2	1	0.2	0.2
72	0	1	1	1	1	1	0.8	0.4	0.4	0.4	0.4	0	0	0	1	0	0
73	1	1	1	1	1	1	1	0.8	0.8	0.8	0.8	0	0	0	0	0	0.4
74	1	0	0.4	0.4	0	0.6	0.4	0.6	0.6	0.4	0.6	0	0	1	0.4	0	0.4
75	1	0	0	0	0	0	0	0.6	0.4	0.4	0.6	0	0	1	0.6	0	0.4
76	0	0	0	1	0	0	0	1	0.8	1	0.8	0	0.8	0.4	1	0	0.8
77	0	0	0	1	0	0	0	1	0.8	1	1	0	0	0	1	0	0
78	0	0	1	0	0	0	0	0.4	0.8	0.4	0.6	0.8	1	0.4	0.4	0.8	0.8

Appendix 2

Synthesis of RBS's in literature

In this part, only the synthetic analysis of some of the evaluated RBS's is discussed.

RBS 2	
<p>Reference: Patrick X.W. Zou, Guomin Zhang, Jiayuan Wang, Understanding the key risks in construction projects in China. <i>International Journal of Project Management</i>, Volume 25, Issue 6, August 2007, 601-614</p> <p>Web link: Click here</p> <p>General subject of the Article/ document: Understand the key risks in construction projects</p> <p>Destination country: China</p> <p>Number of levels: 2</p> <p>Method of development of the RBS:</p> <p> <input type="checkbox"/> Brainstorming <input checked="" type="checkbox"/> Checklist Analysis/literature review <input checked="" type="checkbox"/> Delphi technique (Questionnaire) <input type="checkbox"/> Experience of author <input type="checkbox"/> Interview </p>	
<p>Schematic of the RBS:</p> <p style="text-align: center;"><i>P.X.W. Zou et al. / International Journal of Project Management 25 (2007) 601–614</i></p>	

Acronyms	Represented risk factors		
BG	Bureaucracy of government		
CDR	contractors' difficulty in reimbursement		
CPMA	contractors' poor management ability	SAP	serious air pollution due to construction activities
DV	design variations		
EPGA	excessive procedures of government approvals	SIDM	suppliers' incompetency to deliver materials on time
ICE	incomplete or inaccurate cost estimate	SNP	serious noise pollution caused by construction
IPS	inadequate program scheduling	TPS	tight project schedule
ISI	inadequate site information (soil test and survey report)	UPM	unavailability of sufficient professionals and managers
ISM	inadequate safety measures or unsafe operations	USL	unavailability of sufficient amount of skilled labourer
LAU	lack of readily available utilities on site	VC	variations by the client
LMCS	low management competency of subcontractors	WIME	without buying insurance for major equipment
PCL	poor competency of labourer	WP	water pollution caused by construction
PFP	project funding problems	WSIE	without buying safety insurance for employees
PICM	price inflation of construction materials		
PUDW	prosecution due to unlawful disposal of construction waste		

Comments:

- In this fish-bone diagram, two types of project risks decomposition are combined together: regarding the project life cycle and different perspectives of the project stakeholders. In fact, decomposition of corresponding risks of each partner regarding different phases of the project can be considered as a generic micro tree which is applied for each stakeholder individually. Even, this micro tree is applied to decompose the external risks of the project by the same logic.
- Regarding the level of detail of decomposition, it seems that, the relative large number of attached risk events to “Contractors” category requires more decomposition into lower levels.
- However regarding the attached risk events to “Clients” category, it seems that, finance and management of the project are also undertaken by the clients, but this is not a general case and this RBS might not be applicable to some other projects.
- In this RBS, decomposition of project risks regarding the project phases and stakeholders are comparable with MT#2 and MT#3 in our database. Since they have similar father nodes (project risks), each risk event is connected to one of the project phases and one of the project partners as well.

201 - Project risks
 202 - Project stakeholders
 143 - Management (Project view)
 83 - External Risks (Project phases and project view)

201 - Project risks
 86 - Feasibility (phase)
 39 - Contract (phase)
 56 - Design (phase)
 105 - Implementation (phase)
 160 - Operation (phase)
 136 - Management

- A notable part of risks in real projects are related to the “Contract” phase which are not mentioned in this RBS.
- Definition of some risk events are not precise enough, that can cause confusion and misunderstanding for other users. For instance, “unavailability of sufficient professionals and managers” and “unavailability of sufficient amount of skilled laborers” by this diction seem to be external risks of the project. Unavailability of resources is a context problem and is not related to the performance of contractors. The mentioned risk events are comparable with RE#3 in our database “lack of qualified staff, working for contractors (incompetent staff)” which has precise definition and is related to the project contractors.

RBS 4

Reference:

Artem Aleshin, Risk management of international projects in Russia. *International Journal of Project Management*, Volume 19, Issue 4, May 2001, Pages 207-222

Web link: [Click here](#)

General subject of the Article/ document: Risk management for international projects

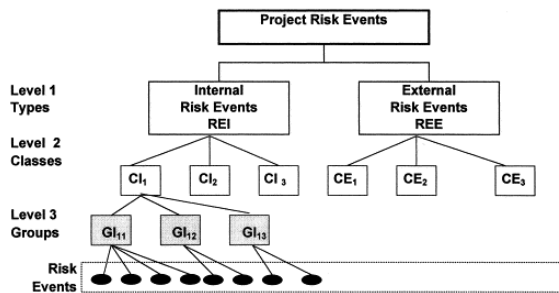
Destination country: Russia

Number of levels: 3

Method of development of the RBS:

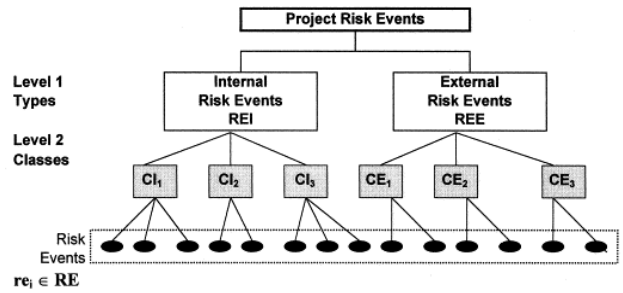
- Brainstorming
- Checklist Analysis/literature review
- Delphi technique (Questionnaire)
- Experience of author
- Interview

Schematic of the RBS:



Where:

- GI₁₁** In Tender Documentation absence of full list of overhead and underground objects situated on the construction sites and on the approaches to them
 - re_{GI11}¹ On the construction site a telephone cable was found
 - re_{GI11}² On the construction route 138 trees have been found
 - re_{GI11}³ In tender there is no information about the location route of the main gas pipeline
 - re_{GI11}⁴ In the area of construction an electric cable has been found
- GI₁₂** In Tender Documentation the changes taken place on the construction sites have not been taken into account. These changes occurred from the moment the completion of Tender Documentation till the moment when the construction sites were transferred to a Contractor.
 - re_{GI12}¹ The construction site is not vacated completely. There are foreign erections, devices, concrete elements.
 - re_{GI12}² On the route of the construction there are five private garages
- GI₁₃** Real characteristics construction site ground does not correspond to the data shown in the Tender Documentation.
 - re_{GI13}¹ An erection planned according to Tender is in the zone of slide. Landslide characteristic of locality and adequate to it counter-landsliding arrangements are not shown in Tender Documentation.



Where:

- CI₁ - Client's mistakes on the phase of Tender Documentation Development;
- CI₂ - Not performing of duties imposed by the Contract on the Client and the Engineer.;
- CI₃ - Additional requirements of Local Authorities and Municipal Services under the construction in progress.;
- REI = CI₁ ∪ CI₂ ∪ CI₃ and CI₁ ∩ CI₂ ∩ CI₃ = ∅
- card (REI) = card (CI₁) + card (CI₂) + card (CI₃)
- CE₁ - Actions of the third parties;
- CE₂ - Unforeseen circumstances;
- CE₃ - Weather conditions;
- REE = CE₁ ∪ CE₂ ∪ CE₃ and CE₁ ∩ CE₂ ∩ CE₃ = ∅
- card (REE) = card (CE₁) + card (CE₂) + card (CE₃)

Comments:

- In this RBS, decomposition of the project risks to internal and external risks is similar with MT#1 in our database.

- Decomposition of internal risks is limited to contract documents, performance of owner and problems with local authorities and municipal services. Clearly, these three categories cannot cover all the internal risks of the project. Important risks such as project management, performance of the other stakeholders and internal financial problems of stakeholders are not covered by this RBS. MT#35 in database decompose the internal risks of the project to:

```

122 - Internal Risks
├── 98 - Financial of stakeholders (Internal Resources)
├── 136 - Management
├── 45 - Contractual
└── 173 - Performance and characteristics of stakeholders

```

which is general and applicable in any other project.

- The external risks are limited only to actions of the third party, unforeseen weather and circumstances. The same as internal category, this decomposition does not cover the wide range of external risks of the project. The risks such as economic and financial, political, legal and regularities and context risks are not covered by the proposed RBS. In our database, MT#4 decomposes the external risks as follow:

```

83 - External Risks (Project phases and project view)
├── 63 - Economic/Financial
├── 185 - Political
├── 131 - Legal and regularities
├── 156 - Natural hazards
├── 230 - Unexpected weather
├── 101 - Force majeure
└── 38 - Context

```

which covers all the probable external risks of projects.

- The third subcategory of internal risks in this RBS (“Additional requirements of local authorities and municipal service...”) seems not to be internal risk for the project, since is not completely manageable and controllable by the project partners. The local authorities and municipal service have the third party role for the project and the corresponding problems must be considered as external risks.

RBS 5

Reference:

David Hillson, Understanding risk exposure using multiple hierarchies, Originally published as a part of 2007 PMI Global Congress EMEA Proceedings – Budapest

Web link: [Click here](#)

General subject of the Article/ document: General RBS

Destination country: -

Number of levels: 2

Method of development of the RBS:

- Brainstorming
- Checklist Analysis/literature review
- Delphi technique (Questionnaire)
- Experience of author
- Interview

Schematic of the RBS:

RBS LEVEL 0	RBS LEVEL 1	RBS LEVEL 2
0. PROJECT RISK	1. TECHNICAL RISK	1.1 Scope definition
		1.2 Requirements definition
		1.3 Estimates, assumptions & constraints
		1.4 Technical processes
		1.5 Technology
		1.6 Technical interfaces
		1.7 Design
		1.8 Performance
		1.9 Reliability & maintainability
		1.10 Safety
		1.11 Security
		1.12 Test & acceptance
	2. MANAGEMENT RISK	2.1 Project management
		2.2 Programme/portfolio management
		2.3 Operations management
		2.4 Organisation
		2.5 Resourcing
		2.6 Communication
		2.7 Information
		2.8 HS&E
		2.9 Quality
2.10 Reputation		
3. COMMERCIAL RISK	3.1 Contractual terms & conditions	
	3.2 Internal procurement	
	3.3 Suppliers & vendors	
	3.4 Subcontracts	
	3.5 Client/customer stability	
	3.6 Partnerships & joint ventures	
4. EXTERNAL RISK	4.1 Legislation	
	4.2 Exchange rates	
	4.3 Site/facilities	
	4.4 Environmental/weather	
	4.5 Competition	
	4.6 Regulatory	
	4.7 Political	
	4.8 Country	
	4.9 Social/demographic	

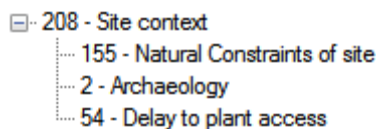
Exhibit 1: Example Risk Breakdown Structure (RBS)
(from Hillson & Simon, 2007)

Comments:

- This RBS represents a particular decomposition of project risks which is comparable with MT#1 in database. The three categories of technical, management and commercial risks which are located beside the “External risks” can be considered as internal risks of the project.
- The RBS is well structured and has a general form; however, it has some drawbacks. The first one is that some of the categories are not clear enough and need more explanation about what they include or exclude. For instance, is the category “1.8. Performance” related to designers or contractors? Or maybe to all the stakeholders?
- The category “Technology”, does it mean the difficulties or availability of needed technology or is related to unfamiliarity of designers with the technology? For the first case, technology must be considered as an external risk for the project, thus, it has not to be a subcategory of technical risks.
- In this RBS, the economic risks which have notable effects on project success are limited to “Exchange rates” but of course it covers a wider domain. In our database, MT#11 decomposes the economic risks as below:



- What type of risks is corresponding to the category “4.8. Country”? Is it different with the political and legislation risks? If not, there is an overlap between risks covered by these subcategories.
- Risks corresponding to “Site” cannot be considered as external risks. For instance, poor planning of site and ground investigation during feasibility phase is an internal risk of the project, thus, they have to be clearly distinguished in RBS. In our database, MT#24 is related to external risks corresponding to site:



- It seems that the category “1.4. Technical process” has some overlap with some other categories such as “Design” and “Performance”. In fact, technical process covers design, estimates, assumptions and technical performance of designer and contractor to execute the plan. So a risk event such as “Defective design due to incorrect evaluation of the water table level”, can be attached to “1.4. technical process”, “1.7. Design” and “1.3. Estimates, assumptions and constraints”.
- As conclusion, the names of the categories have to be precise enough to prevent any confusion or misunderstanding of the users.

RBS 7

Reference:

Sadoullah Ebrahimnejad, Seyed Meysam Mousavi, Hamed Seyrafiانpour, Risk identification and assessment for build–operate–transfer projects: A fuzzy multi attribute decision making model. *Expert Systems with Applications, Volume 37, Issue 1, January 2010, Pages 575-586*

Web link: [Click here](#)

General subject of the Article/ document: Risk management for build–operate–transfer (BOT) projects

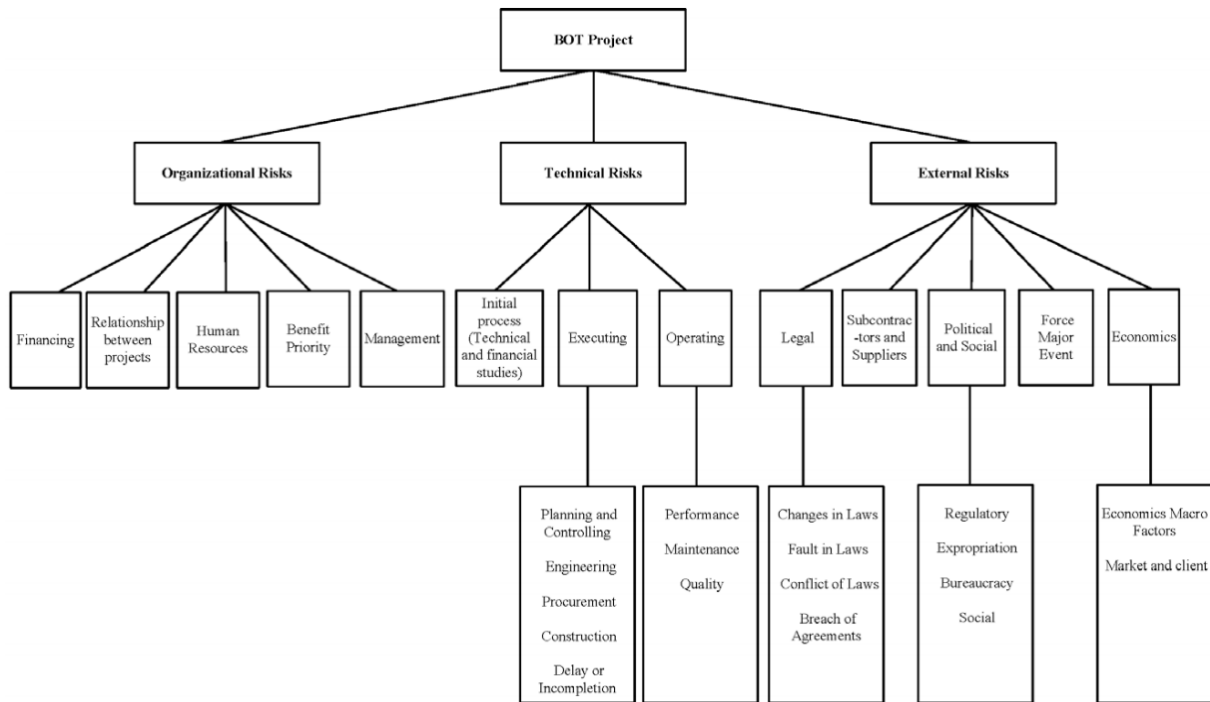
Destination country: Iran

Number of levels: 3

Method of development of the RBS:

- Brainstorming
- Checklist Analysis/literature review
- Delphi technique (Questionnaire)
- Experience of author
- Interview

Schematic of the RBS:



Comments:

- In this RBS the “Organizational risks” and “Technical risks” are located beside the “External risks” which is comparable with MT#1 in our database:

☐ 201 - Project risks
└─ 122 - Internal Risks
└─ 83 - External Risks (Project phases and project view)

- It is strange to find “Subcontractors and suppliers” beside external risks such as legal, Political and economics, since they are two partners of the project.
- The natural hazard are not mentioned in this RBS, however they have an important effect on project success; the same for context risks such as third party, resources context, site context and etc.
- At the first level, the technical risks are decomposed regarding different phases of the project but, decomposition of the “Executing” category is not clear enough. Which kind of risks are covered by the “Engineering” category that are different with “technical planning and controlling” and “Construction”? Their differences and risk domains are not clear enough and it seems that they can cover the same type of risks.
- It seems that control and managing the relationships between project partners, different contractors and subcontractors and also with the other projects (located in external environment of the project as third parties) is the subject of project management. Nevertheless, in this RBS “Relationship between projects“ category is located beside the “management” as a different category!

RBS 8

Reference:

He Zhi, Risk management for overseas construction projects, *International Journal of Project Management*, Volume 13, Issue 4, August 1995, Pages 231-237

Web link: [Click here](#)

General subject of the Article/ document: RBS for overseas construction projects

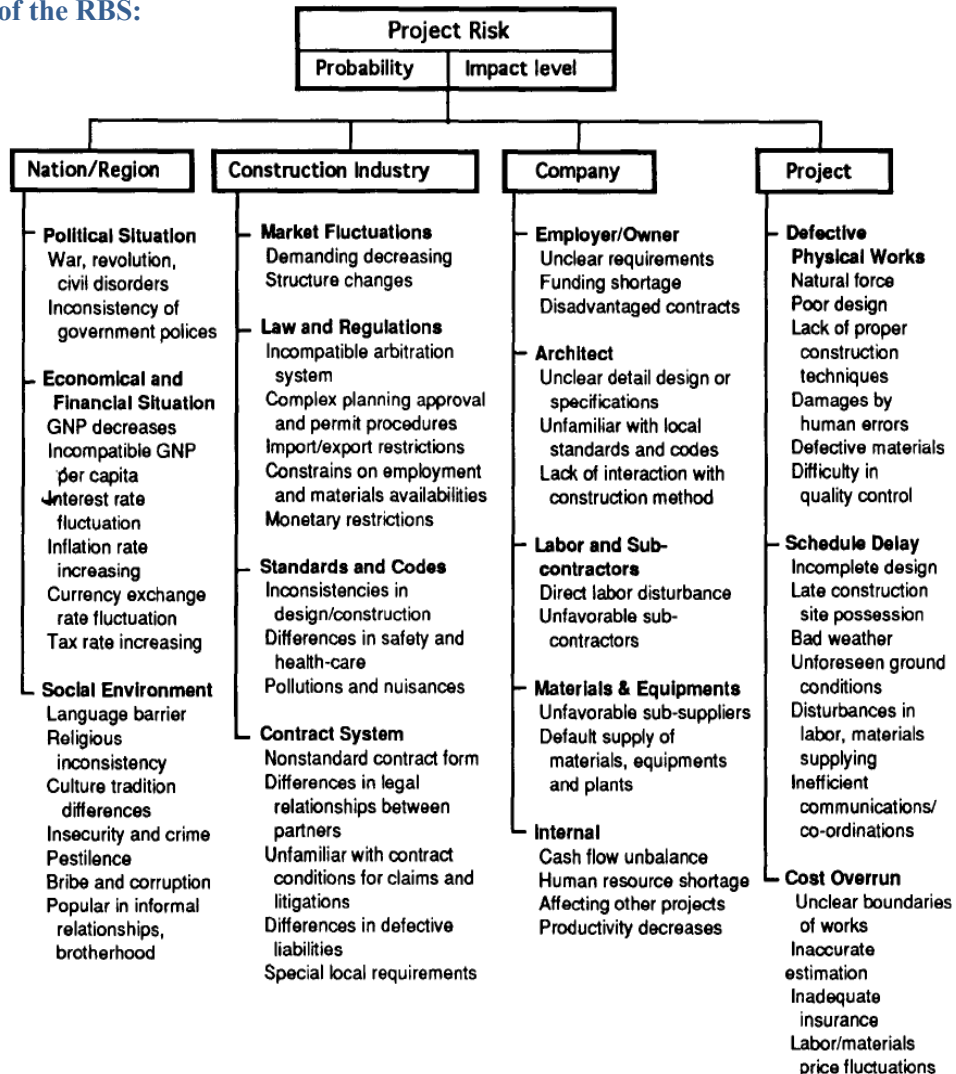
Destination country: China

Number of levels: 3

Method of development of the RBS:

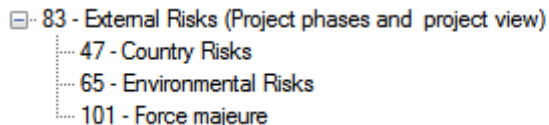
- Brainstorming
- Checklist Analysis/literature review
- Delphi technique (Questionnaire)
- Experience of author
- Interview

Schematic of the RBS:



Comments:

- As the author says, in this RBS, risks are classified in terms of their initial sources: the external and internal aspects of an overseas construction project. Several peripheral circles defining the project environment are defined. The external risks are those changeable factors that relate to the national/regional market or the local construction industry which have significant impacts on the project. The internal risks are those uncertainties inherited by the companies involved or determined by the project's own nature.
- However the idea of this decomposition is creative and valuable, it suffers some drawbacks, the main one being that the project risks are considered as a subcategory of the project risks which is reciprocating. It would be better to select another name for this category at the first level, for instance: "Internal risks of the project".
- At the second level, the internal project risks are decomposed based on the type of effect on the project objectives. However, it has to be noted that, schedule, final cost and quality and performance of the project are the final objectives and cannot be considered as subcategories of the project risks. In other words, delay, cost overrun and defective physical works are the consequence, not the source of the project risks.
- A risk event has different impacts on each one of the project objectives. For instance a risk event such as "Unforeseen ground condition" not only affect the schedule, but of course the final cost and quality of the work. Or as another example, "natural forces" not only has effect on quality of the work, but on the schedule and final cost of the project as well. But of course the impacts are not the same on different objectives and can be more important for one and less important for the others. Thus, it seems that REs grouping, as it is done in this RBS is not accurate and realistic.
- "Labors/ materials price fluctuations" is a risk event which is considerable at the "Nation/region" or "Construction industry" scale. Since in this RBS, risk decomposition is regarding the source of risks, it seems that consideration of this RE at the project level is not proper.
- At the company scale, at level 1, the corresponding risks are decomposed regarding the source of risks: the external activities between companies and the internal activities within company. For the external activities, it seems that the name of the fourth category has to be changed to "Materials and equipments suppliers" to be consistent with the others.
- In our database, MT#1 decomposes the project risks clearly to internal and external risks and MT#5 decompose the external risks as below:



- As the author explains, owner of the project, architect (designers), suppliers and even subcontractors are considered at the outside of the company (contractor) activities circle. This proves that this RBS is applicable for the special perspective of the contractor (company) in an overseas project and cannot represent proper decomposition of the project risks by a global view to the project.

Appendix 3
Software manual

Risk Management

Version 1.0.0.0

User Guide

Manual version 1.0

Correspond to **RISK MANAGEMENT** version 1.0.0.0
May 2011

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1. Introduction

Construction and infrastructure projects are characterized as very complex projects, where uncertainty comes from many sources. Construction projects gather together different stakeholders, having different points of view and objectives that must be taken into consideration. Furthermore, complex and variable underground conditions bring some more degree of uncertainty to every construction project that can affect the schedule, quality, safety and final cost of the work.

We have developed a general method to build RBS in an efficient way to identify and organize risks in construction 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 specific 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 by some more subcategories in special fields. This methodology was fully explained in Chapter 3.

A software has been developed to facilitate the application of this methodology in real projects by project managers. This software is integration of all the concepts and algorithms of this innovated method, with a user friendly interface. It can be used in an advanced level, by risk management experts and project managers. However, anybody who has the basic information of project risk management can use this software easily.

This manual is to explain all the needed information about this software and has four sections. After the first part which is an introduction to this manual, the second one is to know how to install and what can be done with this software. Section three has the precise and detailed information about the different parts of the software. In this section, we can find how to work with software, how to add new data, how to edit or remove the available data and also comprehensive information about error messages and the way to correct the corresponding mistakes. The last section (Section 4) provides some examples of application of this software explaining how to make a new database, add new information or remove the available data. To find the theoretical basis of this software, about Risk breakdown Structure (RBS), the main algorithm, the database, criteria and the applied formulas in this software, refer to Chapter 3.

This work has been developed in the frame of the French ANR-GERMA research program, whose all partners are thanked here for their contribution to discussion and thought provoking ideas. Hope this work can be an effective step to improve the risk management of construction projects.

2. Getting started

2.1. Installation structure

To install this software, *.NET framework 2.0* is needed and should be installed before starting the installation process. The installation engine checks the availability and version of this component of system and if is needed, it will be automatically installed, before starting the main installation wizard.

By click on Setup file, the installation process will be started. Figure 2-1 illustrates the first installation page.

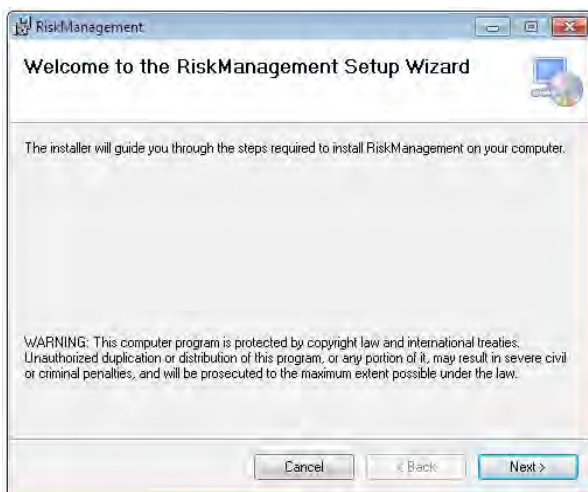


Figure 2-1. First installation window

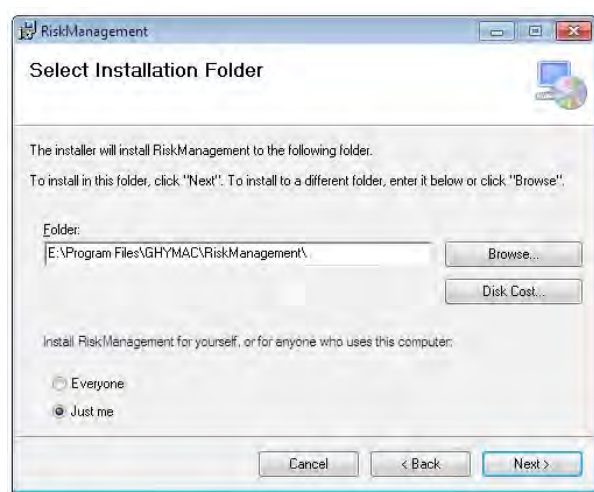


Figure 2-2. Second installation page

By click *Next* button, user can change the installation path in the second window (see Figure 2-2). Following the installation wizard, by click *Next* button in the following windows, the software will be installed automatically.

To start the program, by click on the new icon (*Risk Management*) which is added to list of programs in *start menu*, the main page of the program comes up.

2.2. What Risk Management v.1.0.0 can do?

This software is a useful tool for identification, analysis and hierarchical representation of risks. It can help the project manager to answer to lots of questions such as:

- what are the main risks of the project?
- what are the type of risks?
- who or what is the source of the risk?
- in which phase of the project it can happen?

- is it a significant risk?
- which partner or phase of the project is more risky?

and lots of other common questions in this field that usually are not easy to answer. This software can help to answer these questions systematically, following an advanced methodology of project risk management.

Each user can build his own database of risk events, risk categories and micro trees and the software controls the consistency of data in each step. It is impossible to make a change in the database when it can cause to an inconsistent situation. Also user can use the database of the other users. They can share the information of the database.

A rich database of risks related to the construction projects has been prepared which is useful for the users of this software. We have tried to develop a large database of risks of the construction and tunneling projects which can cover the most frequent risks, from the beginning to the end of the projects life. But of course it is not comprehensive and exclusive, since uncertainty is the inherent nature of risks. In each new project, lots of new risks can be identified but they can be easily added to the database, while the software controls their consistency with the available data in database. This database has been developed based on a thorough analysis and literature review of more than 90 scientific papers and risk management cases for which (Risk Breakdown Structure) RBS is the main method used for risk identification. The combination of this database and the software, equip the manager with a very useful innovated tool which can help to better management of the project risk.

Using this software, the user can identify the possible risks of any special project, from a long list of risk events. The software will categorize these risk events, which can help to better understanding of the risks. This process will be regarding the special requirements of user. The risks are analyzed with the perspective of which one of the project partners? The risks are corresponding to which phase of the project? And what is the main objective of the project risk management? The answer of such questions give required information to the algorithm to make decision for selection of the most convenient RBS's.

The risk values of selected risk events are aggregated on RBS branches to highlight the most risky parts of the project. If a category, at the end of a branch is risky or user is interested to find more details about this category, it can be easily decomposed again to a lower level. In this case all of the information, distribution of risk events, risk values and the five quality notes of the RBS will be recalculated automatically.

As summary, the most important applications of this software can be listed as below:

- Development of a shared linguistic of risks. Each risk event or category has a precise name, definition, type and some other properties which are unique and it enables the managers to discuss risks with a same language.
- Easier and more effective management of a long list of project risks.

- Identification of probable risks of the project.
- Categorization of risk events to risk categories.
- Hierarchical representation of risks (Risk Breakdown Structure).
- Aggregation of risk values through the RBS.
- Highlighting the most risky parts of the project.
- Dynamic identification and analysis of risks, corresponding to each project phase or stakeholder.
- Finding the most convenient RBS for each special case, regarding the requirements of the user, highlighting the project risks and convenient level of details.
- Creating a shared hierarchical representation of risks, between different partners of the project to facilitate discussing about risks of the same project.
- Focusing on each risk category of the project and generate its hierarchical decompositions.
- Development of a risk database for each new project.
- Share the risk database with the other managers of the project.
- Use the experience of other projects in identification and analysis of risks.
- Graphical representation of risk breakdown structure, the risks and their values which can help to easier understanding and diagnosing the risks.
- Manual creation of a risk breakdown structure with any desired root category and level of details.
- Creation of a comprehensive classic report of risk identification, risk analysis and hierarchical representation of risks, to facilitate the communication with the other experts.
- Transfer the risk database to an Access file which can be useful for the non-users of the software.

3. Getting to know Risk Management v.1.0.0

3.1. Main page

By running the program from the start menu, the main window appears as is illustrated in Figure β-1. For the moment, most of the tabs and icons are deactivated.

To build a new project database

the *New* option should be selected from *File* menu, at the top of the page. This function is also available in Tab bar. Thus, each user can build his own database of risks and can use any acceptable name for the new project.

To open an available database

- by click *Open* icon, available in tab bar or from *File* menu at the top of the page and selecting the path of the database in hard disk, the desired database file will be recalled.

This database will be connected to the program and any change or modification can be applied to the data.

- The name and path of the current database, attached to the program, is illustrated at the top-left side of the windows, beside the Risk Management logo and by disconnecting the database, it will disappear (Figure 3-2).

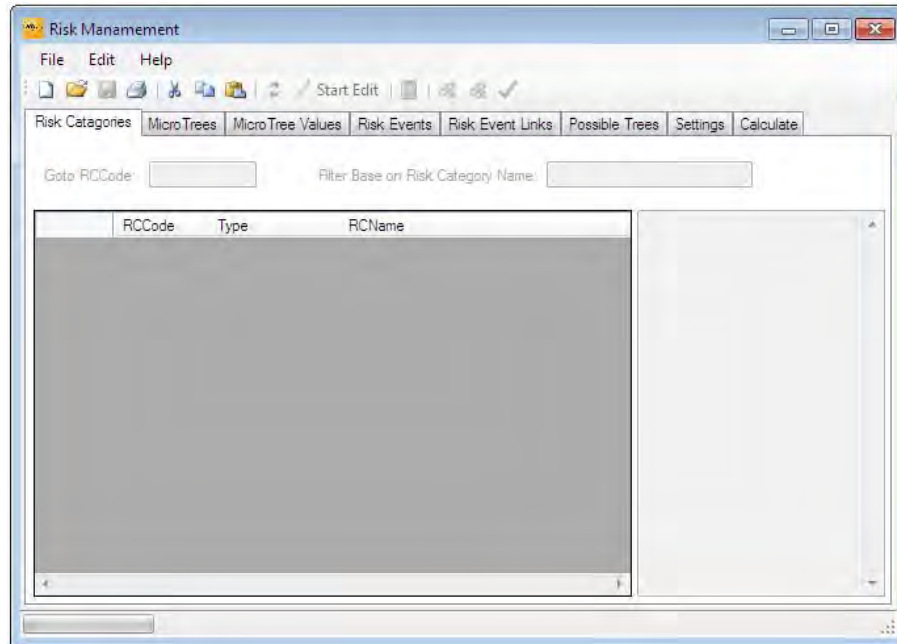


Figure 3-1. Main page of the software

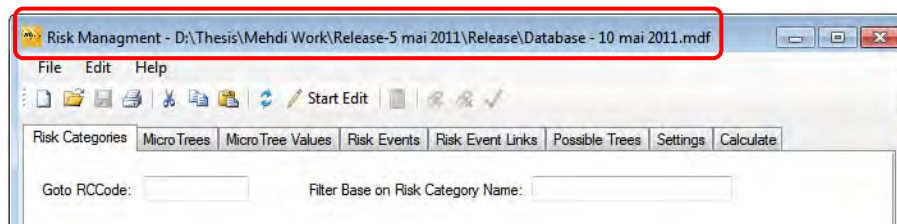


Figure 3-2. Path and name of the connected database to software

- ✚ **To disconnect the database from the software,**
Close option should be selected from **File** menu.
- ✚ **To save the project (database and results) with another name,**
click on **Save as** form **File** menu.
- ✚ **To export the database to an Access file,**
the **Export** option is available in **File** menu. The result is a Xml file. To open this file by Microsoft office Access, this file should be imported by click **External**

Data/Import/XML File, (see Figure β-3). After selection of the exported Xml file at the first page, select **Structure and Data** at the following window (Figure β-4) and click **OK**. All the information in database is transformed into an Access file which can be used as backup or to be shared with other users or project managers.

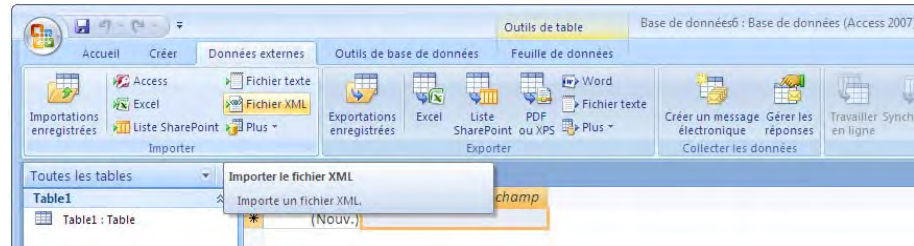


Figure β-3. Import the Xml file to Microsoft office Access

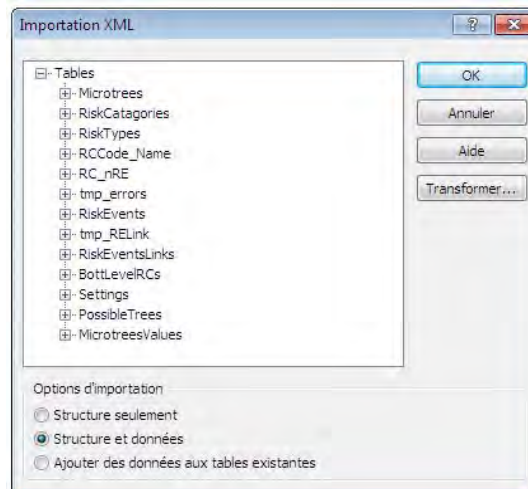



Figure β-4. Import a Xml file to Microsoft office Access

3.2. Risk Categories

This tab represents the Risk Category (RC) database. As is illustrated in Figure β-5, each RC has a code (*RCCode*) which is a unique number, *Type* which can be Generic, Non generic and Extended, name (*RCname*) and *Description*. These are the four basic elements of each risk category.

The raw numbers are in the first column and are different with the risk category codes. Also the total number of available RCs in database is shown, beside the *RCCode* (ex. in Figure β-5, N=218).

 In **Risk Categories** tab, the row numbers and risk category codes are different, and they must not be confused.

By click on each RC, corresponding information appear at the right side of the window. This information is:

- *Risk category (x)*: the risk category code (RCCode: x),
- *Belongs to Micro trees*: the Micro Trees which this RC is one of their subcategories,
- *Father of Micro trees*: the Micro Tree which this RC is the father node,
- *Linked to Selected Risk Events*: the Risk Events which are selected (in Risk Events tab) and have connection with this RC,
- *Linked to Risk Events*: the Risk Events (selected or not selected in Risk Events tab) which have connection with this RC,
- *Description*: is the description of this RC.

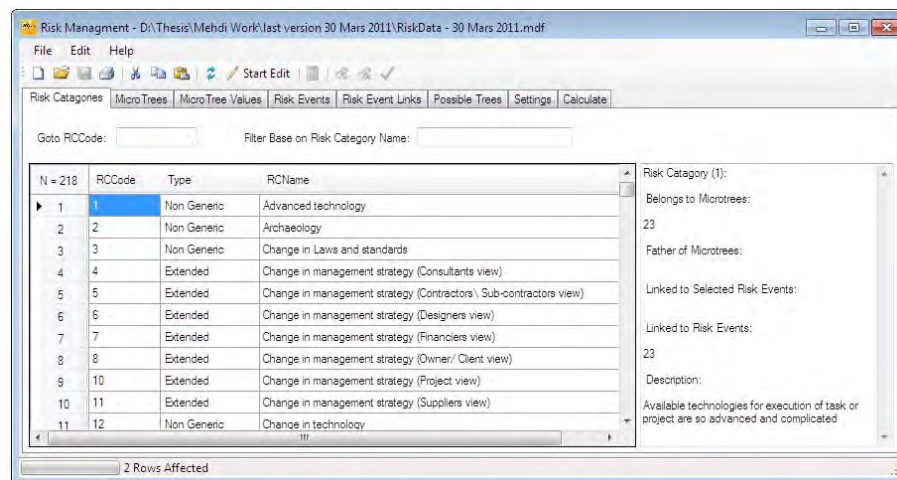





Figure 3-5. Risk Categories database


-  **To select a single RC,**
click on the row number of the RC.
-  **To select all of the RCs in this window,**
 - click on one of the cells in the page and then press **Ctrl+A**,
 - or click on total number of RCs at the top of the page, beside the RCCode,
 - or from **Edit** menu, at the top of the program window, click **Select all**.
-  **To select more than one RC:**
 - For non-adjacent RCs, click the first RC, hold **Ctrl** key, and click each additional RC.

- To select adjacent RCs, click the first one, hold down **Shift** key, and click the last desired RC.

 **To copy the selected RC(s) to clipboard:**

- click **Copy** at Edit menu or from the icon bars at the top of the window,
- or press **Ctrl+C**.

By default, the page is read-only and user cannot change anything. To add any new information or change the available data, first, the page should be unlocked. To do this, click **Start Edit** on the top of the page. The page is unlocked and is ready to apply changes. Also a (*) appears beside the tab name which indicates that this tab is unlocked.

 The *Description* column of RCs is not available when the database is locked. To add or edit descriptions, first, click **Start Edit** at the top of the page.


After click Start Edit at the top of the page, when the RC database is editable:


 **To add a new RC:**


- Go to the last row of the list (which is void) and add a valid RC code (which is an integer and unique in this database), select the type of the RC (Generic: 1, Non generic: 2 and Extended: 3), a valid name (unique in database) and a valid text for description.

 To add a new RC, only the *Description* cell can be left undocumented.

- To save the new RC, click **Stop Edit** at the top of the page.
- To add the new RCs, corresponding information can be pasted into the sheet. To do that, copy the data from Excel or Access worksheets (Figure β-6), click on the RC Code cell of the new row (at the end of the RC list which is indicated by *) and then paste the data by selecting **Paste** from **Edit** menu or paste icon at the top of the page or press **Ctrl+V** on keyboard (Figure β-7).

 To paste a list of new RCs into database, selected data in Excel or Access sheet must necessarily have 3 columns containing non-null cells of: RC code, type and name of the RC. However the forth column (Description) can also be selected to insert the description text of each RC.

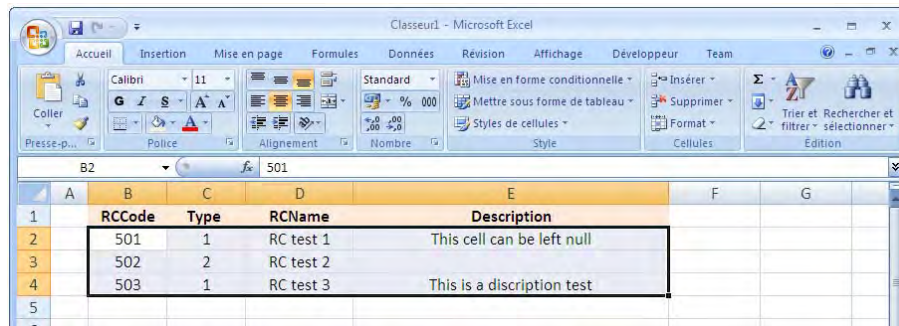
 To indicate the type of the RC, only the corresponding code (Generic: 1, Non generic: 2 and Extended: 3) should be entered.

 If the code or the name of the new RC already exists in RC database, by click **Stop Edit**, an error message appears and doesn't let to add this RC to database.

⚠ To add a new RC, if the RC code, RC name or RC type is left null, by click **Stop Edit**, an error message appears and doesn't let to add this RC to database.

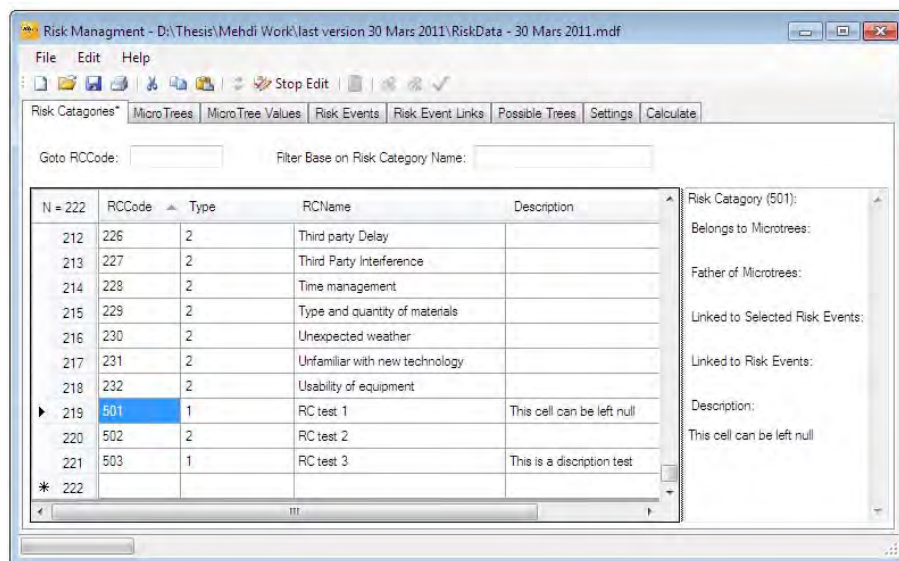
⚠ To add a new RC, after enter the text or number in each cell, **Enter** is needed (or moving to the other cells by mouse or arrow keys), otherwise, the change of the cell will not be applied.

⚠ After change in the list of RCs, by click **Stop Edit**, the changes will be saved into the database automatically. Also the new list can be saved manually by click **Save** icon at the top of the page. In any case, the page has to be locked again by click **Stop Edit** before leaving the tab.



	A	B	C	D	E
1		RCode	Type	RCName	Description
2		501	1	RC test 1	This cell can be left null
3		502	2	RC test 2	
4		503	1	RC test 3	This is a discription test
5					

Figure 3-6. Copy the list of new RCs from Excel



N	RCode	Type	RCName	Description
212	226	2	Third party Delay	
213	227	2	Third Party Interference	
214	228	2	Time management	
215	229	2	Type and quantity of materials	
216	230	2	Unexpected weather	
217	231	2	Unfamiliar with new technology	
218	232	2	Usability of equipment	
219	501	1	RC test 1	This cell can be left null
220	502	2	RC test 2	
221	503	1	RC test 3	This is a discription test
* 222				

Risk Category (501):
 Belongs to Microtrees:
 Father of Microtrees:
 Linked to Selected Risk Events:
 Linked to Risk Events:
 Description:
 This cell can be left null

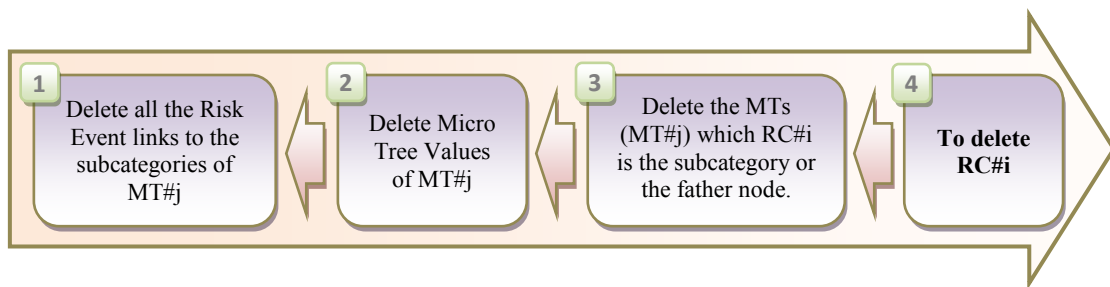
Figure 3-7. Paste the data in RC sheet

✚ To change or remove the available data,

- First, click **Start Edit**, then by click on any cell, the content can be modified. Then, press Enter or move to another cell by mouse or array keys. At the end, to save and lock the page, click **Stop Edit**.
- To delete the RCs, select them and then press **Delete**.

⚠ To delete a RC, it must not have any connection with other elements of the database. It means that it has not to be a father node or subcategory of any MT and it has not to have any connection with the available risk events in the database. To be sure about it, just click on RC and check the information at the right side of the window. If there is any connection with MTs or REs, it has to be removed before deleting the RC, otherwise the program doesn't let it to be deleted and an error message appears.

⚠ To delete a RC that has connection with the other elements of the database, the sequential steps must be as below:



⚠ Change of the RC code is not possible. To do that the category has to be deleted (if is possible and has no connection with the other elements of the database) and then be added with the new code.

✚ To search a risk category:

To find a RC in database, there are two search engines at the top of the page. **Goto RCCode**, to search a RC by its code and the other one, **Filter Base on Risk Category Name**, to search a RC by its name. The second one is able to find any keyword in RCs' names, even if the keyword is not at the beginning of the RC name.

The number of RCs filtered by a keyword is represented at the row numbers column header (ex. N=24).

✚ To sort the data in columns:

Click on the header of the column, the data will be sorted alphabetically. Click again, the sort will be reversed.

3.3. Micro Trees

This tab represents the Micro trees (MT) database. As is illustrated in Figure β-8, each MT has a code (*MTCode*) which is an integer and unique number, *Type* (Generic, Non generic and Extended), a *Father* node and at least two subcategories. The header of the subcategory columns are labeled with *RCi* (i=1 to 10).

By click on each part of a MT, its schematic form appears at the right side of the window. Selection of more than one MT is also possible (see Figure β-9). In this schematic view, the code and the name of the father node and subcategories are shown in a hierarchical form. The rules for selection or copy of the MTs to clipboard are the same with RCs (See section β.2).

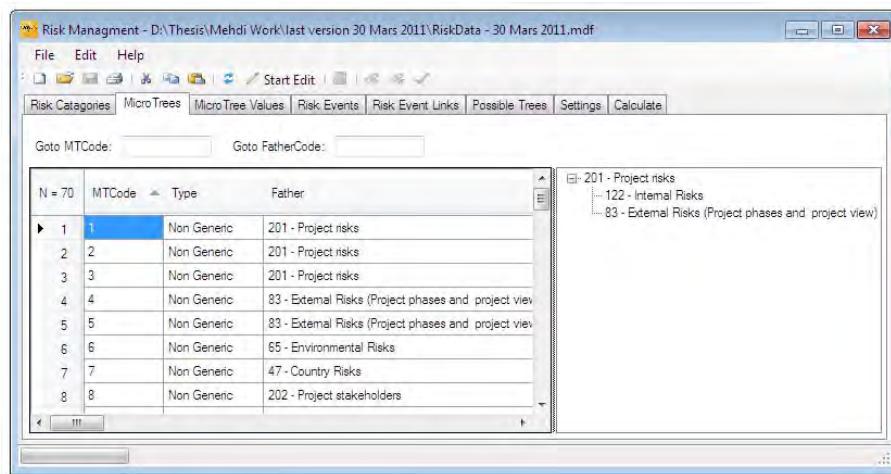



Figure β-8. Micro Trees database

The raw numbers are at the first column and are different with the micro tree codes. Also the total number of available MTs in database is represented, beside the *MTCode* (ex. in Figure β-9, N=70).

 In Micro Trees tab, the row number and Micro Tree codes (MTCode) are different, and must not be confused.

By click **Start Edit** at the top of the page, when the MT database is editable:

To add a new MT:

- Go to the last row of the list (which is void) and add a valid MT code (which is integer, and unique in this database), and select the type of the RC (Generic: 1, Non generic: 2 and Extended: 3). To enter the father node, click on the corresponding cell, a dropdown window will appear. Select the father node from the list. To cancel the selection of the father node press **Escape**. In a same way, the subcategories can be selected.

- To save the new MT, click **Stop Edit** at the top of the window.
 - ! To add a new MT, if the code of the MT already exists in MT database, by click **Stop Edit**, the program doesn't let to add it into database.
 - ! A new MT has to have at least a unique and valid code, a father RC and Subcategories, otherwise the program doesn't let to be added to the database.
 - ! If the new MT is similar with an available MT, the program informs user by an error message, indicating the code of the existing MT and doesn't let it to be added to the database.
 - ! A RC cannot be the father node and one of the subcategories of the same MT.
 - ! A RC cannot be presented more than one time as subcategory of a MT.
 - ! To add a new MT, after entering the data in each cell, **Enter** is needed (or moving to the other cells by mouse or arrow keys), otherwise, the change of the cell will not be applied.
- To add new MTs, corresponding information can be pasted into the sheet. To do that, copy the data from Excel or Access worksheets (Figure β-10), click on the MTCode cell of the new row (at the end of the MT list which is marked by *) and then paste the data by selecting **Paste** from **Edit** menu or paste icon at the top of the page or press **Ctrl+V** on keyboard (Figure β-11).

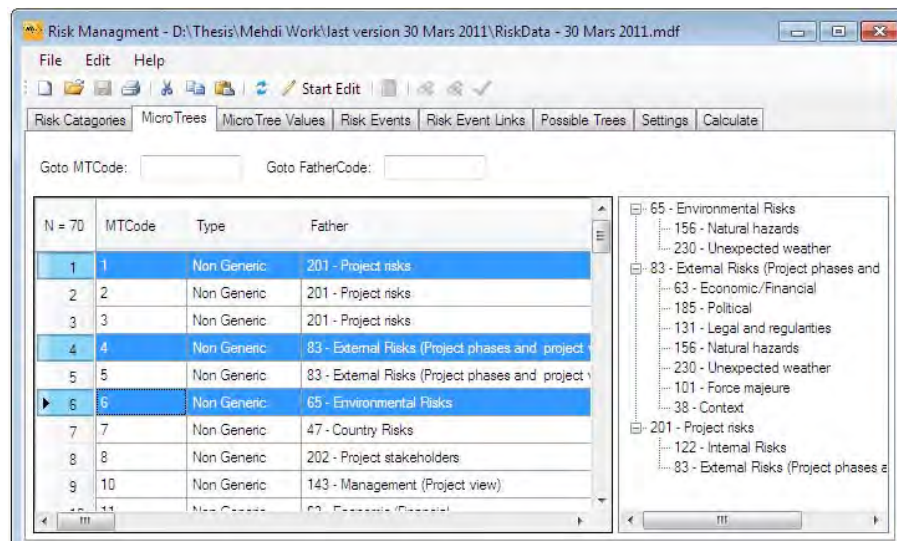


Figure β-9. Selection of more than one MT by holding Ctrl key.

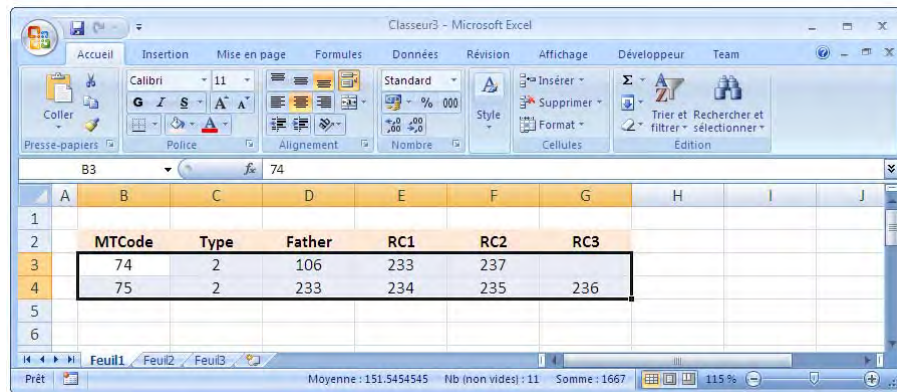


Figure 3-10. Copy the list of new MTs from Excel.

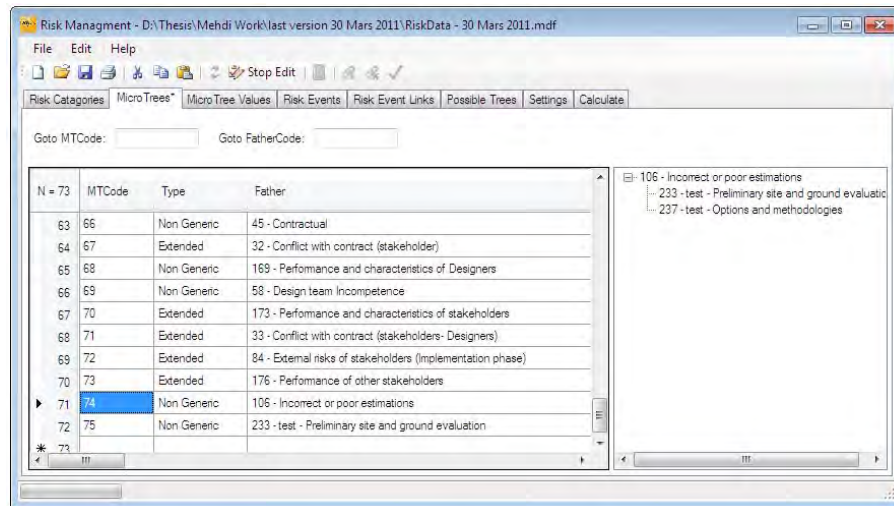


Figure 3-11. Paste the data in MT sheet

⚠ To add a new MT, the RCs of the father node and subcategories must be already registered in RC database, otherwise, the program doesn't let it to be added to the database.

⚠ As it is shown in Figure 3-10, for the type of the MT the corresponding number (Generic: 1, Non generic: 2 and Extended: 3) and for the RCs, just the RC code (which is an integer number) has to be entered. Any other format causes an error message and the program doesn't let to the new MT to be registered in the database.

🔍 To search a Micro Tree:

- By MT code, enter the MT code which is an integer number. The MT will be selected and illustrated automatically.
- By the father node, enter the RC code of the father. All of the corresponding MTs will be selected and illustrated automatically (see Figure 3-12).

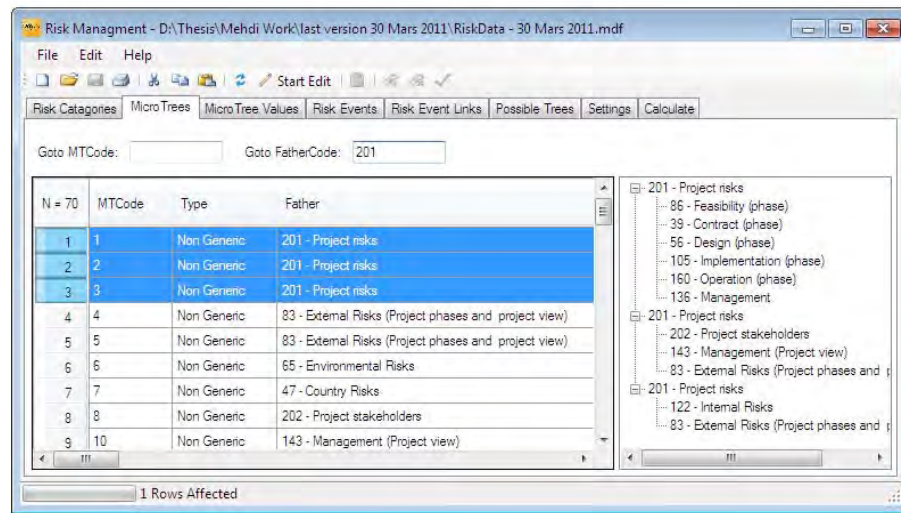


Figure 3-12. Search the MT(s), knowing the father node

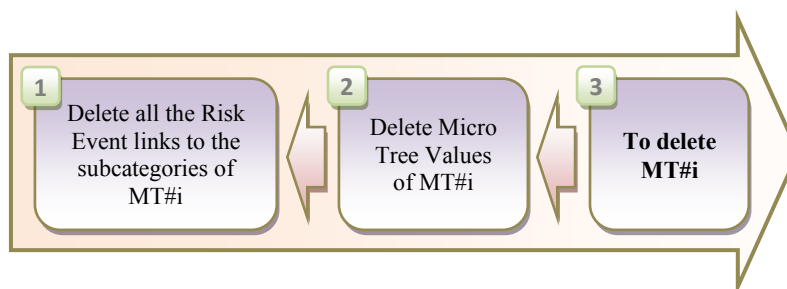
✚ To sort the data in columns:

Click on the header of the column, the data will be sorted alphabetically. Click again, the sort will be reversed.

✚ To change or remove the available data:

- First, click **Start Edit**, then by click on any cell, the content can be modified. Then press **Enter** or move to another cell by mouse or array keys. At the end click **Stop Edit**, to save and lock the page.
- To delete a MT (if it is possible), select it and then press **Delete**.
- To delete one of the subcategories of a MT, select the subcategory and then press **Shift+Esc**.

⚠ To delete a MT, first it has to be removed from the **Micro Tree Values** tab, and also all the connections of risk events with the categories of the MT have to be removed. Otherwise, the program doesn't let to delete the MT. The sequential removing steps of the connections are as below:



3.4. Micro Tree values


In this page, the adequacy weighting factors of the MTs for different stakeholders, project phases and project objectives are available. In this page each MT has a code which is an integer number and 17 weighting factors which are numbers between zero and one. These numbers and the header labels are represented in Table 3.1. Each MT can be searched easily by the search engine at the top of the page. Also the methods of selection and copy of the data, are the same as for risk categories (See section 3.2).


Table 3.1. Weighting factors of Micro Trees


MT Code	Project Stakeholders						Project Objectives			Project Phases							
<i>MTCode</i>	Designers_stk	Financiers_stk	Owner_Clients_stk	Contractors_stk	Suppliers_stk	Consultants_stk	<i>Project_stk</i>	Price_obj	Time_obj	Quality_obj	<i>Project_obj</i>	Feasibility_phase	Contract_phase	Design_phase	Implementation_phase	Operation_phase	<i>Project_phase</i>


To add a new MT,

- After click **Start Edit**, go to the last row of the list (which is void and is marked with *) and enter a valid MT code (which is integer, and unique in this database), and then add 17 weighting factors.
- To save the new MT, click **Stop Edit** at the top of the page.

 If the entered weighting value is greater than 1.0, an error message will appear and the program doesn't let it to be saved.

 If the new MT code already exists in **MT Values** database, the program informs user by an error message, indicating the code of the similar MT and doesn't let to add it to the database.

 To add a new MT in this page, the weighting factors cannot be left null, otherwise, an error message indicates the cell which has null value.

 To add a new MT in this page, the MT Code must be already registered in RC database, otherwise, the program doesn't let to add the new MT and its values into database.

- To add new MTs with their weighting factors, the values can be pasted into the sheet. To do that, copy the data from Excel or Access worksheets (Figure 3-13), click on the

MTCode cell of the new row (at the end of the MT list which is marked by *) and then paste the data.

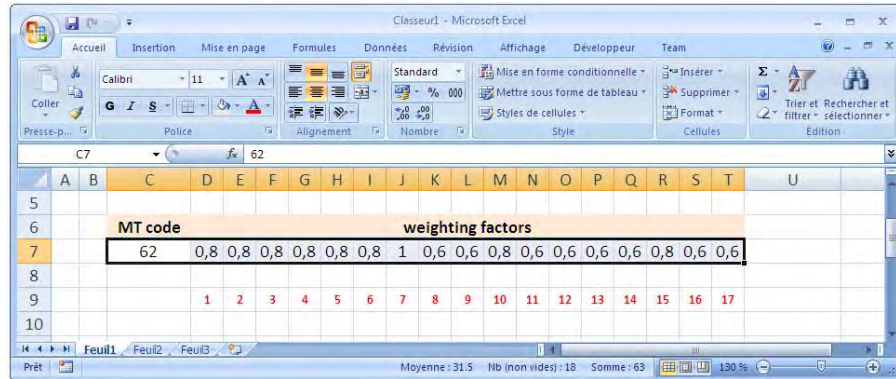


Figure 3-13. Copy the MT values in Excel

✚ To change or remove the values of MTs

- First click **Start Edit**, then by click on any cell, the content can be modified. Then press **Enter** or move to another cell by mouse or array keys. At the end, to save and lock the page, click **Stop Edit**.
- To delete the MTs, select them and then press **Delete**.


✚ To sort the data in columns

Click on the header of the column, the data will be sorted alphabetically. Click again, the sort will be reversed.

3.5.Risk Events

This tab represents the database of Risk Events (RE). As is illustrated in Figure 3-14, each RE has a code (*RECode*) which is an integer and unique number, a name, values of probability, and three values of impact factor.

The raw numbers are in the first column and are different with the Risk event codes. Also the total number of available REs in database is represented beside the *RECode* (ex. in Figure 3-14, N=169).

 In Risk Events tab, the row number and RE codes are different, and must not be confused.

By click on each RE, corresponding information appears at the right side of the windows. This information is:

- *Risk Event (x)*: the risk event code (RECode: x),
- *Is connected to Risk Categories*: the Risk categories which have a connection with this RE, directly, if they are bottom level categories or an indirect connection when they are the father of bottom level RCs. The direct links are marked with (*) beside the RC code. As an example, in Figure β-14, RE#13 has a direct link with RC#104 and 215. The other RCs are the fathers of these two RCs.
- *Is connected to Micro trees*: the MTs which have connection with this RE. It means this RE has connection with at least one of the subcategories of these MTs.

By selecting more than one RE, the corresponding information of the last one is shown. The rules of selection and copy of the data are the same with Risk categories (see section β.2).

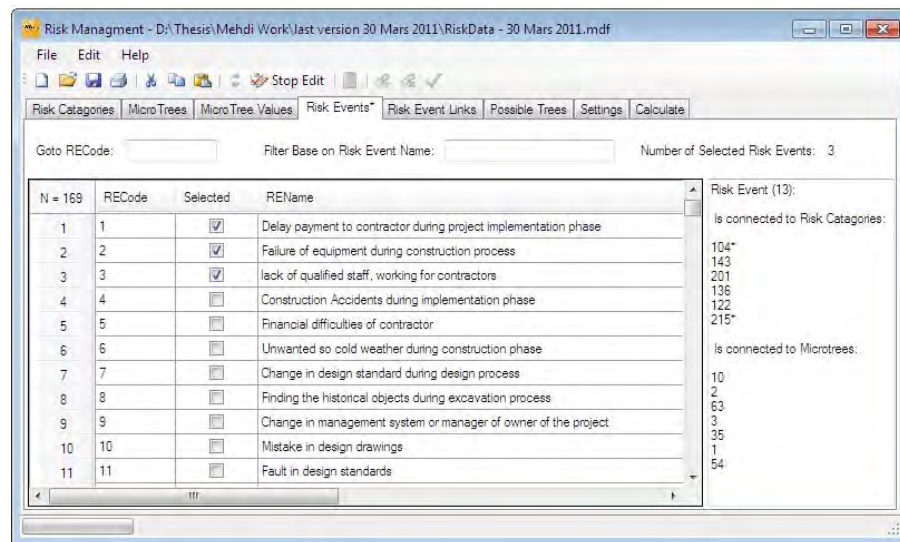


Figure β-14. Risk Event (RE) database

✚ To mark a RE as Selected.

- Just the selected REs are considered as the input of the RBS generation process and for calculation of the project risk.
- To select a RE, after click **Start Edit**, in **Selected** column, click on of the desired Risk Event.
- To select all of the REs, right click on the sheet and then **Select All**.
- To deselect the marked REs, right click and then **Unselect All**.
- The total number of selected REs is presented at the top of the windows (see Figure β-14).

✚ To add a new RE

- After click **Start Edit**, go to the last row of the list (which is void and is marked with *) and add a valid RE code (which is integer and unique in this database), a valid name (unique in database) and four values of probability and impact factors.
-
- The probability value can be varied in the range of (0, 1) but for the impact values (*Impact_Price*, *Impact_Time*, *Impact_Quality*), the acceptable range depends on the risk analysis function which will be selected in setting tab. For the *max* and *modified max* methods, the probability values are in the (0, 1) range but for the *summation* method, even the values greater than 1 are acceptable (for more information see chapter 3).
- To add a new RE, the corresponding values (probability and impact factors) can be left null. In this case by default, 0.0 is considered as their values (see Figure 3-15).
- To save the new RE, click **Stop Edit** at the top of the page.

N	RECode	Selected	REName	Probability	Impact_Price	Impact_Time	Impact_Quality
147	147	<input type="checkbox"/>	Change of design because of change of order or scope responses by owner of the project	0.4	0.6	0.7	0.1
148	148	<input checked="" type="checkbox"/>	Environmental pollution during implementation phase due to poor performance of contractor	0.9	0.5	0.8	0.8
149	149	<input type="checkbox"/>	Evacuated elements are not consistent with design plans due to poor performance of contractor	1	0.3	0.6	0.5
150	150	<input checked="" type="checkbox"/>	Damage to persons or property or materials due to poor safety and health management of the project	0.6	0.9	0.7	0.4
151	151	<input type="checkbox"/>	Project design does not comply with building regulations	0.2	0.7	0.6	0.4
152	152	<input checked="" type="checkbox"/>	Unproven design solutions accepted by consultants	0.2	0.9	0.6	0.6
153	153	<input checked="" type="checkbox"/>	Consultant lacks in adequate number of staff (insufficient human resources) during implementation phase	0.8	0	0.1	0.1
154	154	<input type="checkbox"/>	Delay of contractor in final billing presentation	0.6	0.6	0.8	0.8
155	155	<input checked="" type="checkbox"/>	Technical mistakes during construction stage by contractor	0.3	0.5	0.3	0.2
156	156	<input checked="" type="checkbox"/>	Inadequacy of site inspection by consultant during implementation phase	0.8	0.4	0.9	0.2
157	157	<input checked="" type="checkbox"/>	Inconsistency in time schedule of different stakeholders due to poor communication management	0.7	0.9	0.8	0.4
158	158	<input type="checkbox"/>	Delay of bank in project fund allocation during feasibility phase	0.6	0.6	0.8	0.1
159	159	<input type="checkbox"/>	Test risk event	1	0	0	0

Figure 3-15. Add a new risk event

⚠ If the entered values are greater than 1.0, while the risk analysis function in setting tab has been selected to be one of the *max* or *modified max* functions, an error message will appear and the program doesn't let to save the new RE.


⚠ If the entered name or code of the RE already exists in RE database, an error message will appear and the program doesn't let to save the new RE.

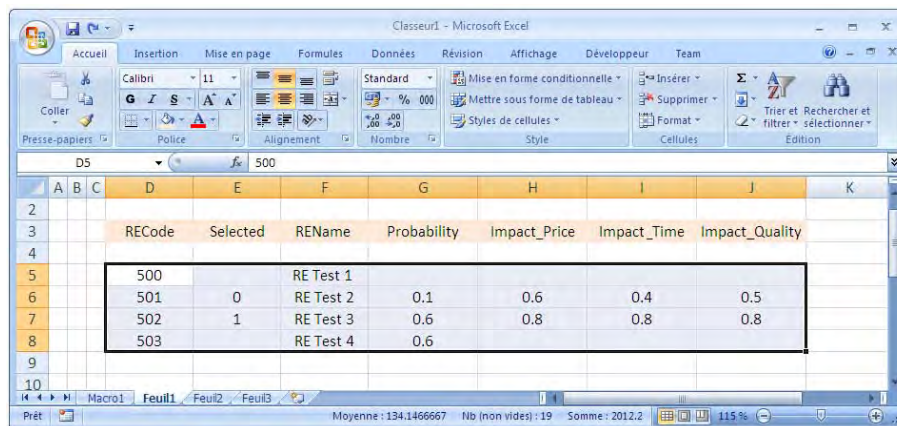
⚠ To add a new RE, after enter the data in each cell, **Enter** is needed (or moving to the other cells by mouse or arrow keys), otherwise, the change of the cell will not be applied.

⚠ After change in the list of REs, by click **Stop Edit**, the changes will be saved into the database automatically. Also the new list can be saved manually by click **Save** icon at

the top of the page. In any case, the page has to be locked again by click **Stop Edit** before leaving the tab.

- To add the new REs, corresponding information can be pasted into the sheet. To do that, copy the data from Excel or Access worksheets, see Figure β-16, click on the RECode cell of the new row (at the end of the RC list which is indicated by *) and then paste the data by selecting **Paste** from **Edit** menu or paste icon at the top of the page or press **Ctrl+V** on keyboard.

 To paste a list of new REs into database, selected data in Excel or access sheets have to necessarily have at least 3 columns of: RE code, a null column corresponding the **Selected** column of the database and the name of the REs. However the second cell can contains the value of 0 (not selected) or 1 (selected) if user wants to define the status of selection of REs, see Figure β-16.





RECode	Selected	REName	Probability	Impact_Price	Impact_Time	Impact_Quality
500		RE Test 1				
501	0	RE Test 2	0.1	0.6	0.4	0.5
502	1	RE Test 3	0.6	0.8	0.8	0.8
503		RE Test 4	0.6			

Figure β-16. Copy the list of new REs from Excel.

To change or remove the available data

- First click **Start Edit**, then by click on any cell, the content can be modified. Then press **Enter** or move to another cell by mouse or array keys. At the end click **Stop Edit**, to save and lock the page.
- To delete the REs (if it is possible), select them and then press **Delete**.

 To delete a RE, it has not to have any connection with the other elements of the database (links between the RE and RCs). To be sure about it, just click on the RE and check the information at the right side of the window. If there is any connection with MTs or RCs, it has to be removed, before deleting the RE (by removing the connections of the RE with RCs, the links with MTs will be removed automatically)

 Changing the RE code is not possible when it has connections with RCs and MTs. To do that, first, these connections have to be removed.

To search a risk Event

- To find a RE in the database, there are two search engines at the top of the page. **Goto RECode**, to search a RE by its code and the other one **Filter Base on Risk Event Name**, to search a RE by its name. The second one is able to find any keyword in REs' names, even if the key word is not at beginning of the RE name.
- The number of REs filtered by a keyword is represented at the row numbers column header (ex. N=5).

To sort the data in columns

Click on the header of the column, the data will be sorted alphabetically. Click again, the sort will be reversed.

3.6. Risk Event Links

This page represents the connections of risk events to risk categories. The direct links are defined by user by connection of REs to bottom level categories. The indirect links are generated automatically by the program regarding the father-son relations of RCs in MT database. As an example, in Figure β-17, RE#f has a direct link to RC#i and indirect links to RC#j and K since they are the “father” and “grandfather” on RC#i.

In *Risk Event Links* page, each row represents a connection. It has the RE code, the RE name, the RC code which RE is connected to, the RC name, the code of MT which this RC is one of its subcategories (*MTCode*), the “children” of this RC (*PrevRC*) which is the subcategory of (*PrevMT*) and *OriginRC* which indicates the bottom RC that this connection is coming from. As an example, the connections regarding Figure β-17, are represented in Table β.2.

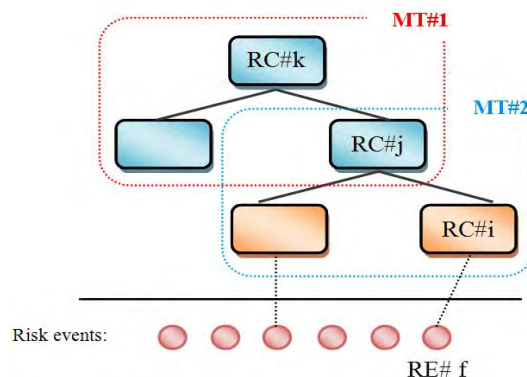


Figure β-17. Connection of a RE to Risk categories

Table 3.2. An example of Risk Event Links

RECode	REName	RCCode	RCName	MTCode	PrevRC	PrevMT	OriginRC
f	Name of RE#f	i	Name of RC#i	2	-	-	i
f	Name of RE#f	j	Name of RC#j	1	i	2	i
f	Name of RE#f	k	Name of RC#k	-	j	1	i

N	RECode	REName	RCCode	RCName	MTCode	PrevRC	PrevMT	OriginRC
1	1	Delay payment to contractor during project implementation p...	76	External Risks (Of Contractors\ Sub-contractors)	48			76
2	1	Delay payment to contractor during project implementation p...	44	Contractors / Sub-contractors	8	76	48	76
3	1	Delay payment to contractor during project implementation p...	202	Project stakeholders	2	44	8	76
4	1	Delay payment to contractor during project implementation p...	201	Project risks		202	2	76
5	1	Delay payment to contractor during project implementation p...	76	External Risks (Of Contractors\ Sub-contractors)	72			76
6	1	Delay payment to contractor during project implementation p...	84	External risks of stakeholders (Implementation ph...	32	76	72	76
7	1	Delay payment to contractor during project implementation p...	105	Implementation (phase)	3	84	32	76
8	1	Delay payment to contractor during project implementation p...	201	Project risks		105	3	76
9	1	Delay payment to contractor during project implementation p...	178	Performance of other stakeholders (-Contractors\ ...	49			178
10	1	Delay payment to contractor during project implementation p...	44	Contractors / Sub-contractors	8	178	49	178
11	1	Delay payment to contractor during project implementation p...	202	Project stakeholders	2	44	8	178

Figure 3-18. Risk Event Links database

- By click **Only Show Direct Links to Bottom Risk Categories**, just the direct links will be shown in the list (see Figure 3-18).
- The raw numbers are in the first column and are different with the risk event codes. Also the total number of links is represented beside the *RECode* (ex. in Figure 3-18, N=2828).



In **Risk Event Links** tab, the row number and risk event codes are different, and must not be confused.

- The rules for selection or copy of the data to clipboard are the same as for RCs (See section 3.2).

To sort the data in columns

Click on the header of the column, the data will be sorted alphabetically. Click again, the sort will be reversed.

To search a risk Event

There is a search engine at the top of the page, *Goto RECode*.

To add new links

Click  at the top of the page. A new window appears (see Figure 3-19).

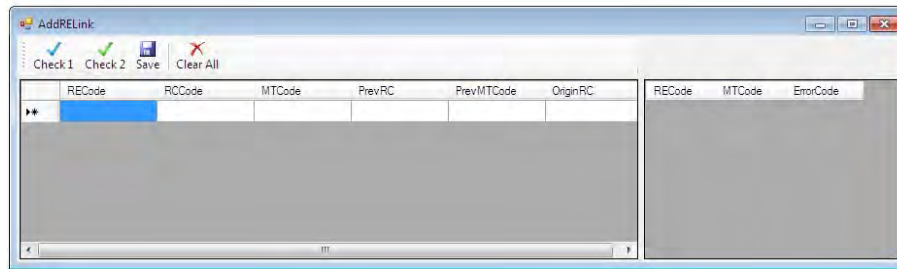


Figure β-19. Add new links of REs to RCs

- In this window (**Add Risk Event Link**) just the direct links has to be entered by user. The indirect links are generated automatically by the software.
- Go to the first void row which is indicated by *. Enter the code of the RE and in the second column, the corresponding RC code. For the other new links do the same.
- Before generation of indirect links, to delete a row, select the row by click on row number of desired cell and then press **Delete**.
- Before saving new links into database, the two main consistency checks of risk event links must be controlled by click **Check 1** and **Check 2** at the top of this window. If the new links are consistent, they can be saved by click **Save** icon.

! **Consistency 1:** Each RE can be affected once (and only once) to one of the subcategories of a MT (see Figure β-20-A).

! **Consistency 2:** For the MTs with the same father node, if one of them can cover a RE, the others have to (necessarily) cover it as well (see Figure β-20-B).

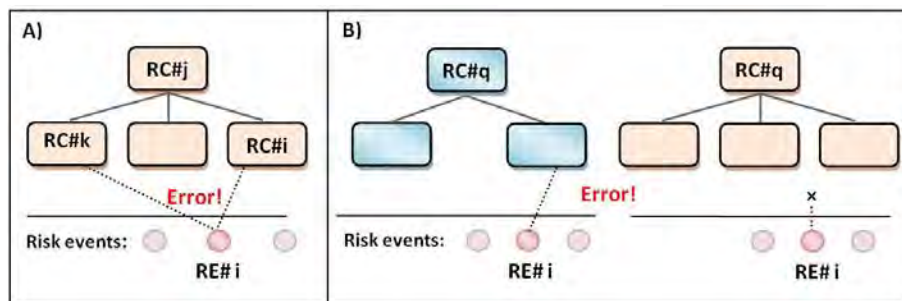


Figure β-20. Consistency control of information in RE Links database

! If user clicks directly on **Save** icon (without controlling the two consistency checks) the program automatically controls the consistency of new links before saving them into database.

✚ Consistency check 1 :

- By click **Check 1**, the program generates the indirect links and then controls the first consistency.
- To clear this windows (delete all the links which are shown in this window) click **Clear All**.
- If the consistency check 1 is valid, a message box informs this validation (See Figure β-21), indicating the number of new links which are controlled.
- If the consistency check 1 is failed, a message box informs user, indicating the code of corresponding MT (see Figure β-22). In this case user has to clear the page, and add the new modified links again. This error message means that in new risk event links, there is at least one RE which has connections to more than one of the subcategories of the mentioned MT.
- After validation of consistency check 1 and generation of indirect links, to see just the direct links, click **Only Show Direct Links to Bottom level Risk Categories**.

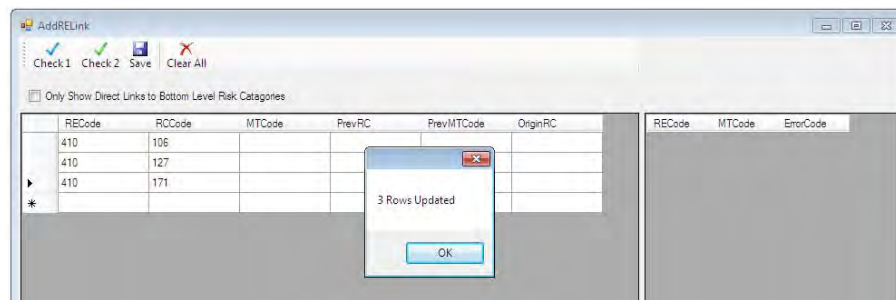


Figure β-21. Consistency check 1 is valid.

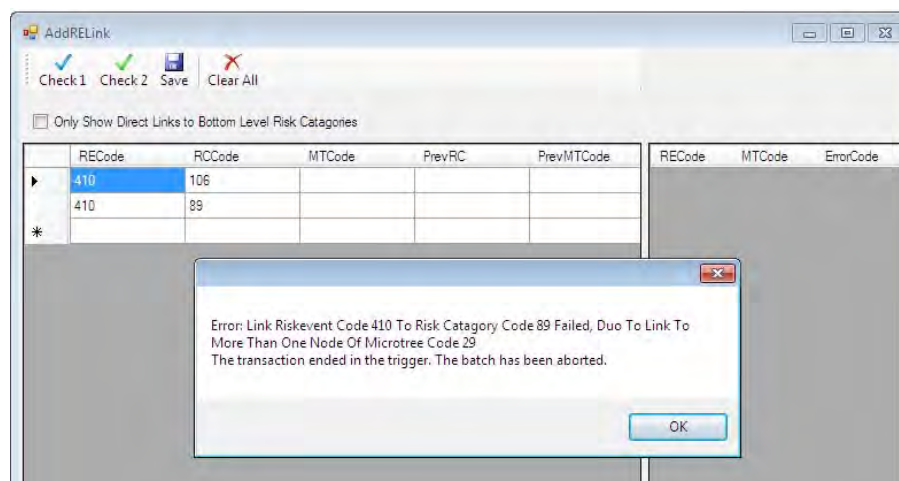



Figure β-22. Failure of consistency check 1.

 A Risk Event can have **direct links** only to the bottom level Risk categories. As is illustrated in Figure β-23, RE#410 cannot be linked directly to RC#201 which is not a bottom level RC (a bottom level RC in database has no subcategories or in other words, a bottom level RC is not the father of any MT in database).

- If a link is duplicated in the list of new RE links, a message box informs user, indicating the code of RE and RC (see Figure β-24).

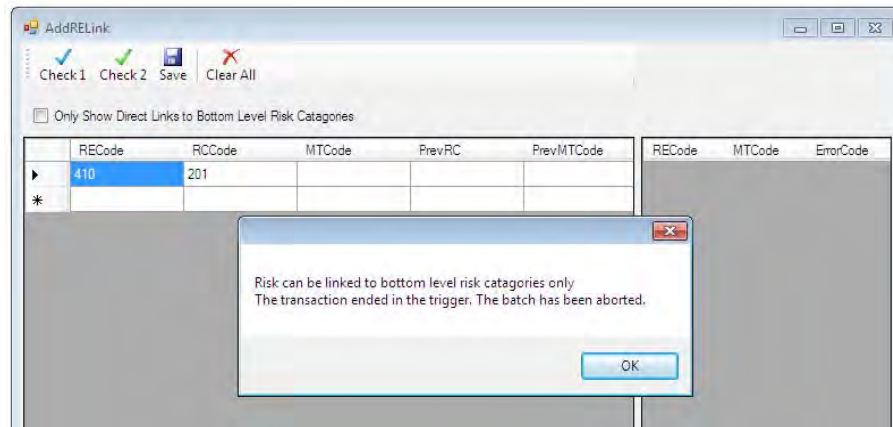


Figure β-23. Error message, RE can have direct links only to the bottom level RCs.

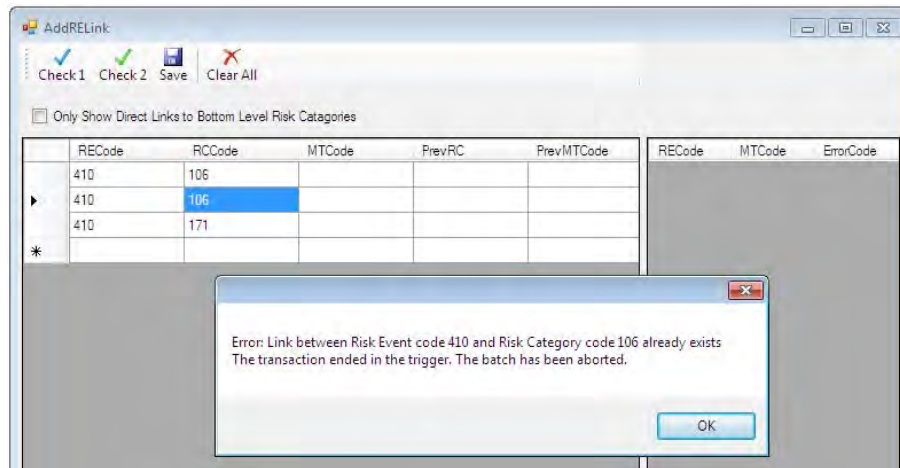


Figure β-24. Error message: Duplicate RE link

Consistency check 2 :

Figure β-25 represents the MT database and three MTs which have the same father node (Market at MT#17, 18 and 19). If a new link is defined by the user to one of the subcategories of these three MTs, necessarily two other links have to be defined to connect the RE to the other MTs. As an example a new link is defined to connect RE#410 to RC#220 which is the

subcategory of MT#19. By click **Check 2**, the indirect links are generated and then the Consistency check 2 is controlled.

As expected, this unique link causes an inconsistent situation in database. An error message informs user, (see Figure β-26). The detailed report of consistency control is represented at the right side of this window (Error table). In this table, the first column indicates the risk event code and the second one is the micro tree code. For example in Figure β-26, the first row of the error table means that RE#410 has to be also connected to one of the subcategories of MT#17. The *ErrorCode=2* means that this error is due to Consistency Check 2. Also the other rows of the error table indicate that RE#410 has to be connected also to one of the subcategories of MT#18 and MT#3. It should be noted that the subcategories of MT#3 are not bottom level categories and to solve the inconsistent situation, occurred in this MT, a direct link has to be added between RE#410 and one of the sons (or grandsons) of the father node of MT#3, which should be a bottom level RC.

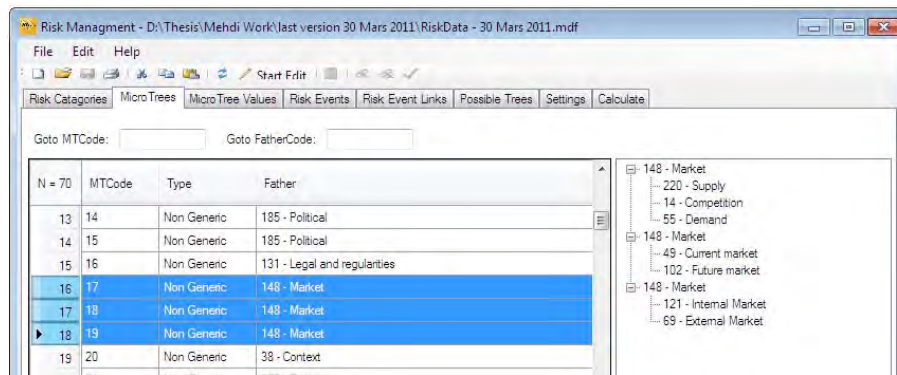


Figure β-25. MT database which has three MTs to decompose Market category.

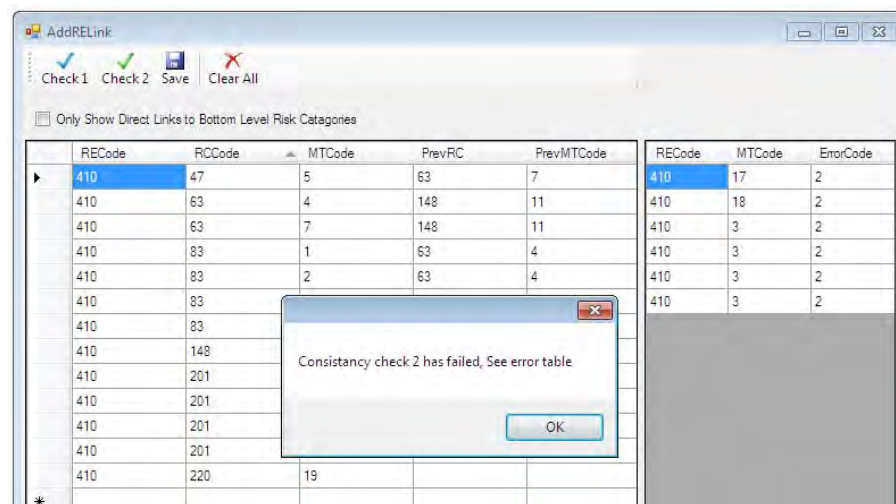


Figure β-26. Failure of consistency check 2

⚠ If the consistency check 1 or 2 was failed or an error message was reported, the list has to be cleared (by click **Clear All** icon to delete all the direct and indirect links) and then the modified links (just direct links) be added again.

⚠ By click **Save**, all new links will be saved into database, just if there is no error message. Otherwise, even if the error is related to just one of the new links, the other new links also (which have no consistency error) will not be registered. In this case the list has to be cleared and the modified links have to be added again.

- To save the new links to database, click **Save** icon. The program controls the consistency check 1 and 2 and if there is no error or inconsistent situation, the links will be added to database. Close this window and return to the risk event tab. The new links are available in the main list.

⚠ A risk event cannot be attached to more than one RC of an RBS. This constraint is another way to express the consistency check 1. As is illustrated in Figure 3-27, if user connect RE#i to RC#k and RC#q, the consistency check 1 for MT#i which is at the upper levels of the RBS, is not valid due to more than one connection of the RE to its subcategories (which here are indirect connections). So the program doesn't let to save these two links into the database.

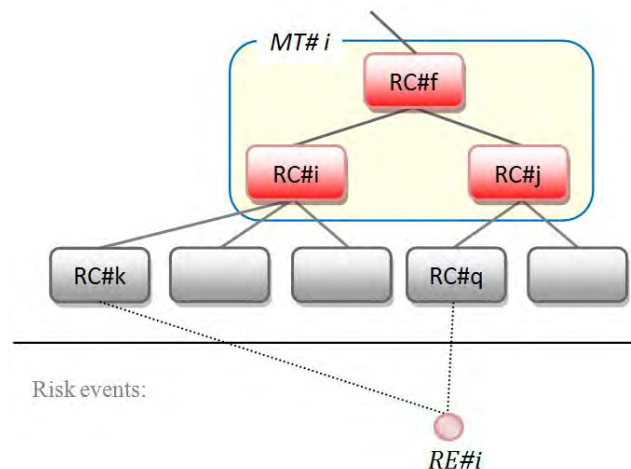




Figure 3-27. A risk event cannot be attached to more than one RC of an RBS

✚ To change or remove the available links

In **Risk Event Links** tab, the links are not editable. To modify a link, first, it has to be removed and then be added again by the modified form.

- To delete a link(s), select it (them) by click on corresponding row number(s), then click  at the top of the window in icon bar.

 Delete the connection of RE#i with a RC, also causes to delete all the links of RE#i to the other RCs. Figure 3-28 illustrates the message box which informs user about deleting all connections of the selected RE. In this message box the codes of the selected REs which will lose all the connections are indicated.

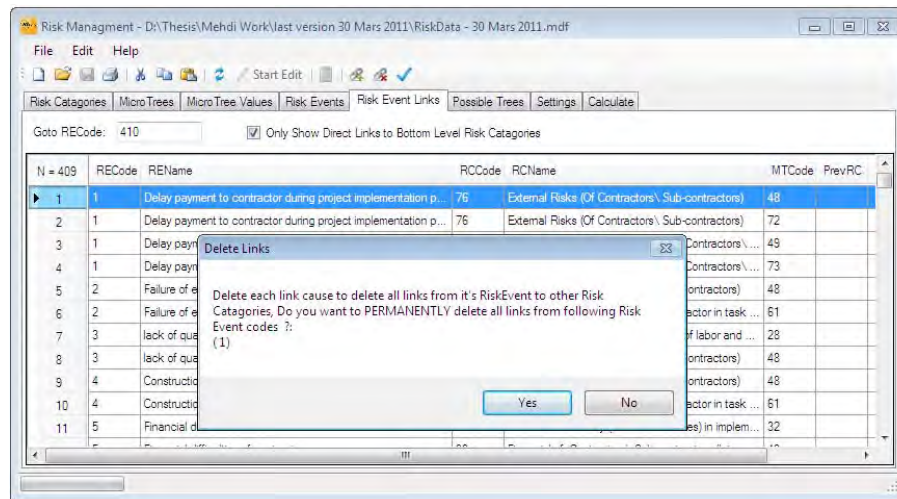




Figure 3-28. Delete a link of RE in database

Control the consistency of links in database

- If user makes changes in RC or MT database, the consistency of links with the other parts of the database can be controlled by click  at the top of the window. This icon is active just in **Risk Event Links** tab. If the database is not valid, a message box informs user. To see the report of errors (error table) go to **Add New Links** page by click on  at the top of the page. The error table is at the right side of the window. The possible error codes are:

Error Code 1: is due to consistency check 1. It means the RE is connected to more than one subcategory of the mentioned MT.


Error Code 2: is due to consistency check 2. It means the RE has to be connected also to one of the subcategories of the mentioned MT.

Error Code 3: means that the mentioned RE is connected directly to the father node of the mentioned MT which is not a bottom level RC.

- To remove the errors, the corresponding RCs or MTs have to be controlled and the mistakes have to be corrected. If the error is due to an inconvenient link, it has to be modified (see the last section “To change or remove the available links”).

3.7. Possible Trees

In this page user can generate all the possible homogeneous trees. These trees are made by combination of different micro trees available in the database. These trees are homogeneous, which means that all the branches have been extended to a same level (if there are MTs to decompose the subcategories).

 At **Possible Trees** tab, user can just see the results of the assembling algorithm, which generates all the possible homogeneous RBS's by combination of different MTs available in database. At the **Calculate** tab, the algorithm regenerates all possible trees to calculate the values of risks and the five quality notes. So it is not important whether if, in this page, user has generated the possible trees or not. So this tab (Possible trees) is useful just when user is interested to generate all possible trees resulted by the assembling algorithm, without any calculation or ranking process.

As is illustrated in Figure β-29, the left side of the window represents the available MTs in database. By click on each one, it can be extend to see the subcategories. To reload the list of the MTs, click **Load Microtrees** at the top of the page. To generate all possible trees click **Generate Possible Trees**. The root of all the trees is *Project Risks* by default. It can be changed to another RC in **Settings** tab. The branches of the generated trees can be extended more by click on + or be minimized by click on - . It should be noted that the structure of the generated trees are fixed and extension or minimization of the branches is just to represent or hide the branches and not changing the structure of the trees.

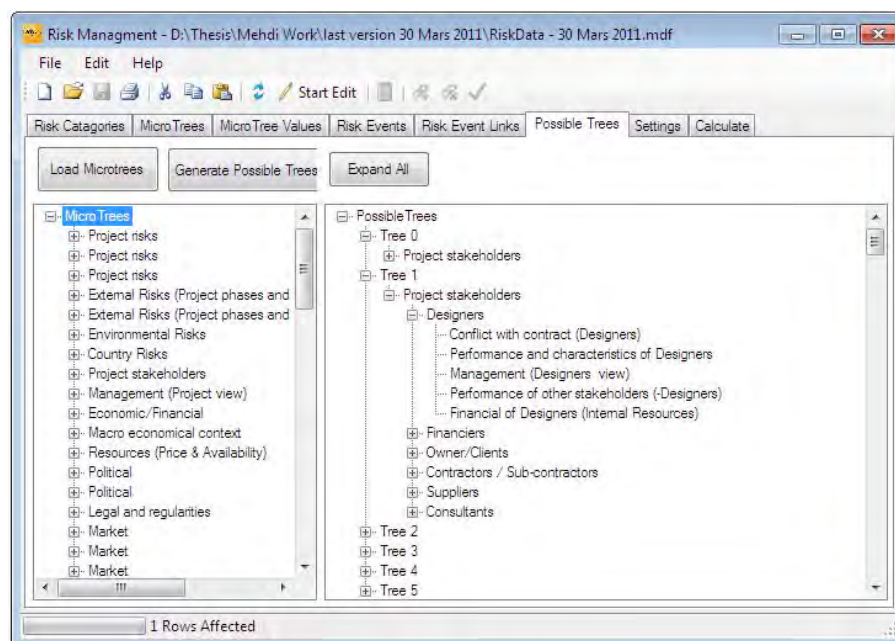


Figure β-29. Generation of all possible trees

3.8. Setting

In this tab, user can set all the essential parameters needed for generation and ranking of the possible trees (Risk Breakdown Structures). To change the settings, first, click **Start Edit**, the page will be unlocked and ready to apply the changes (see Figure 3-30).

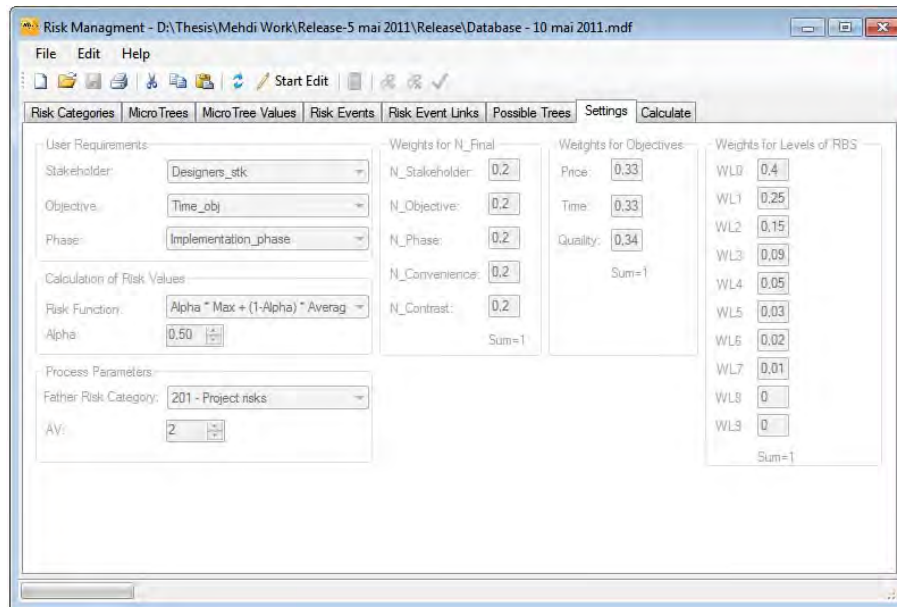


Figure 3-30. Setting tab

This window includes:

User Requirements:

Stakeholder: to chose the desired stakeholder of the project. The final RBS should be adequate for the selected stakeholder. The contents of this menu are: Designers, Financiers, Owner_clients, Contractors, Suppliers, Consultants and project. All the items have an extension of (_stk). The last item (*Project_stk*) indicates all of the project stakeholders. In other words, it is chosen when then objective is generation of RBS's which can be used by all of the partners of the project, a shared tool to facilitate the communication and discussion of partners about the project risks.

Objective: to chose the objective of the project risk management. It can be price (Price_obj), time (Time_obj), quality (Quality_obj) of the project or all together (Project_obj).

Phase: to chose the desired phase of the project. The final RBS should be adequate for the selected phase of the project. The contents of this menu are: feasibility, contract, design, implementation, operation and Project_obj which means all the project phases.

✚ Calculation of risk values:

Risk Function: is to select the function to calculate the risk value of each risk category as a function of the values of attached REs. For the moment there are three options:

- $R_{RC} = \text{Max} (R_{REs})$
- $R_{RC} = \alpha \cdot \text{Max} (R_{REs}) + (1-\alpha) \cdot \text{Average} (R_{REs})$
- $R_{RC} = \text{Summation} (R_{REs})$

Where R_{RC} is the risk value of the RC, R_{REs} is the values of the attached REs and α is the aversion coefficient (higher value of α , more the maximum value of risk events is highlighted). The value of α can be defined in this part and is a number between 0 and 1. The third option (summation) is the explained method in Chapter 3, section 3.4.

✚ Process parameters:

Father Risk Category: to select the main root of the trees. By default, *Project Risks* is the root of all the trees. To change it, click on category name, and select the desired RC from the dropdown menu. It can be changed also by the arrow keys. The contents of this list are all the available risk categories in RC database.

Av: is the desired number of attached REs to each bottom level category. This value is used to calculate the first quality note of each RBS which is N_{conv} . This value should be equal or greater than the number of selected REs, otherwise, N_{conv} will be zero for the RBS's.

✚ The three other part:

Weights for N_{Final} : are the weighting factors of the different quality notes to calculate the global quality notes of RBS's. The summation of the five weighting factors should be 1.0.

Weights for objectives: are the weighting factors of the different objectives (time, quality and price) to calculate the global risk value of a RC, when the objective is time, quality and price, all together. In this case, for each RC, three different risk values are calculated regarding three different objectives. Then the global risk value (or note) of the RC is calculated using weighted average function. This part is active only when at *User requirements/ Objective* the last option (Project_obj) is selected.


Weights for levels of RBS: are the weighting factors of the different levels of RBS. The summation of these values has not to exceed 1.0. To get more information about calculation of these weights, see chapter 3 of this manuscript.

- To save changes, click **Stop Edit**.



Any changes in setting page causes to lose all of the last calculation results. In this case, the results have to be calculated again.

3.9. Calculate

- Generation of all possible trees, calculation of the five quality notes of each RBS and aggregation of risk values on RBS branches are done in this tab (see Figure β-31). To start the calculation process click  at the top of the page. The status of calculation process is represented at the bottom of the window.

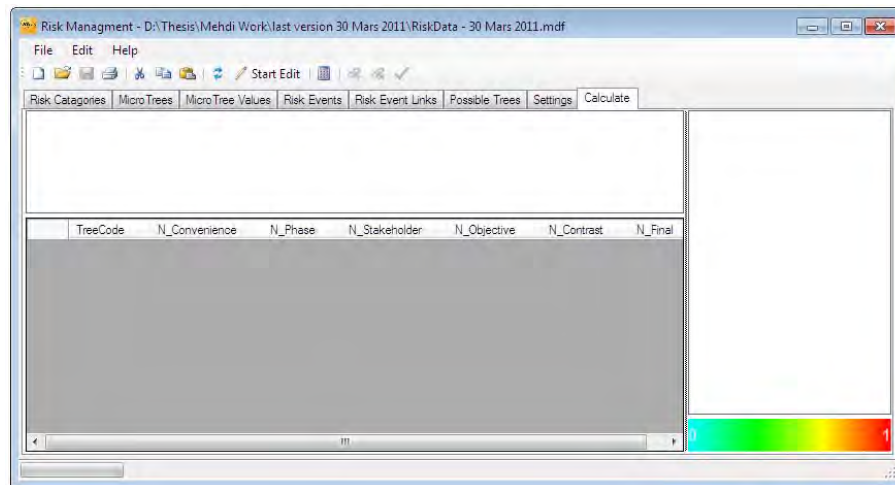


Figure β-31. Calculation tab

- ⚠ If user has forgotten to lock one of the pages of the program before starting the calculation process, an error message appears, (see Figure β-32). The unlocked tab is marked by * at the top-right side of the tab icon (ex. in Figure β-32, Setting tab is marked). To solve this problem click **Stop Edit** at the top of the page and start the calculation again.

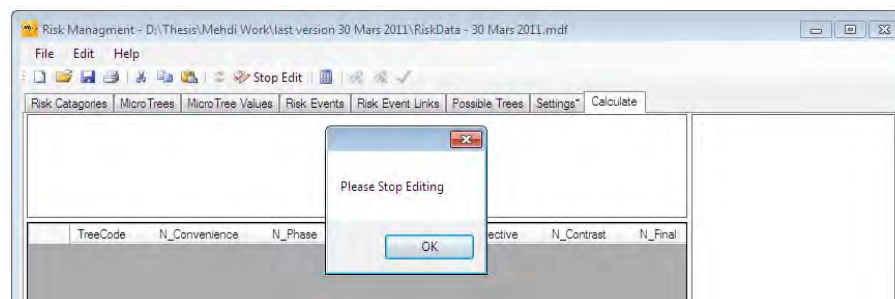



Figure β-32. Error message, stop editing

- ⚠ If user has forgotten to validate the database before the calculation process, an error message appears as is illustrated in Figure β-33. To validate the database, at the top of **Risk Event Links** tab, click . To get more information see section β.6.

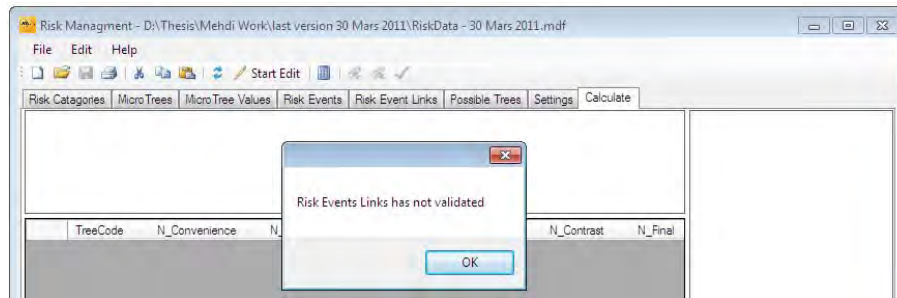


Figure β-33. Error message, the database has to be validated.

- At the end of calculation process, as is illustrated in Figure β-34, a report is presented at the top of the page, including: the father node of the RBS’s, number of generated RBS’s and list of the selected REs.

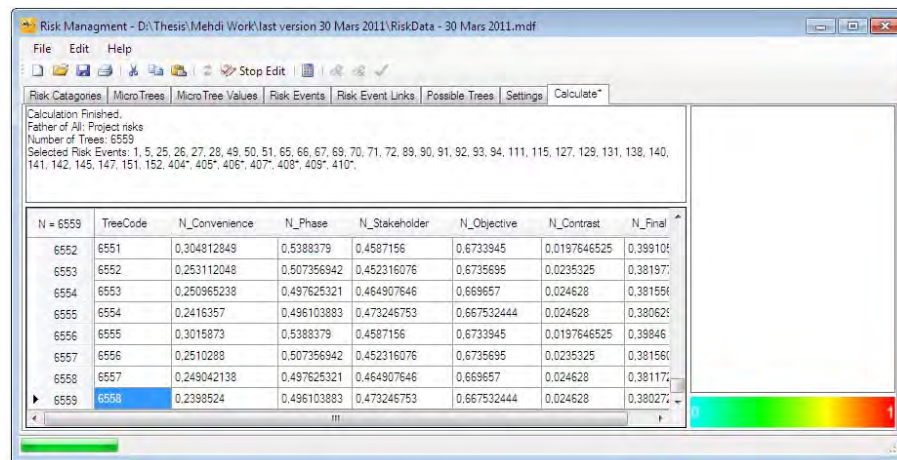


Figure β-34. Calculation results

⚠ Just the selected risk events (in “**Risk Events**” tab) are considered as the input of the RBS generation and risk analysis process. To see how to select a RE from the list of available REs in database see section β.5. In report of the calculation process, as is illustrated in Figure β-34, the codes of the selected REs are provided.

⚠ Some of the RE codes (in the final calculation report, at the top of the page) are marked with * which means that however the RE was selected by the user in **Risk Events** tab but it has no connection with the RCs of the generated RBS’s. This case can happen when links of a new RE have not yet defined, or if a category, except the “project risks” has been selected as the root of the RBS’s in setting tab.

- To see the generated RBS’s, click on the row number of the RBS at the left side of the window (see Figure β-35). Also selection of more than one MT is possible by holding

down the **Ctrl** key (For the non-adjacent RBS's) or **Shift** key (For the adjacent RBS's) and clicking on row numbers of the desired MTs, and the tree structure of all the selected RBS's will be illustrated.

- Each RBS has a row number, a unique code (*TreeCode*), and five quality note of $N_{convenience}$, N_{phase} , $N_{stakeholder}$, $N_{objective}$, $N_{contrast}$ and a final global note of the RBS (N_{final}).

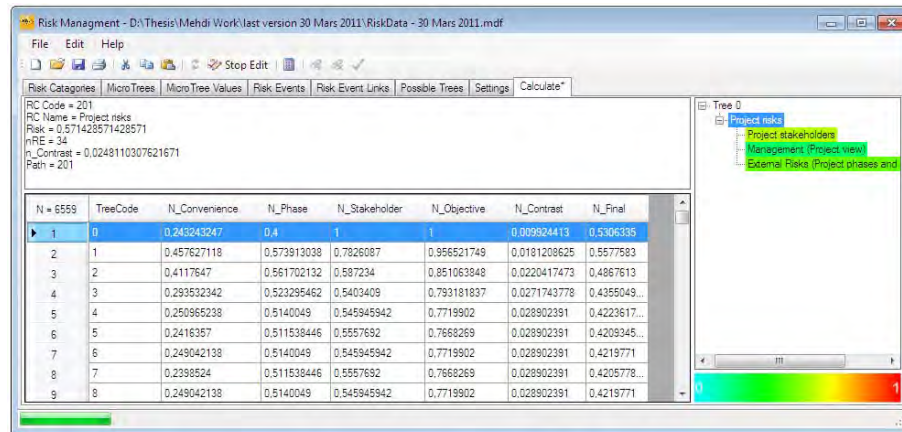


Figure β-35. Calculation tab, see the results

✚ To sort the quality notes in columns


Click on the header of the column, the data will be sorted alphabetically (Min-Max). Click again, the sort will be reversed. By sorting the values in each column, user can find the maximum or the minimum value and the corresponding RBS. For example to find the best RBS which has the maximum value of N_{Final} , sort this column to find the maximum value, the corresponding RBS is the best one. By the same method, user can find the best RBS regarding each one of the 5 global notes.



In RBS result table, the row numbers and MT codes are different, and must not be confused.

✚ To see the detailed results of each RC


- Click on RC at the right side of the page. The corresponding data will be represented at the top of the page (see Figure β-35) which are the code (*RC Code*) and the name (*RC Name*) of the selected RC, the risk value of the RC (*Risk*) corresponding to the selected objectives in **Setting** tab, the number of REs attached to this RC (nRE), $n_{contrast}$ and *path* which is the way to traverse the tree from root to this RC.
- The color of each RC represents the risk values. A color spectrum at the bottom of the page shows the corresponding color for different risk values.
- To hide the branches of a RC, click on (–) at the left side of the category name and to expand it click on (+).

 When the value of a parameter is (-1) means that the value of this parameter is null.

To delete an RBS(s)


- Select the desired RBS by click on row number and then press **Delete** on keyboard.
- To select more than one RBS, hold down the **Ctrl** key (For the non-adjacent RBS's) or **Shift** key (For the adjacent RBS's) and click on row numbers of the desired MTs.
- To keep some RBS's and delete the others, first select those ones you want to keep, click **Select Inverse** from the right click menu and then press **Delete** on keyboard.
- To select all the RBS's, click on the header of the row number column, all the RBS's will be selected, then press **Delete** on keyboard.

To save the results

Click  at the top of the page

To make changes in database or setting tab after calculation process:

- First, the **Calculate** tab which is unlocked (and is marked with * at the right side of the tab name) has to be closed by click **Stop Edit**. A question is asked, asking about saving the results. By selecting **Yes**, all of the RBS's that are available in RBS list will be saved to the database. By selecting **No**, all the results will be deleted.
- If the results are saved, when user click on **Start Edit** to make changes in database or settings, a message will appears, informing that the results have to be deleted before any change (see Figure 3-36). By selecting **Yes** all the results will be deleted. After change in database or settings of the program, the project has to be calculated again.

 Any change in database or settings of the program causes to lose all of the calculation results. User can save the project with final results with another name using **Save as** from **File** menu at the top of the window. Then changes can be applied to the original file.

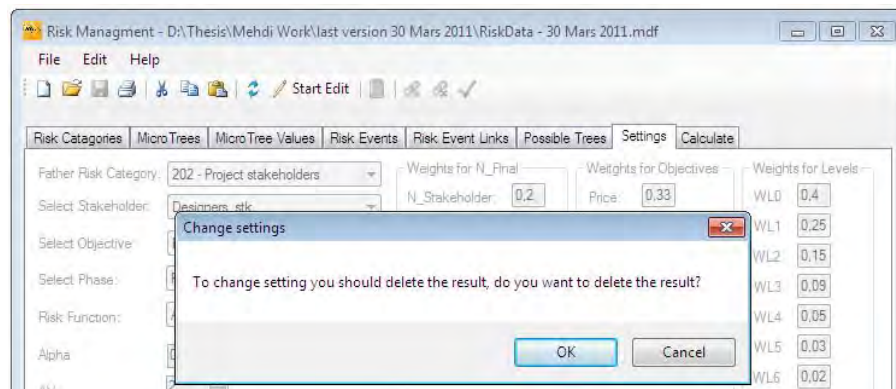


Figure 3-36. Change the settings, after calculation

✚ Improve the RBS by further decomposition of a RC(s) or deleting a MT(s)

- To see more details of a RC, user can decompose it more, manually. To do that, click on the desired RC, right click, select **Decompose by** and then select one of the available MT(s), see Figure β-37 . The category will be decomposed and the code of the RBS will be changed by adding (**_Modified**) to the RBS code at the root of the RBS structure. In fact it is a new RBS and the five quality notes are recalculated for this new RBS. To see these new notes, the new RBS has to be saved. To do that, click on one of the RCs of the RBS, right click and then select **Insert as new**. The new RBS will be saved by a new code. A message box informs this new code (see Figure β-38).
- To regroup the subcategories of a RC, right click on desired RC, select **Delete nodes**. All the subcategories of this RC will be deleted and it will be recalculated again. Clearly, the result is a new RBS with new quality notes. The name of the RBS also is changed by adding (**_Modified**) to the RBS code at the root of the RBS structure. To see the new quality notes, the new RBS has to be saved. To do that click on one of the RCs of the RBS, right click and then select **Insert as new**. The new RBS will be saved by a new code. A message box informs this new code.



To see the new quality notes of a modified RBS, it has to be saved.

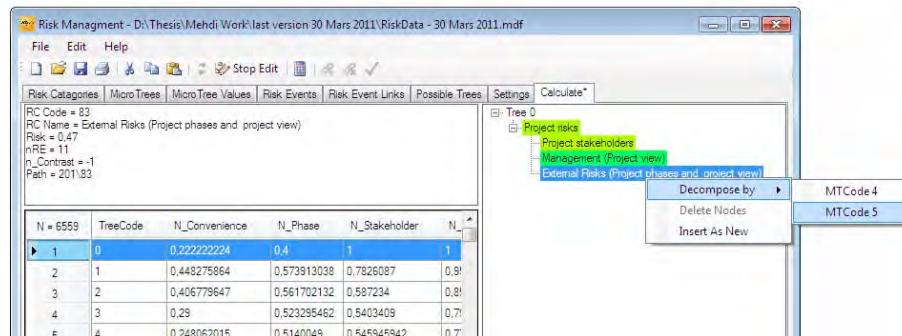


Figure β-37. Manual decomposition of a RC

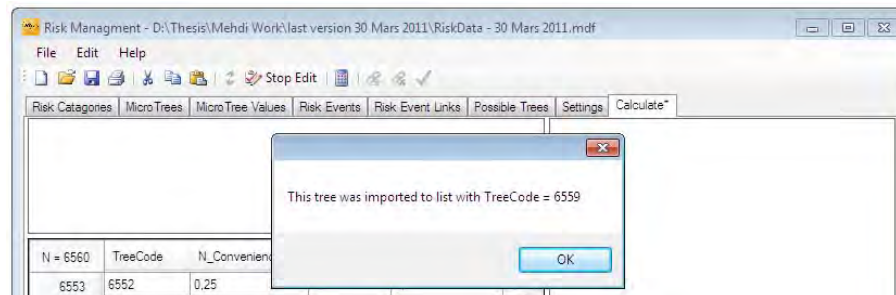


Figure β-38. Save the modified RBS to database

3.10. Get Report

To get a report of calculation process and corresponding information of the favorable RBS(s), just click **Print** at the top of the window. This function is available from the **File** menu or directly by pressing **Ctrl+p**. The result will be represented in a new window (see Figure β-39), containing the input data and representation of the selected RBS's. To select the RBS just click on the row number of the desired RBS. More than one RBS can be also selected using **Ctrl** (For the non-adjacent RBS's) or **Shift** key (For the adjacent RBS's).

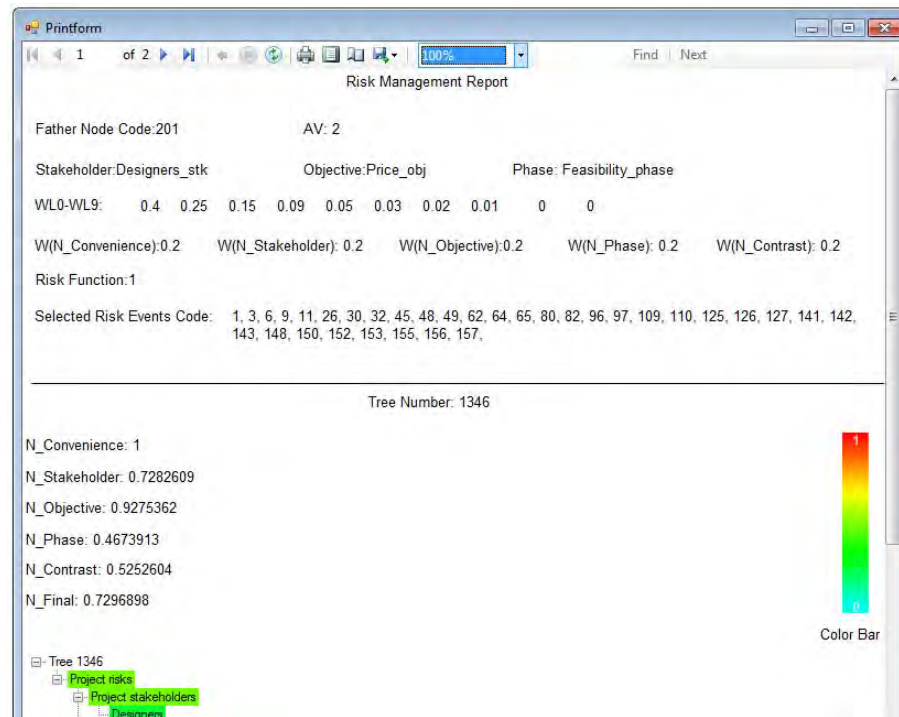


Figure β-39. Report of the calculation

At the top of this window as is illustrated in Figure β-39, some icons are available to review the page(s) and print the report. This report can be saved as a PDF, word or excel file by click on save icon at the top of the window and selecting the desired format from the dropdown window.

The first line of report contains the father node of the RBS's and the value of A_v . The second line is the desired phase, stakeholder and objective of the project. The weighting values of different levels of the RBS are represented in line 3, and line 4 contains the weighing of the five RBS quality notes to calculate the global quality note. Next line contains the corresponding code of the risk analysis functions which can be:

$$2 : R_{RC} = \text{Summation} (R_{REs})$$

$$1 : R_{RC} = \alpha \cdot \text{Max} (R_{REs}) + (1-\alpha) \cdot \text{Average} (R_{REs})$$

$$0 : R_{RC} = \text{Max} (R_{REs})$$

and the last part is the list of selected risk events which are considered as the input of the calculation process. If the code of a risk event is marked by *, means that however the RE was selected by user in **Risk Events** tab, but it has no connection with the RCs of the generated RBS's. This case might happen when a RC, except *Project risks* is selected in **Setting** tab as the root of the generated RBS's.

The second part of the report is the representation of the selected RBS(s), the code of the RBS(s), the five quality notes and the global quality note of each RBS (*N_Final*).

4. Examples

In this section, we present some practical examples which show how to use this software to identify and manage the project risks. In each example, we are focusing more on some special parts of this software, to discuss details, the error messages and show some special cases which user may need to know.

4.1. Example 1


In this example, we are going to build a new project file with a new database. The main objectives of this example are:

- general introduction to different parts of the software,
- know how to build a new project file,
- know how to add information to new database,
- management of the information, available in database,


Run the program and build a new project file:

- From **Start menu/ All programs** select “Risk Management” to run the program. In the main page of the program all the tabs are inactive and there is no information in the active page.
- To build a new project file, from **File** menu at the top of the page, select **New**. This command is also available in icon bar at the top of the page or directly by pressing **Ctrl+N**.
- In the new window, the path, the name and the type of the new project file can be chosen (see Figure 4-1). The file type is: *Sql Mdf file* which is a SQL Server database file. Select a name for the new project file (in this example: *Example 1*) and click **Save** to build a new database with the desired name. Now, the new project file with an empty database is ready to use. The name and the path of the new generated project file are shown at top of the window.

Add new risk categories:

- By default, the database is read-only and user can not make any changes in database. To unlock the database must click  **Start Edit** in icon bar at the top of the window. Now,

the database is editable and a new empty row is added to the list of risk categories. This row is marked with * at the row number.

- For the moment the tab of **Risk Categories** is unlocked and the data, just in this tab, are editable. The * beside the name of the tab indicates that this tab is unlocked. This tab has to be locked again before start any other changes in the other tabs. To do that, click  **Stop Edit** at the top of the page.

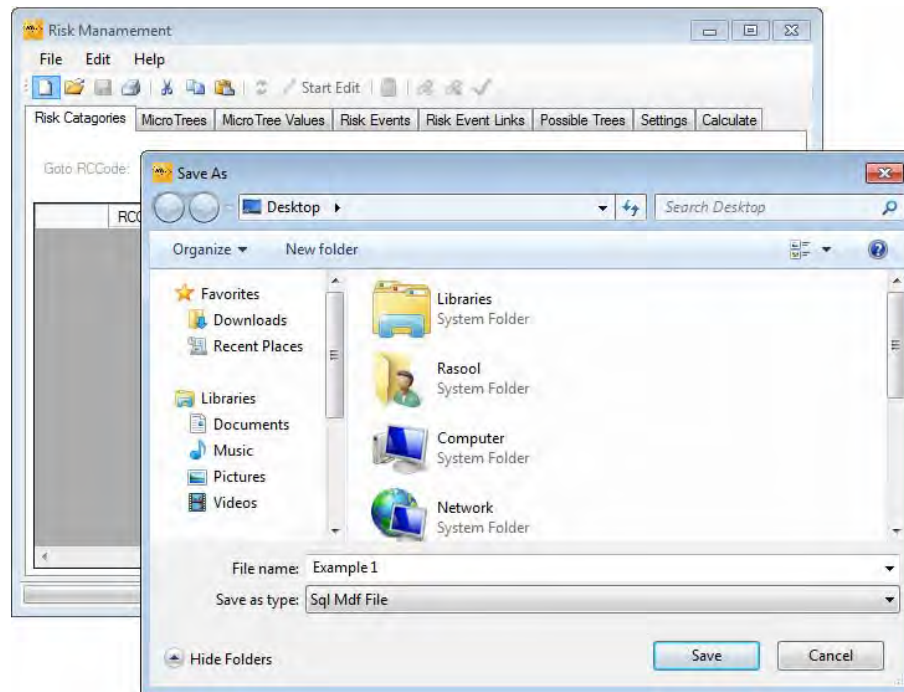



Figure 4-1. New project file

- After clicking **Start Edit**, to add the first new risk category, at the first row of the list, click on *RCCode* cell and type: “201”. It is notable that the RC code can be any integer number.
- To input the type of the RC in second cell, type 1, 2 or 3 for generic, non generic and extended RCs, respectively. These codes also can be selected from the dropdown menu as is illustrated in Figure 4-2.
- Input “*Project risks*” as the RC name in the third cell.
- The fourth cell is the description of RC. Type: “*Possible risks that can happen for project*” or paste the text after copy from another program (Excel, Word, etc...). However, this cell can be left undocumented.
- Don’t forget that during definition of a new RC, user have not to leave this active tab (Risk Categories) without clicking on  **Stop Edit**. Otherwise, an error message will appears.

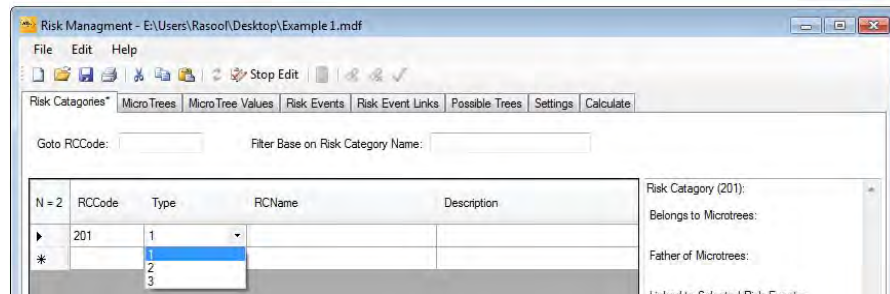



Figure 4-2. Add a new risk category

- Don't forget that after typing the text in each cell, the change will be applied just after pressing **Enter** or moving to the other cells by mouse or array keys.
- After input different elements of the new RC (which *RCCode*, *Type* and *RCName* are essential) to register into the database click  **Stop Edit**. Click **Yes** and the first RC will be added to the database (Figure 4-3). By the same way, add the two other RCs, as are illustrated in Figure 4-4.

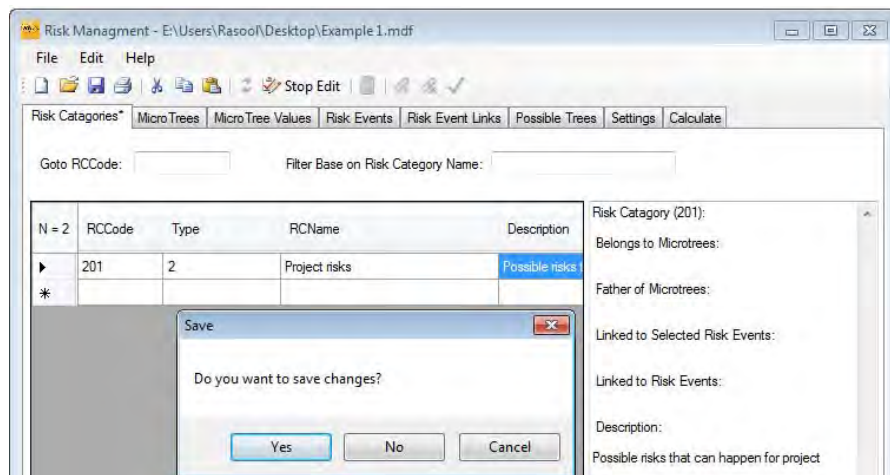


Figure 4-3. Add a new risk category into database

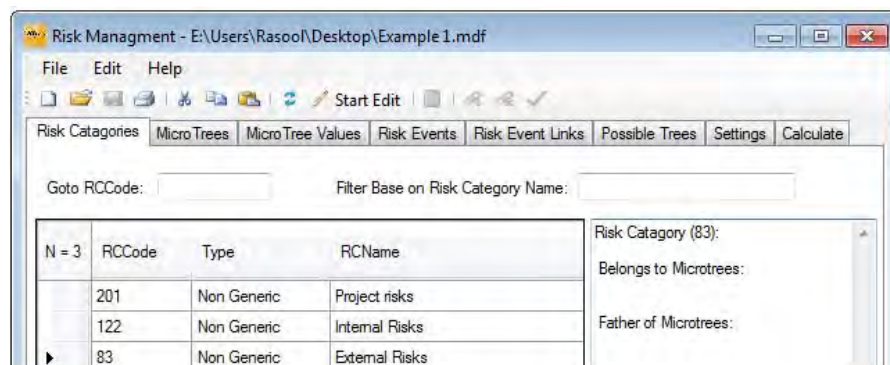





Figure 4-4. Add three new risk categories into database

Add new micro tree

- In the *Micro Trees* tab, click  **Start Edit** to unlock this tab.
- The objective is to build the first micro tree, which decomposes the *Project Risks* category to *Internal Risks* and *External Risks*. Click on *MTCODE* cell of the first row which is marked with * and input “1” as the MT code. Select the type of the MT as *Non Generic*. The father code is “201” and the subcategories are 122 and 83. You can type these codes in the corresponding cells or select from the dropdown menu in each cell. At the end, press enter and to register this new MT, click **Stop Edit** and **Save** the changes.
- The new MT is added into database. The schematic form of the MT is shown at the right side of the window.
- In *Risk Categories* tab, click on RC#201. At the right side of the window, the corresponding information is represented. It can be seen that this RC is the father of MT#1. Click on RC#122, check that this RC belongs to MT#1.

Add the micro tree values

- Each micro tree has some inherent properties which are related to the adequacy of MT for different phases, stakeholders or the objectives of the project. The adequacy of each final RBS for an special case can be evaluated as a function of adequacy notes of its MTs.
- MT#1 decomposes the project risks regarding the source of the risks, into internal and external risks. This MT is not able to highlight clearly the risks corresponding to different partners or phases of the project. These inherent adequacy notes of the MT have to be determined by user qualitatively, which enables the program to evaluate the quality notes of the RBS’s.
- Click  **Start Edit** to unlock this tab.
 - Click on *MTCODE* cell of the first row which is marked with *. Input “1” as the MT code then input the weighting factors as are indicated in Table 4.1. These values are comparative and they will be more meaningful when we will add some new MTs to the database. At the end, press enter and then click  **Stop Edit** and **Save** the changes.

Add risk events


- In *Risk Events* tab Click  **Start Edit** to unlock this tab.
- As is illustrated in Figure 4-5, a list of risk events has been prepared in an Excel worksheet. In this table, the first column is the RE code, the second column has been left empty, which is corresponding to the **Selected** column in database and the third column is the name of the RE. We will add all of these REs to the database. The probability and impact factors cells of the REs are left null and the program considers them as zero values. However, these cells can be filled if the values are known.

Table 4.1. Adequacy factors of MT#1

Project stakeholders	MT1
Designers	0
Financiers	0
Owner/Clients	0
Contractor/ Subcontractors	0
Suppliers	0
Consultants	0
All the stakeholders (Project)	0

Risk management objectives	MT1
Final price	0.4
Time	0.4
Quality	0.6
All	0.6


Project phases	MT1
Feasibility	0
Contract	0
Design	0
implementation	0
Operation	0
All the phases (project)	0

RECode	Selected	REName	Probability	Impact_Price	Impact_Time	Impact
1		Delay payment to contractor during project implementation phase				
2		Change in management system or manager of owner of the project				
27		Poor communication between stakeholders of the project to manage the project				
32		Poor exchange of information between designers				
72		Complexity of internal management of owner of the project				
6		Unwanted so cold weather during construction phase				
7		Change in design standard during design process				
8		Finding the historical objects during excavation process				
11		Fault in design standards				
12		War or revolution happening during construction phase				

Figure 4-5. Table of new risk events in excel worksheet.

N	RECode	Selected	REName	Probability	Impact_Price	Impact_Time	Impact
*		<input type="checkbox"/>					

Figure 4-6. Add new risk events

- Paste the data by pressing **Ctrl+V** or click **Paste** from the **Edit** menu at the top of the page (Figure 4-6).
- The RE codes and RE names are added to the list.
- To save these new REs, click  **Stop Edit** and then **Save** the changes (Figure 4-7).

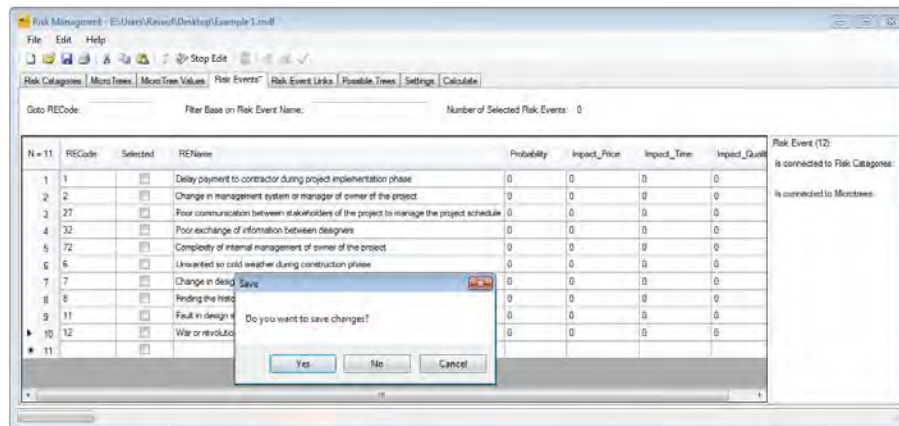




Figure 4-7. Save the new risk events into database

- Up to here, we have defined the new risk categories, a MT and some risk events. The following step is definition of links between REs and RCs.

Definition of risk event links

- The defined REs in database must have links with appropriate RCs, to be considered during selection of the most convenient RBS and calculation of the risk value of RCs. This links have to be defined by user, between each RE and the corresponding bottom level RCs in database. The indirect links automatically will be generated by software, following the hierarchical connections of the categories in MT database and direct links defined by user. The software controls the consistency of information regarding the two consistency criteria.
- In **Risk Event Links** tab, click  **Add Links** at the top of the window. A new window appears.
- The first risk event (RE#1: Delay payment to contractor during project implementation phase) is an internal risk of the project. So it should be connected to RC#122. To make this link, in the new window, click on **RECode** cell of the first row which is indicated by * and input the RE code: "1". Then, shift to the second cell: **RCCode** and input "122" and then press **Enter**.
- Before saving this link into database, the first and second consistency checks have to be controlled. In this example, for the moment we have just one MT and obviously the

second consistency which is concerning to the MTs with the same father node is not discriminant.

- Click **Check 1** at the top of the window. The first consistency control is checked and a message box confirms the validation, as is illustrated in Figure 4-8. In fact, first, software generates all the indirect links based on the new direct links added by the user and then controls the consistency of all the direct and indirect links.
- In this example RE#1 was linked to RC#122 directly by the user. The software has also generated the indirect links (here just one). RC#201 is the father node of RC#122, and so has an indirect link with RE#1. The second row at the RE links table, as is illustrated in Figure 4-9, represents this generated indirect link.
- Click **Check 2** at the top of the window. A message box informs the validation (Figure 4-10).
- To save this new link click  **Save**. A message box confirms the registration of this new links (see Figure 4-11). In this box, select **No**, because the new links of the other REs have to also be added.

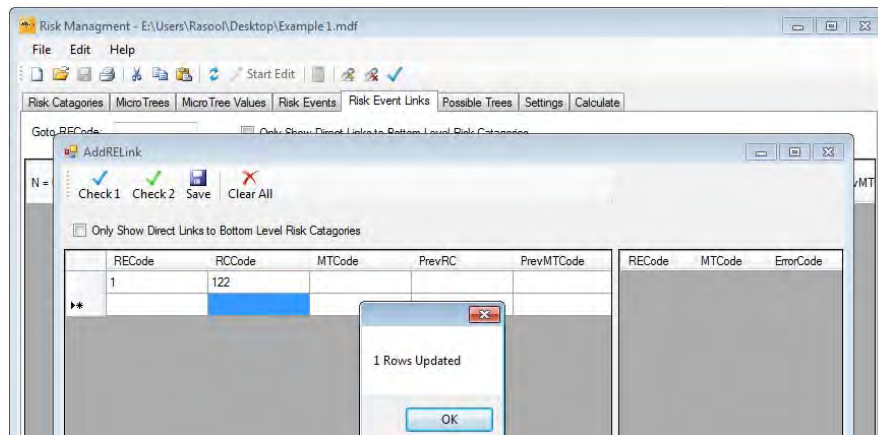


Figure 4-8. Add new RE link, confirmation of consistency check 1

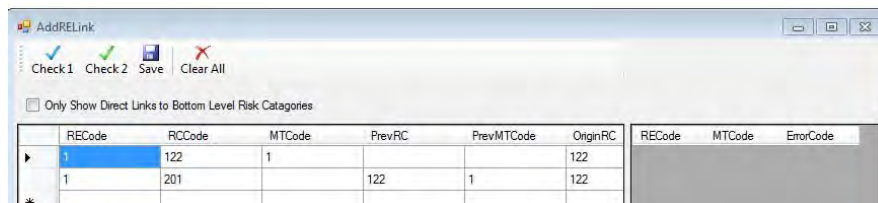


Figure 4-9. Add new RE links, generation of the indirect links

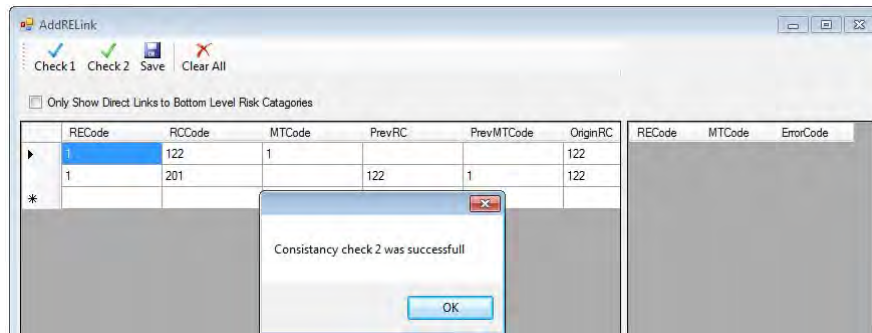


Figure 4-10. Add new risk RE link, confirmation of consistency check 2.

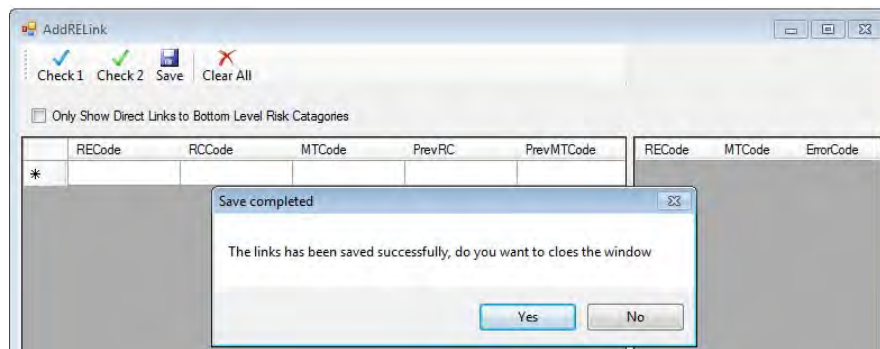



Figure 4-11. Save new links into database

- Input the other new direct links as are illustrated in Figure 4-12 and then directly click  **Save**. The software generates all the indirect links and controls the first and second consistency checks automatically before saving them into database.
- Close this window and return to the main page. 20 new links are available in this page which 10 of them are indirect links. To see just the direct links, mark **Only Show Direct Links to...** at the top of the page (see Figure 4-13).

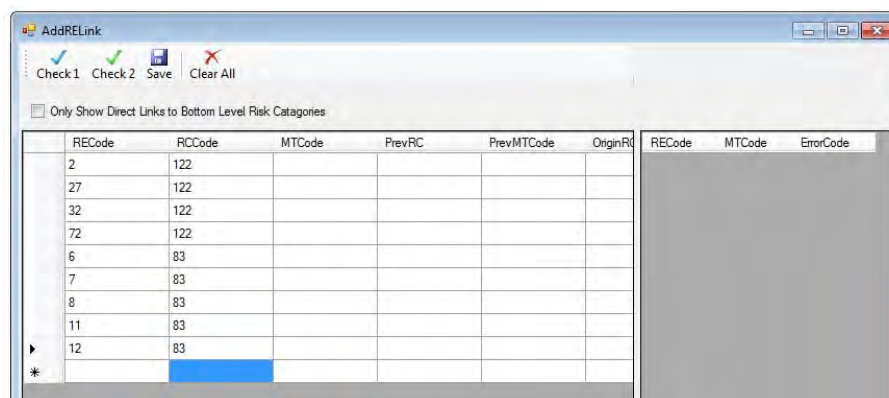


Figure 4-12. Add the other new RE links

N = 10	RECode	REName	RCCode	RCName	MTCode	PrevRC	PrevMTC	OriginRC
1		Delay payment to contractor during project implementation p...	122	Internal Risks	1			122
2		Change in management system or manager of owner of the ...	122	Internal Risks	1			122
3	27	Poor communication between stakeholders of the project to ...	122	Internal Risks	1			122
4	32	Poor exchange of information between designers	122	Internal Risks	1			122
5	72	Complexity of internal management of owner of the project	122	Internal Risks	1			122
6	6	Unwanted so cold weather during construction phase	83	External Risks	1			83
7		Change in design standard during design process	83	External Risks	1			83
8	8	Finding the historical objects during excavation process	83	External Risks	1			83
9	11	Fault in design standards	83	External Risks	1			83
10	12	War or revolution happening during construction phase	83	External Risks	1			83

Figure 4-13. New RE links in database

- Up to this step, all the data were registered into database. However, these information can be edited, removed or new data can be added into database.

✚ Generation of possible trees

- There is just one MT in the database (MT#1) and it is clear that just one RBS can be built. In **Possible Trees** tab, at the left side of the window, expand the only MT available in database. Project risks are decomposed into internal and external risks.
- Click **Generate Possible Trees** icon at the top of the window and then select **Yes** to show the generated RBS's (here just one RBS). Expand the generated RBS. As was expected, there is only one possible RBS (See Figure 4-14).
- It should be noted that generation of all possible RBS's in this tab is not mandatory for the calculation process in the following step and is just to show the results of the assembling algorithm without risk analysis or ranking operation.

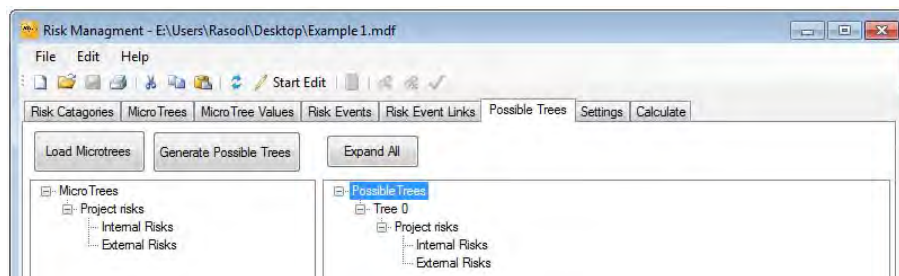




Figure 4-14. Generation of all possible trees

✚ Settings

- In Settings tab, Click  **Start Edit** and then, set the parameters as are illustrated in Figure 4-15. These parameters will be more explained in the next examples. Before going to the next step click  **Stop Edit** to unlock this tab.

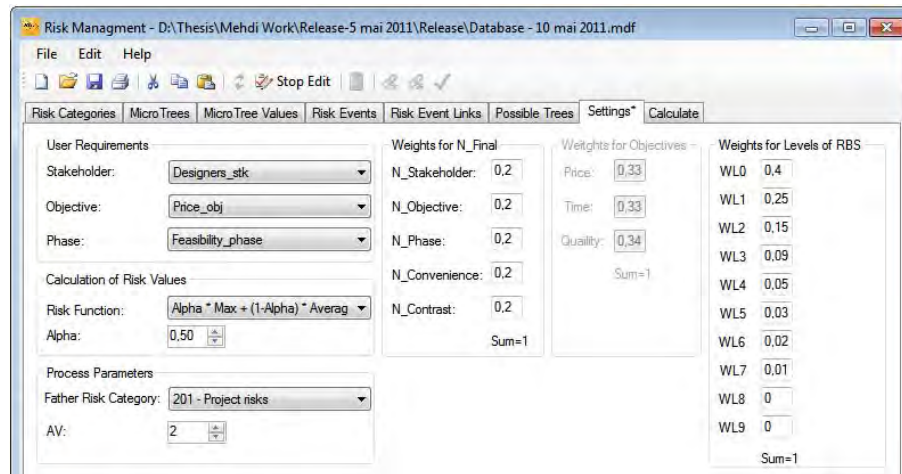


Figure 4-15. Setting parameters

Calculate

- Before the calculation process, the desired risk events have to be selected. In the **Risk Events** tab, first, unlock the page and then select all of the REs as is illustrated in Figure 4-16. To select all of the risk events, select **Select All** from the right click menu or select them one by one.

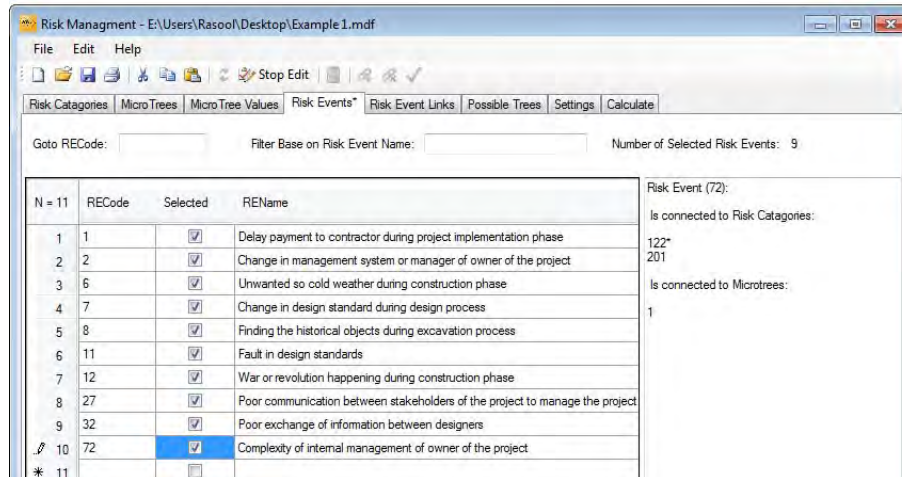





Figure 4-16. Selection of risk events

- Click  **Stop Edit** to save the changes.
- In **Calculate** tab, click  at the top of the page to start the calculation process. A message box will appear, indicating that the database has to be validated (see Figure 4-17).
- To validate the database, in **Risk Event Links** tab click  at the top of the window. Then press **OK**.

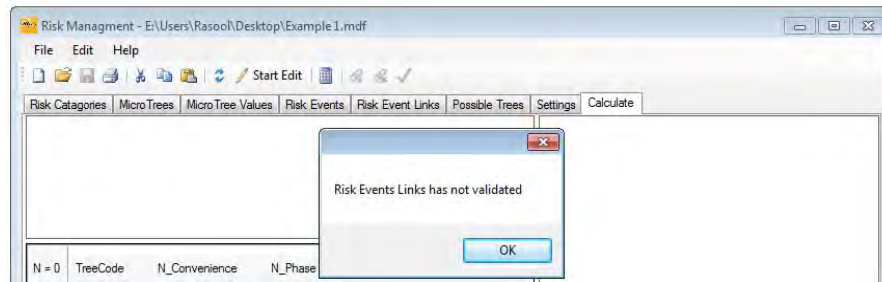



Figure 4-17. Message box, before starting the calculation process

- Now, return again to **Calculate** tab and click .
- When the calculation process terminates, a general report will be represented as is illustrated in Figure 4-18. This report confirms the successful termination of calculation process and contains the root category of the RBS's, number of generated trees and the code of selected REs.

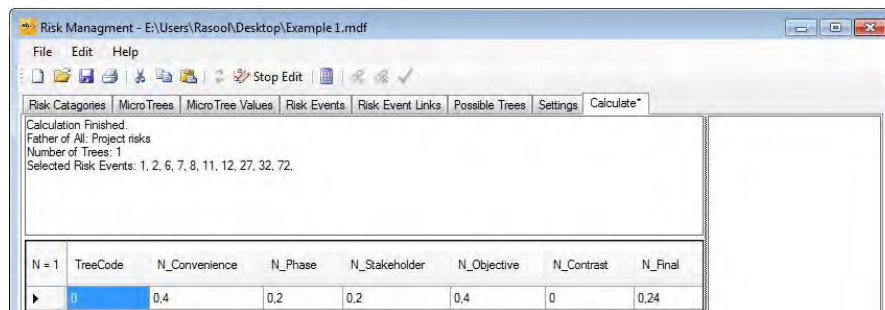


Figure 4-18. The results of the calculation process.

- Click on the row number of the RBS. The RBS will be represented at the right side of the window with the colors which indicate the risk value of the categories (see Figure 4-19).

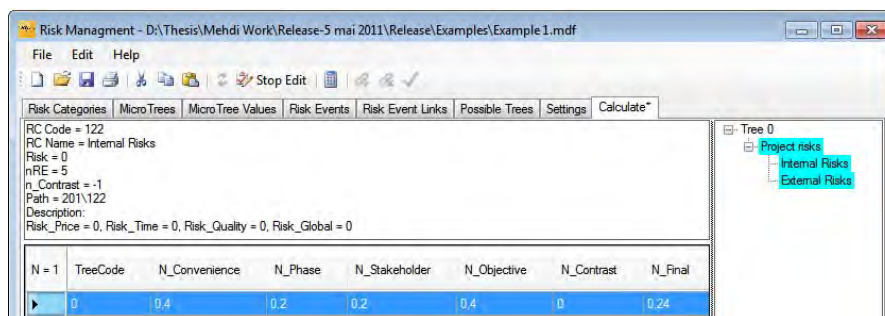



Figure 4-19. Result of the calculation process

- Click on **Internal Risks** category. The corresponding information is represented at the top of the page. The risk value of each RC is a function of the value of attached REs. The risk value of this category is zero (Risk=0) because the risk value of the attached risk events are zero. In fact, during definition of the risk events, the probability and impact factor cells of the REs were left undocumented and software considered them as zero values. There are 5 REs attached to this RC (nRE=5). The contrast value of this RC is null (which is indicated with -1), since it has no subcategory. The term **Path**, indicates the RC code and tree traversal path to get the root of the RBS (here, Project risks). The last term, **Description**, indicates the risk values of this RC, regarding to different objectives. This term is useful just when the selected objective in settings tab is all the objectives (*Project_obj*). In this case, in addition to global risk value (or note) of the RC, the values related to each one of the objectives (price, time and quality) are also represented.
- For this RBS, five quality notes and a global quality note have been calculated: $N_{Convenience}$ which evaluates the level of details of the RBS. N_{Phase} , $N_{Stakeholder}$ and $N_{Objective}$ which are associated with the adequacy of the RBS with requirements of the user and $N_{Contrast}$ which evaluates the contrast of risk values on different RBS branches. In this example, the contrast note is zero for the RBS, because the risk values of the categories are zero.

Save and close the project file

- To save the results, click  **Stop Edit** and then select **Yes**.
- To close the program select **Exit** from the **File** menu at the top of the window.

4.2. Example 2

In this example we use the created database in the last example (example 1) to show how additional data can be added to the database and how the software controls the consistency of data. The main objectives of this example are to show:

- how to open a database file,
- how to create a new project file, using the data in another database,
- how to add new risk categories, micro trees and risk events,
- how to edit or remove the data.

✚ Run the program and open the project file

- From **Start menu/ All programs** select “Risk Management” to run the program. The main page of the program will be open. In this window all the tabs are inactive and there is no information in the active page.
- From **File** menu, select **Open** and then select the file of the last example (Example 1) as is illustrated in Figure 4-20 and click **Open**.
- From **File** menu, select **Save As** to save this project file with a new name. Input “*Example 2*” as the file name, then press **Save**. A new project file is generated and automatically is connected to the program (see the top of the window, where the name and the path of the database is represented). After this, any changes will be saved into the new project file (Example 2). In other words, we have created a new project file, using the information of another database.

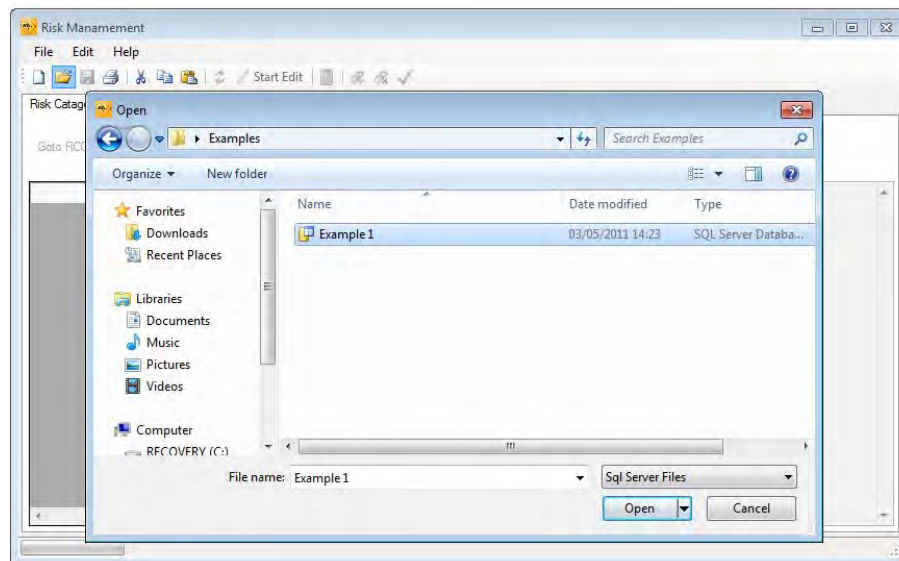


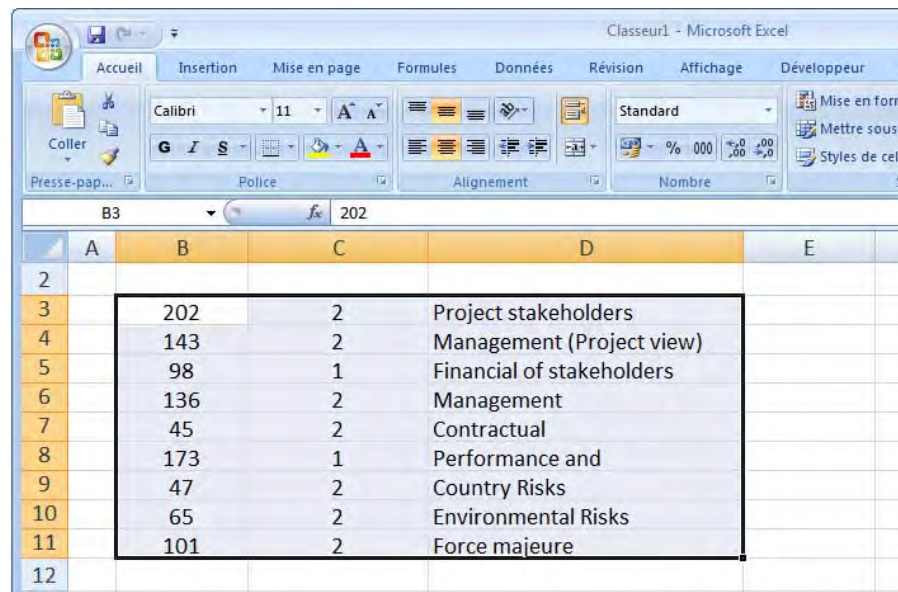


Figure 4-20. Open a project file

✚ Add new risk categories

- Database already has three RCs. In **Risk Categories** tab click on RC#83. The corresponding information of this RC is shown at the right side of the window. This RC is the subcategory of MT#1, is not the father node of any MT, is linked with REs#6,7,8,11 and 12 which are also selected in **Risk Events** tab and is connected with REs#6,7,8,11 and 12. These two last terms are not always the same but in this example, all the risk events which have link with RC#83, are also selected as desired REs.
- Click on RC#201. However it is not a bottom level category but it has links with lots of risk events. In fact these links are indirect.
- By default, the database is read-only and user can not make any changes in the database. To unlock the database must click  **Start Edit** in icon bar at the top of the window. A message box appears, indicating that the change of data or settings in database will cause to lose of results, saved from the last calculation process. Select **OK**.
- We are going to add some new risk categories into database which are listed in an excel file. Select the list of new RCs in the excel file as is illustrated in Figure 4-21 and then press **Ctrl+C**.
- Click on **RCCode** of the first empty row which is indicated with * (see Figure 4-22) and press **Ctrl+V**. To save these new risk categories, click  **Stop Edit** and then select **Yes**.



	A	B	C	D	E
2					
3		202	2	Project stakeholders	
4		143	2	Management (Project view)	
5		98	1	Financial of stakeholders	
6		136	2	Management	
7		45	2	Contractual	
8		173	1	Performance and	
9		47	2	Country Risks	
10		65	2	Environmental Risks	
11		101	2	Force majeure	
12					

Figure 4-21. Insert new risk categories into database, copy from an excel file

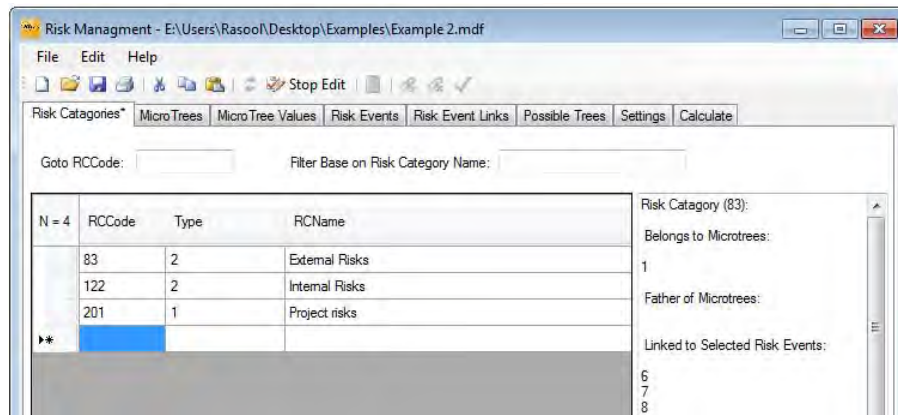




Figure 4-22. Paste new RCs into database.

✚ Add new micro tree

- In the **Micro Trees** tab click  **Start Edit** to unlock this tab.
- We are adding 3 new MTs into database as are illustrated in Figure 4-23. Input the corresponding data and then click  **Stop Edit** and then select **Yes**.

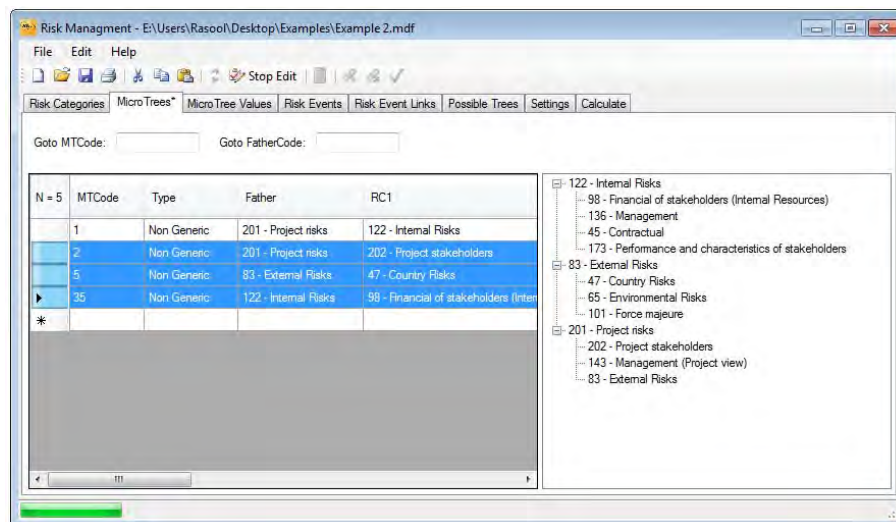


Figure 4-23. Add new MTs into database



✚ Add the micro trees values

- MT#2 decomposes the project risks regarding the different partners of the project. This MT is adequate when user is interested to focus on risks, allocated to one of the stakeholders of the project. However this MT doesn't categorize the risks clearly considering different phases of the project, but decomposition regarding project stakeholders is more convenient than decomposition of MT#1 because of the sequential and time dependency

of the performance of stakeholders. The same pair comparisons have been done between all the MTs and the adequacy notes were determined as are represented in Table 4.2.

Table 4.2. Adequacy factors of MT#2,5 and 35

Project stakeholders	MT2	MT5	MT35
Designers	1	0.2	0
Financiers	1	0.2	0
Owner/Clients	1	0.2	0
Contractor/ Subcontractors	1	0.2	0
Suppliers	1	0.2	0
Consultants	1	0.2	0
All the stakeholders (Project)	1	0.8	0.4
Risk management objectives	MT2	MT5	MT35
Final price	1	1	0.8
Time	0.6	1	0.6
Quality	1	0.4	0.8
All	0.8	0.8	0.8
Project phases	MT2	MT5	MT35
Feasibility	0.4	1	0
Contract	0.4	1	0
Design	0.4	1	0
implementation	0.4	1	0.4
Operation	0.4	1	0
All the phases (project)	0.4	1	0.4

- In *Micro Tree Values* tab click  *Start Edit* to unlock this tab.
- The list of MT values can be filled, cell by cell. However, in this example, this table have been created in an excel file and can be easily transferred into the database. Select the table as is illustrated in Figure 4-24 and copy the data, pressing *Ctrl+C*. In *Micro Tree Values* tab click on *MTCode* cell of the first new row which is marked with * and paste the data by pressing *Ctrl+V*.
- Click  *Stop Edit* and *Save* the changes.

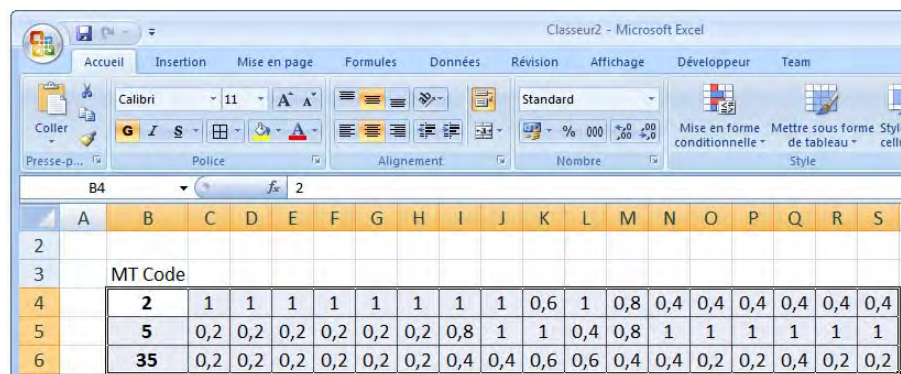


Figure 4-24. Copy the MT values from an Excel file




Add risk events and risk event links:

- 10 risk events are available in the database. In this example, we will not add any new RE.
- These 10 REs are directly attached to RC#122 or RC#183 (these links were defined in Example 1), then we added a MT which decomposes RC#122 to four subcategories. It means, there are some REs which are attached to a non-bottom risk category. There is the same problem for RC#83, which creation of MT#5 leads to an inconsistent situation. In fact the corresponding REs of RC#83 have to be attached to its subcategories (the same for RC#122).
- Creation of the new MTs in database, caused also to another problem which is related to MT#2. Both of MT#1 and MT#2, decompose the project risks (MT#201). It means, if a RE can be attached to one of the subcategories of MT#1, necessarily, it must be attached to one of the subcategories of MT#2 (consistency check 2). For the moment, all of the REs are attached to one of the subcategories of MT#1 without any connection to the subcategories of MT#2. It means the *Consistency Check 2* is not valid for the available database.
- To better understanding of the existing problems of the database, we continue this example, without solving these problems and we will see the reaction of the software.

Generation of possible trees





- To see how many RBS's can be generated by assembling the available MTs, in the *Possible Trees* tab, click **Generate Possible Tress** and then select **Yes** to show the RBS's. Before starting this process, check all of the MTs, at the left side of the window and be sure that are correct. Also in *Settings* tab be sure that **Father Risk Category** is RC#201.
- The result is 4 RBS's as are illustrated in Figure 4-25.

Calculate

- In *Calculate* tab click  at the top of the page to start the calculation process. As was expected, a message box appears, which indicates that the database has been changed and it should be validated before the calculation process.
- To check the validation of the database, in *Risk Event Links* tab click  at the top of the window. A message box appears, indicating that the database is not valid (Figure 4-26).
- To check the table of errors, click  **Add Risk Event Link** at the top of the window. The table of errors is represented in Figure 4-27. In the following, the errors are explained in detail.

Validation of database

Errors related to RE#1:

- The first error indicates that RE#1 is connected to one of the subcategories of MT#1 which is not a bottom level category. To check this problem, return to the main page, in **Risk Event Links** tab, mark **Only Show Links to Bottom Level Risk Categories**. RE#1 (Delay payment to contractor during project implementation phase) has a direct link with RC#122 (Internal Risks) and as is illustrated in Figure 4-28, RC#122 is not a bottom level category. To solve this problem, this link has to be replaced with a connection with one of the subcategories of MT#35 which decomposes RC#122. This RE can be attached to RC#173 (Performance and characteristics of stakeholders).
- The second error (the second row of the error table) indicates that RE#1 must have a connection with one of the subcategories of MT#2. As is illustrated in Figure 4-28, MT#1 and MT#2 has the same father node. RE#1 has a link with RC#122, which is the subcategory of MT#1. Necessarily it must be connected to one of the subcategories of MT#2. This risk event can be connected to RC#202 (Project Stakeholder).
- These two errors were corresponding to RE#1. As result, the connection of RE#1 to RC#122 has to be removed and two new connections have to be added: RE#1 to RC#173 and RE#1 to RC#202. Return to the main window, in the **Risk Event Links** tab, click on the row number of the first link, to select the connection of RE#1 to RC#122 (see Figure 4-29) and click  at the top of the window in icon bar. A message box appears, indicating that by removing this link, all the links between RE#1 and other RCs (direct and indirect links) will be removed. So before removing a link, be sure that you have noted somewhere all the direct links of the RE. In this example, RE#1 has just 1 direct link (to RC#122). So, select **Yes** and the links of RE#1 will be removed from the list.
- Now we can add the two new links. Click  **Add Risk Event Link** at the top of the window, and fill the table as is illustrated in Figure 4-30. Check the consistency check 1 and 2 and then click  **Save** and select **Yes** to register the new links (direct and indirect links) into database. In **Risk Event Links** tab, check the new links, added to the database.
- Now, control the validation of database again, by click  at the top of the window. RE#1 is not in the error table anymore.

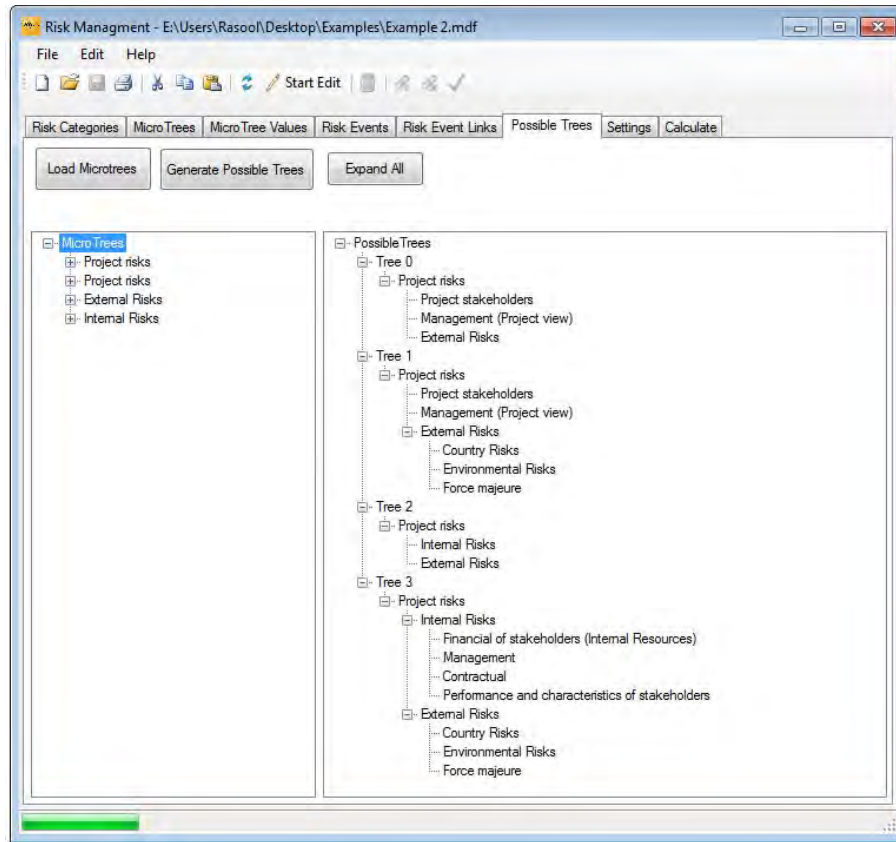


Figure 4-25. Generation of all the possible RBS's

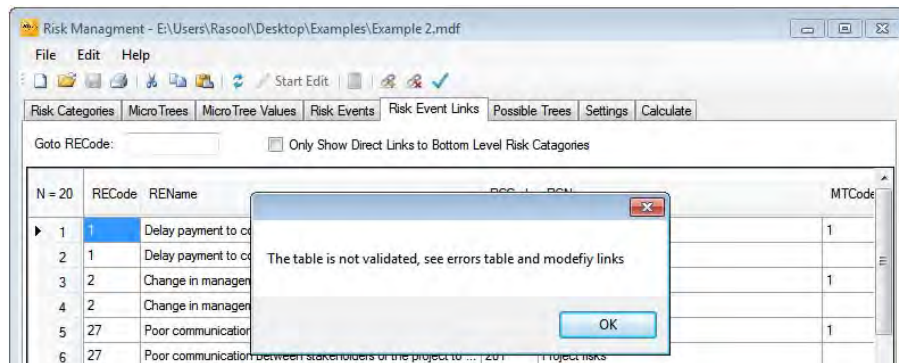


Figure 4-26. The risk event links are not valid

RECode	RCode	MTCODE	PrevRC	PrevMTCODE	RECode	MTCODE	ErrorCODE
1					1	1	3
1					1	2	2
2					2	1	3
2					2	2	2
27					27	1	3
27					27	2	2
32					32	1	3
32					32	2	2
72					72	1	3
72					72	2	2
6					6	1	3
7					7	1	3
8					8	1	3
11					11	1	3
12					12	1	3

Figure 4-27. Error table

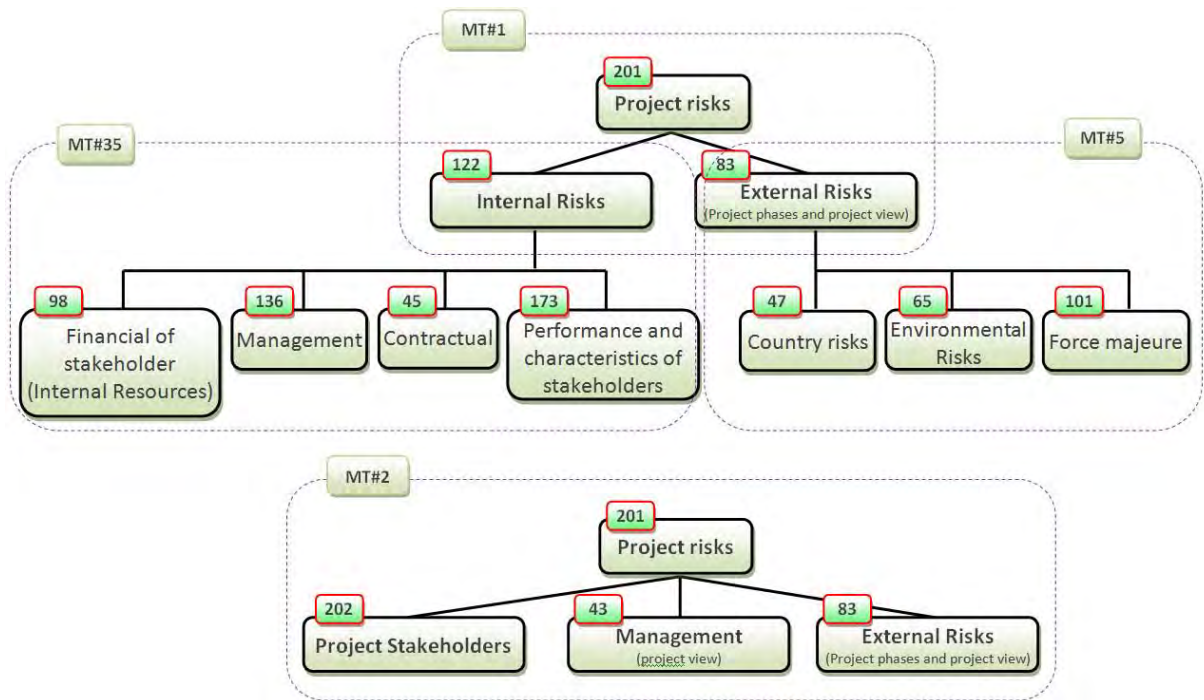


Figure 4-28. Schematic view of the MTs

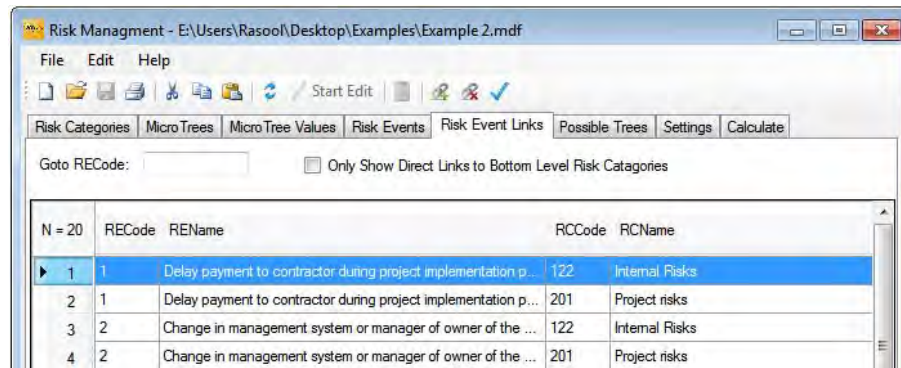


Figure 4-29. delete a risk event link

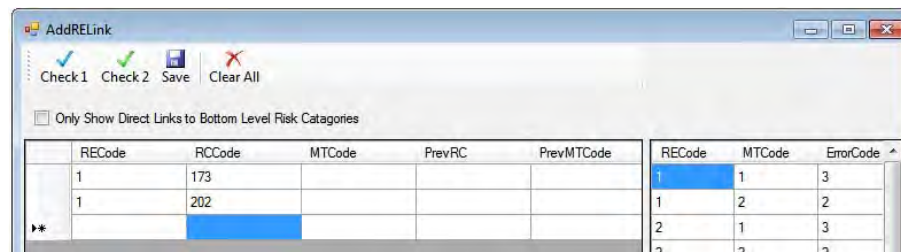


Figure 4-30. Add two new RE links

Errors related to the other REs:

- RE#2 (change in management system or manager of owner of the project) has two errors (see Figure 4-27), the first one indicates that RE#2 is connected to one of the subcategories of the MT#1, which is not a bottom level category. Looking at the **Risk Event Links** tab, it can be seen that this RC has a direct link to RC#122 which is the father of MT#35. The second error indicates that RE#2 must have also a connection with one of the subcategories of MT#2. These two problems are the same with the errors of RE#1. This RE can be attached to RC#173 as the subcategory of MT#35 and to RC#202 as the subcategory of MT#2.
- As result, the link of RE#2 to RC#122 has to be removed and two new links have to be added: RE#2 to RC#173 and 202.
- For RE#27, 32 and 72 also, the problem is the same as for RE#1.
- RE#6,7,8,11 and 12 have the same problem. In fact all of these REs are attached to RC#83 (External Risks) which is not a bottom level category and have to be replaced by a link with one of the subcategories of RC#83 in MT#5.
- The links which have to be removed and the links that have to be added to the database are represented in Table 4.3. To add or remove the links, do the same as for RE#1. Just it should be noted that before adding the new links of a RE, first, must delete its existing

links with RCs. So, at a first step, all the links mentioned in Table 4.3 have to be removed, and then, the new links will be added. The final RE links are illustrated in Figure 4-31.

Table 4.3. List of RE links that have to be removed/ added

The links that have to be deleted			The links that have to be added		
RE#2	to	RC#122	RE#2 to RC#202		
			RE#2 to RC#173		
RE#27	to	RC#122	RE#27 to RC#143		
			RE#27 to RC#136		
RE#32	to	RC#122	RE#32 to RC#202		
			RE#32 to RC#136		
RE#72	to	RC#122	RE#72 to RC#202		
			RE#72 to RC#136		
RE#6	to	RC#83	RE#72 to RC#65		
RE#7	to	RC#83	RE#72 to RC#47		
RE#8	to	RC#83	RE#72 to RC#47		
RE#11	to	RC#83	RE#72 to RC#47		
RE#12	to	RC#83	RE#72 to RC#101		

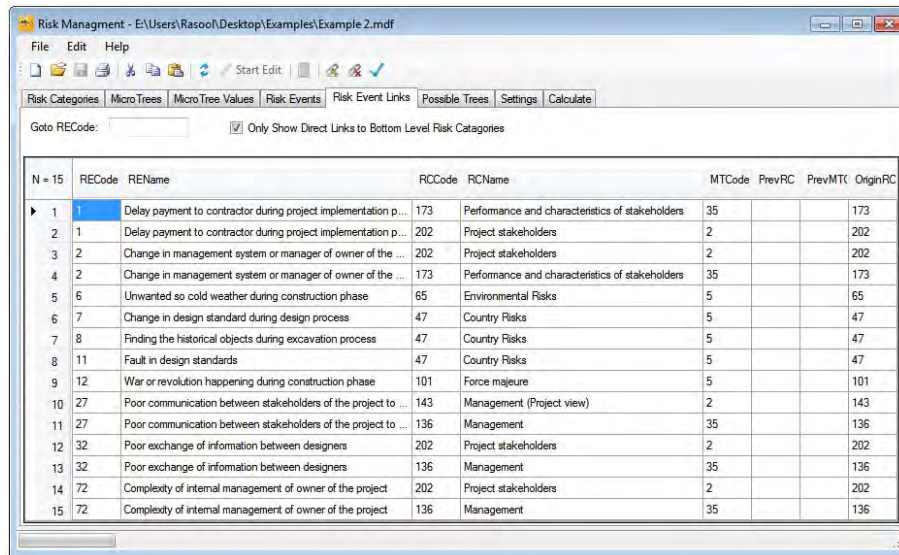



Figure 4-31. Final risk event links

- To finish this example, save the project by click  at the top of the window and close the software.

4.3. Example 3

Different parts of the database are strongly tied together, since each element has an interface with the other parts of the database. As is illustrated in Figure 4-32, a MT is defined as a connection between some RCs, each RC is connected with some REs, each MT is in connection with the corresponding MT values, the subcategory of a MT is the father node of another MT, a RE may has connection to more than one RC, a RE has direct connection, only to the bottom level RCs and some other constraints and interfaces which make a nested network. By adding any new item to the database, this complexity increases progressively. In such a nested network, removing an item can affect strongly the other elements and may cause to confusion of the database. Thus, the consistency of database is controlled automatically when user wants to make any change in database. The consistency of database is controlled following lots of constraints and criteria, which ensure the stability and validity of the database.

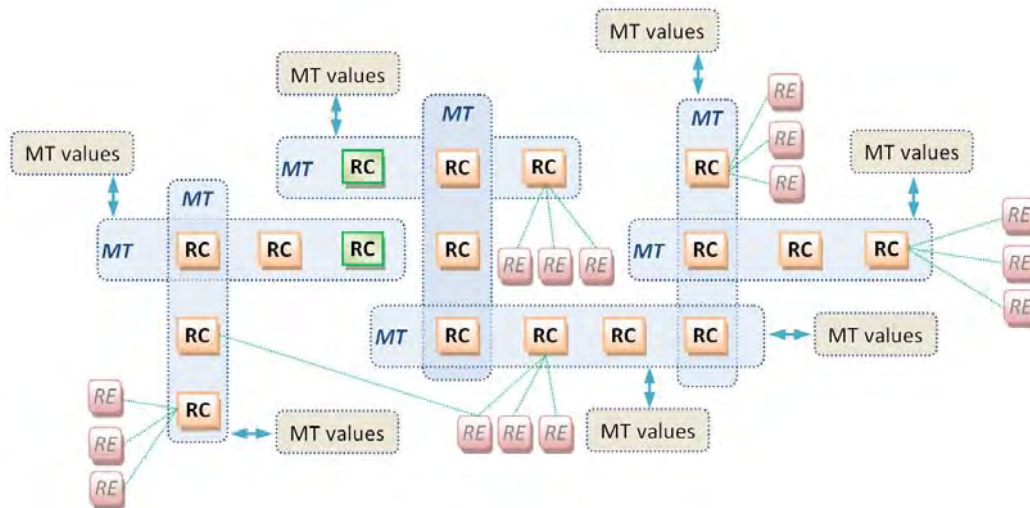


Figure 4-32. Interfaces of the database elements

Any change in database that causes to an inconsistent situation is prevented by the software and user is informed by a warning message. Now, the question is that how a MT, RC or a RE can be removed from the database while it has lots of connections with the other elements? In this example we answer to this question, using the database, created in the last example (Example 2).

The main objectives of this example are:

- Know how to remove a MT, RC or a RE from the database,
- Validation of the RE links, after removing a MT.

Run the program and build a new project file

- From *Start menu/ All programs* select “Risk Management” to run the program.

- Open the project file of the last example (Example 2) and save it with the new name of *Example 3*.

Delete a risk event

- In this part, we are going to remove RE#6 (Unwanted so cold weather during construction phase) from the list of risk events.
- In *Risk Event* tab, select RE#6. The corresponding information of this RE is represented at the right side of the window (see Figure 4-33). This RE is connected to RC#65, 83 and 201. The connection with RC#65 is direct since this RC is marked with * and with the two other RCs is indirect. These 3 RCs are the subcategories of MT#5,1 and 2. So this RE has also links with these 3 MTs.

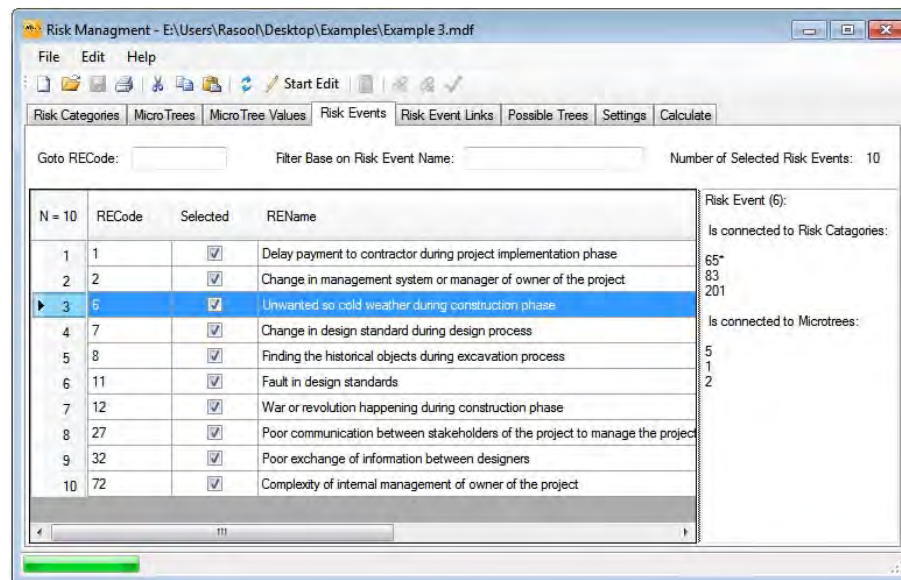









Figure 4-33. Delete a RE in the database

- Click  **Start Edit** to unlock the page. Then select RE#6 by click on the third row number and press **Delete** to remove this RE. This RE will be removed from the list of risk events, but this change has not yet applied in the database. To save this change, click  **Stop Edit** and select **Yes**. As it was expected, an error message appears. This error is due to the connections of RE#6 with the other elements. Till these connections exist, this RE cannot be deleted. Click **OK** to close this message. Click again  **Stop Edit** and select **NO**.
- As is illustrated in Figure 4-32, the only direct interface of the risk events are with the risk categories. By removing the direct links of a RE, all the indirect connections will be removed automatically, then the RE can also be deleted.

- As was said, RE#6 has just one direct link which is with RC#65. In **Risk Event Links** tab, select the direct link of RE#6 to RC#65 and to delete this link click  at the top of the window. A warning message appears, indicating that, deleting of this link cause to delete all the links of the RE. Select **Yes**.
- In **Risk Events** tab select again RE#6. At the right side of the window you can see that this RE has not connection with any RC or MT anymore. Now, removing of this RE, can not affect the validity of the database.
- Unlock the page and delete this RE. At the end click  **Stop Edit** and select **Yes** to save changes.

Delete a micro tree

- In this part, we will delete MT#5 which decomposes the external risks into three subcategories.
- In **Micro Trees** tab, select MT#5. RC#83 is decomposed into RC#47, 65 and 101 as is illustrated at the right side of the window.
- In **Risk Categories** tab click on RC#47, the corresponding information is represented at the right side of the window. This RC is connected to RE# 7, 8 and 11. Do the same with RC#65 and 101. RC#65 is not connected to any RE and RC#101 is connected just to RE#12.
- The subcategories of MT#5 are the bottom level categories and are not the father of any other MT. So, removing this MT can not affect the other MTs.
- So to remove this MT we have to:
 - a. remove all the links between REs, connected to the subcategories of MT#5,
 - b. remove micro tree values corresponding to this MT, in **Micro Tree Values** tab,
 - c. remove MT#5 from the MT database,
 - d. connect the mentioned REs, to the father node of MT#5.
- In **Risk Event Links** tab, select the direct links of RE#7, 8, 11 and 12 as is illustrated in Figure 4-34 and click  and then select **Yes** to save changes.
- In **Micro Tree values** tab select MT#5, unblock the page and then press **Delete** to remove the corresponding values, corresponding to MT#5. To save the changes click  **Stop Edit**.

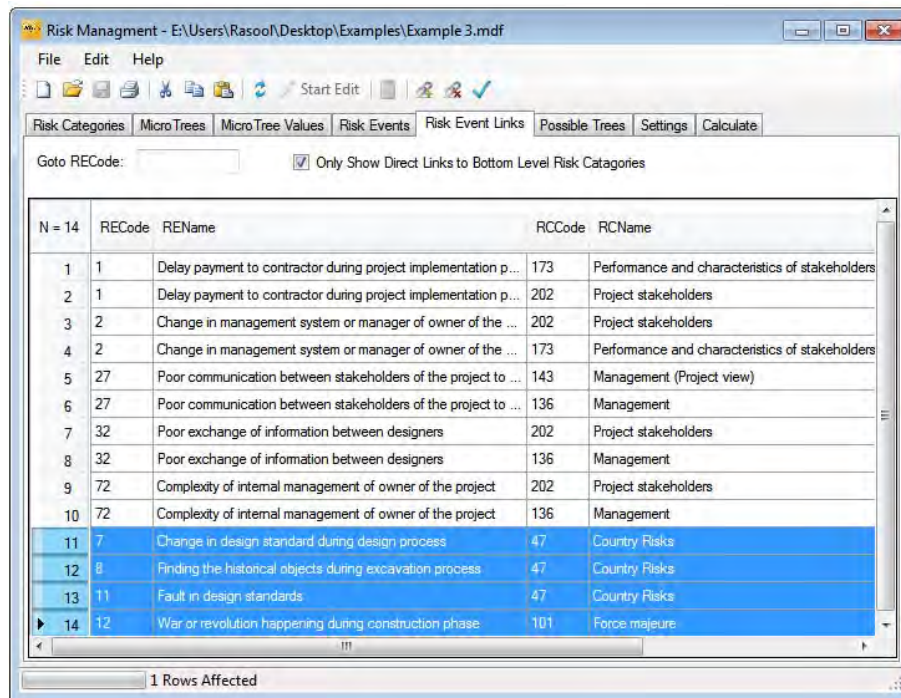




Figure 4-34. Delete the risk event links

- In **Micro Trees** tab, select MT#5, unlock the page and press **Delete** to remove this MT. To save the changes click  **Stop Edit** and select **Yes**.
- The last step is the connection of RE#7, 8, 11 and 12 to the father node of MT#5 which is RC#83. These REs were connected to the subcategories of this RC, we removed MT#5 so these REs have to be connected directly to RC#83.
- In **Risk Event Links** click  **Add Risk Event Link** and connect RE#7,8,11 and 12 to RC#83 as is illustrated in Figure 4-35. Check the consistency check 1 and 2 and then save the new links.
- In **Risk Categories** tab, click on RC#83 and at the right side of the window, you can see that RE#7, 8, 11 and 12 are in connection with this RC.

Delete risk categories

- In the last part of this example we are going to delete some risk categories.
- In **Risk Categories** tab, by click on RC#47, 65 and 101 you can see that these RCs don't have any connection with REs and MTs. In fact, during the two last parts of this example we removed all of the connections of these three RCs.

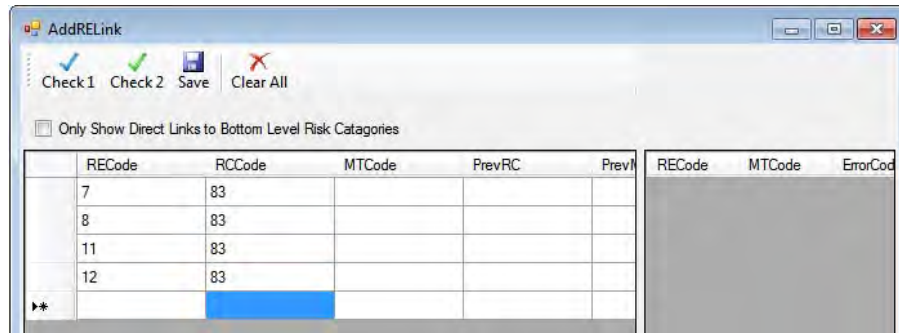



Figure 4-35. Add new risk event links

- In **Risk Categories** tab, select these RCs (as is illustrated in Figure 4-36), unlock the page and then press **Delete**. To save the changes, click  **Stop Edit** and then select **Yes**.

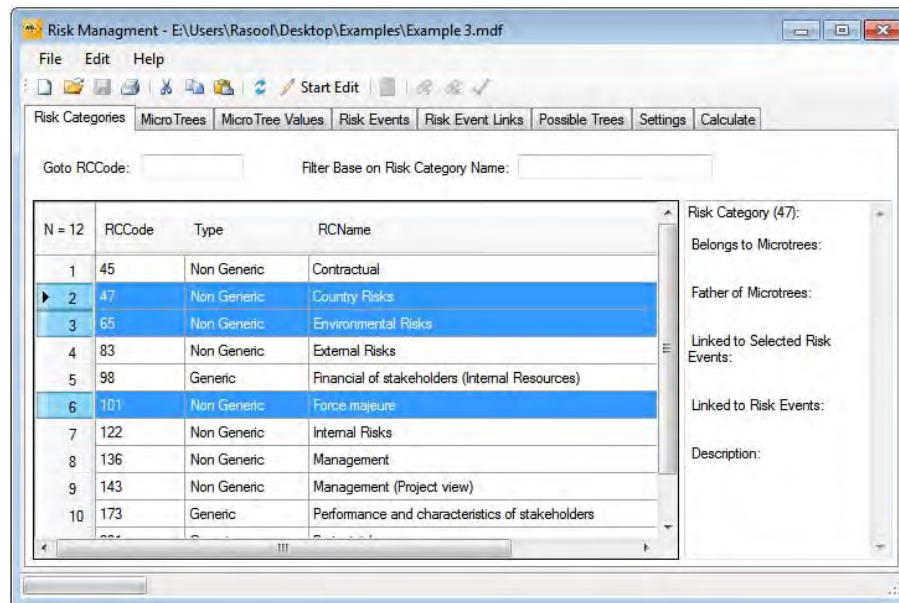


Figure 4-36. Delete risk categories