12TH INTERNATIONAL DEPENDENCY AND STRUCTURE MODELLING CONFERENCE, DSM'10
22 – 23 JULY 2010, CAMBRIDGE, UK

MODELLING RISK INTERACTIONS TO RE-EVALUATE RISKS IN PROJECT MANAGEMENT

Chao Fang, Franck Marle and Ludovic-Alexandre Vidal
Ecole Centrale Paris, Laboratoire Genie Industriel

Keywords: project management, complexity, risk interactions, risk structure matrix, risk propagation

1 INTRODUCTION

Project risk management is crucial and indispensable to the success of project. In recent decades, projects have been dealing with increasing amounts at stake and facing a growing complexity (of both their structure and the context). Risks have then become higher in terms of number and global impact within the complexly interacted risk network. For instance, there might be propagation from one "upstream" risk to numerous "downstream" risks; on the other side, a "downstream" risk may result from occurrence of several "upstream" risks in different domains. The extreme of this phenomenon is the famous "domino effect", or chain reaction. Another example is the existence of loops.

A number of risk management methodologies and associated tools in academia and industry have been developed with qualitative or quantitative approaches (Chapman & Ward, 2003; PMI, 2004). However, current methodologies fail to represent the real complexity of risks in project. Many existing methods independently analyse and manage individual risks, and generally list and rank them upon one or more characteristics. Some methods comprise cause-effect links with a tree structure, but they are still focused on one single risk (Carr & Tah, 2001; Heal & Kunreuther, 2007). Several papers about Bayesian Belief Network (BBN) appeared in recent years in the domain of project risk management (Fan & Yu, 2004; Lee, Park, & Shin, 2008). BBN method is able to model risk relationships with a network structure. Nevertheless, BBN demands oriented links and is inherent acyclic so that it is incapable of modelling the loop phenomenon.

In order to manage risks in complex project, interactions must be integrated with classical characteristics of risks, and propagation behaviour in risk network needs to be analysed. Design Structure Matrix (DSM) has proved to be a practical tool for representing and analysing relations and dependencies among system components (Browning, 2001). In this paper we present a method based on structure matrix to model risk interactions and to re-evaluate risks for assisting managers make more reliable decisions.

2 MODELLING OF PROJECT RISK INTERACTIONS

2.1 Identification of risk interactions

Identification is the first step to detect and establish the cause-effect relationship between risks. Classical dependency and structure matrix of project objects, such as tasks, actors and other different components in project, can facilitate identifying the correlations of risks related to these objects, with the help of expertise and previous experience.

We define the Risk Structure Matrix (RSM), which is a binary and square matrix. We have $RSM_{ij} = 1$ when there is a link of potential causality from R_j to R_i, as described in (Marle & Vidal, 2008). RSM is the DSM with project risks as system elements. It represents causal interactions in the complex project risk network. RSM can also be regarded as a multiple-domain matrix (MDM) because risks reside in and could interact across different domains in project (Biedermann & Lindemann, 2008).

2.2 Classical analysis on RSM for risk management

Some classical DSM analysis can be applied on RSM to help the process of risk management.

- Through partitioning analysis, risks can be sequenced and classified into different categories. For example, risks without input while leading to several others are likely to be source risks;

risks with many inputs as well as many outputs can be considered as transition risks in project; downstream risks without output are accumulated risks, often related to project performance like schedule, cost or quality. Strategies for mitigating risks in different categories are likely to be different.

- Raising the adjacency matrix from the first to *n*-th power allows for identification of successively higher order loops (Ledet & Himmelblau, 1970). Potential risk propagation loops within the complex risk network can then be identified thanks to a method which calculates the powers of RSM.
- Clustering of risks provides interfaces for decoupling subsystems and helps manager to assign risk owners. Marle and Vidal developed an algorithm to cluster risks by their interactions (Marle & Vidal, 2008).

2.3 AHP-based evaluation of risk interactions

Numerical structure matrix can provide more detailed information of the risk network for management. Evaluation is the process of measuring and estimating the strength of link between risks. The Analytic Hierarchy Process (AHP) developed by Thomas Saaty is a multi-criteria decision-making method based on the use of pairwise comparisons, which generate the elaboration of a ratio scale (Saaty, 2003). An AHP-based assessment of risk interactions is conducted to get numerical values in the dependency matrix (Marle & Vidal, 2008).

First, risks are evaluated regarding their contribution to any R_k in terms of risk input (comparison on rows). In other words, for every pair of risks which are compared, the expert should assess which one is more important in terms of probability to be an input (i.e., a cause) for R_k. Numerical values are obtained thanks to the use of traditional Saaty scales. Then, the same process is carried out for risk outputs (comparison on columns). The combination of eigenvectors permits to build up two square matrices we name NEM (numerical effect matrix) and NCM (numerical cause matrix). Indeed, for each risk R_i, we calculate the eigenvectors of the two AHP matrices corresponding to it, in terms of inputs and outputs. The eigenvectors which are associated to the maximum eigenvalues correspond to the *i*-th row of the NEM and the *i*-th column of the NCM. Then the Risk Numerical Matrix (RNM) is defined by the global weighting operation in equation (1):

$$RNM(i,j) = \sqrt{NCM(i,j) \times NEM(i,j)}, \quad \forall (i,j), 0 \le RNM(i,j) \le 1 \qquad (1)$$

This calculation permits an overall estimation of the *(i, j)*-th term since it aggregates (at the same level of influence) the two approaches respectively based on causes and effects.

3 PROPAGATION CALCULATION AND RISK RE-EVALUATION

3.1 Concepts and assumptions

In the matrix model, evaluated numerical value of cause-effect interactions in RNM can also be interpreted as *transition probability* between risks. In reality, risks are sometimes caused by external events or by risks which were not identified in the system. In other words, they may also occur spontaneously due to some unknown or undefined reason outside the scope of the model. Therefore, we define *spontaneous probability* and assign to it with the value of original risk probability, which is evaluated by classical method of project risk management without considering interactions.

Some assumptions are made in order to calculate risk propagation in the network.

- Project can be divided and risk propagation can be analysed according to stages. Transitions between risks happen when project gets into the subsequent stage.
- A risk may occur more than one time during the project (this does accord with the situation in reality). Risk frequency is thus accumulative if arising from different causes.
- The structure and values of RNM do not vary with stages. In other words, there is no added or removed risk, and the transition probability between risks will not change during the analysis.

3.2 Risk propagation model

In classical methods, risks are often analysed and prioritised based on the two concepts of probability and impact (or gravity). In this research, risks are re-evaluated by taking into account their propagation behaviour in the network.

In the risk propagation model, supposing there are *n* identified risks in the network, we use vector *s* to present the spontaneous probability of risks. *P(R)* is the vector of risk probabilities. The *n*-order square matrix *A* indicates the RNM of transition probabilities.

s is the initial vector of risk probabilities. The probability vector of risks propagated from initial states equals $A^m \cdot s$ after *m* stages. If we only consider *m* steps of propagation, then the re-evaluated risk probability vector is

$$P(R) = s + \sum_{i=1}^{m} A^i \cdot s = (I + \sum_{i=1}^{m} A^i) \cdot s = (\sum_{i=0}^{m} A^i) \cdot s \tag{2}$$

where I is the *n*-order identity matrix. If not considering the limit of stages in project, then

$$P(R) = \lim_{m \to \infty} (\sum_{i=0}^{m} A^i) \cdot s \tag{3}$$

We multiply both sides of equation (3) by $(I - A)$, and then we get that

$$(I - A) \cdot P(R) = (I - A) \cdot (\sum_{i=0}^{m} A^i) \cdot s = (I - A^{m+1}) \cdot s \tag{4}$$

Since *A* is composed of transition probabilities with values less than 1, usually the following condition is satisfied:

$$\lim_{m \to \infty} A^{m+1} = 0 \tag{5}$$

Here 0 is the zero matrix. Risk probability can be re-evaluated by the following equation:

$$P(R) = (I - A)^{-1} \cdot s \tag{6}$$

Secondly, it is possible to predict the consequences of the occurrence of one or more initial risks. In this model, we assign for instance 100% to the spontaneous probability of R_i, while all the other risks have 0% initial values. That is to say, the initial vector $s = I^i$, where I^i is the *i*-th column of identity matrix *I*. We can then anticipate the occurrence of the rest of the network, and thus evaluate the global consequences of R_i.

Criticality is another important indicator used for prioritizing risks. It is generally a combination of probability and gravity, or simply defined as the product of them in many classical methods. Similar to risk probability, we can refine risk criticality by incorporating all the potential consequences in the network of a given risk. Giving R_i with its re-evaluated probability instead of 100%, we redefine its criticality by:

$$C(R_i) = \sum_{j=1}^{n} G(R_j) \cdot P_{R_i}(R_j) \tag{7}$$

where $C(R_i)$ is the criticality of R_i; $G(R_j)$ is the original evaluated gravity of R_j; and $P_{R_i}(R_j)$ indicates the probability of R_j as the consequence of $P(R_i)$. According to equation (6), the re-evaluated risk criticality is expressed by the equation:

$$C(R_i) = G^T \cdot (I - A)^{-1} \cdot (I^i \cdot P(R_i)) \tag{8}$$

This re-evaluation of criticality enables us to get new priority results and to develop new mitigation plans.

4 A SIMPLE EXAMPLE FOR ILLUSTRATION

Here we use a simple example to demonstrate the risk propagation model and to show how to apply this method into project. This example is a system with 7 identified risks. After the modelling of risk interactions as described in section 2, we get the RSM of the risk network (Figure 1) and the RNM with numerical values. The RNM is indicated by matrix *A* in equations.

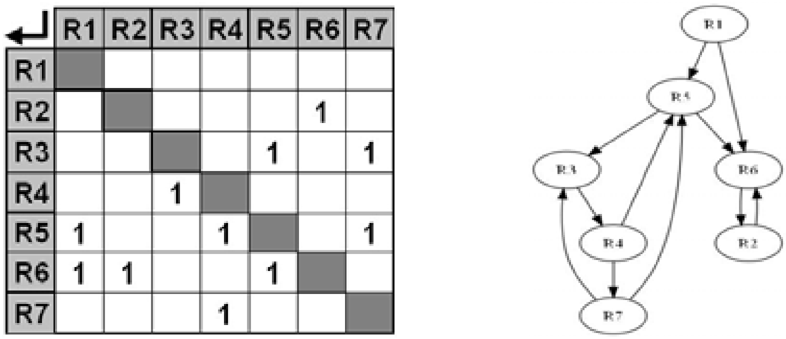


Figure 1. RSM and risk network of the example

$$A = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.08 & 0 \\ 0 & 0 & 0 & 0 & 0.15 & 0 & 0.125 \\ 0 & 0 & 0.25 & 0 & 0 & 0 & 0 \\ 0.32 & 0 & 0 & 0.28 & 0 & 0 & 0.09 \\ 0.42 & 0.39 & 0 & 0 & 0.22 & 0 & 0 \\ 0 & 0 & 0 & 0.22 & 0 & 0 & 0 \end{bmatrix} \quad (9)$$

To interpret this matrix, for example, $A(4,3) = 0.25$ indicates that if risk 3 is activated, then there is a transition probability of 25% originating from risk 3 to trigger risk 4. The spontaneous probability vector and gravity vector of risks are acquired through evaluation by classical methods, namely *s* and *G* given as follows:

$$s = \begin{bmatrix} 0.350 & 0.220 & 0.220 & 0.170 & 0.080 & 0.010 & 0.010 \end{bmatrix}^T \quad (10)$$

$$G = \begin{bmatrix} 20.0 & 25.0 & 100.0 & 10.0 & 10.0 & 125.0 & 50.0 \end{bmatrix}^T \quad (11)$$

Here the gravity values in *G* can be understood as potential impact of risks, such as capitalized loss. We are able to calculate the risk propagation according to equation (6), and then get the re-evaluated risk probability vector:

$$P(R) = (I - A)^{-1} \cdot s = \begin{bmatrix} 0.350 & 0.245 & 0.267 & 0.237 & 0.264 & 0.311 & 0.062 \end{bmatrix}^T \quad (12)$$

Equally, risk criticalities are calculated according to equation (8), and risks are prioritised based on different indicators. These results are consolidated and compared with those of classical method, as shown in Table 1.

Table 1. Risk re-evaluation and prioritisation results, compared with classical method

Ranking	By Spontaneous Probability		By Re-evaluated Probability		By Classical Criticality		By Re-evaluated Criticality	
	Risk ID	Value	Risk ID	Value	Risk ID	Value	Risk ID	Value
1	R1	0.350	R1	0.350	R3	22.0	R6	40.7
2	R2	0.220	R6	0.311	R1	7.0	R1	32.5
3	R3	0.220	R3	0.267	R2	5.5	R3	29.5

4	R4	0.170	R5	0.264	R4	1.7	R2	18.6
5	R5	0.080	R2	0.245	R6	1.3	R5	14.6
6	R6	0.010	R4	0.237	R5	0.8	R4	9.6
7	R7	0.010	R7	0.062	R7	0.5	R7	4.3

From the results in Table 1, we can see that the probability of some risks has notably increased after re-evaluation, such as R6 and R5. This kind of risks has little probability to happen spontaneously, but some other events may lead to them. The risk prioritisation results have changed after taking into account risk interactions in the network. For example, in classical method R3 was considered to be the most critical risk, but the one with the highest re-evaluated criticality is R6. Moreover, in the new prioritisation results, the value gap between risks becomes different from that in the results of classical method. For instance, R5 and R7 are two risks with low criticalities and R5 is ranked superior to R7. After re-evaluation, R5 is stilled ranked superior to R7, but the gap between their relative criticality values becomes much larger. This is the opposite for R3 and R2. R2 is still behind after re-evaluation, but closer.

5 CONCLUSION AND PERSPECTIVE

Based on the investigation of current methodologies and their limits for the complexity of project risk network, we present in this paper the modelling of risk interactions for project risk management. New applications of existing techniques like DSM and AHP are developed to identify and evaluate risk interactions.

The risk propagation model is presented to analyse propagation behaviour in the risk network. It enables to re-evaluate risks with their characteristics, such as risk probability and risk criticality. The results provide project managers with new insight on risks and their relations, and help to plan effective mitigation actions. A simple example is given to illustrate the application of this model. This method is also implemented on a case study of tramway infrastructure project with tens of risks.

As a next step, eigenstructure analysis could be performed to evaluate potential importance of risks in the global network. Smith and Eppinger conducted some related analysis on eigenvalues and eigenvectors of work transformation matrix in the field of engineering design (Smith & Eppinger, 1997). In order to mitigate the uncertainty of estimated inputs, sensitivity analysis on risks and interactions should be conducted. Furthermore, if more parameters like resource, cost and risk lifecycle are included and calculated, modelling propagation with a simulation tool could be more applicable. We are also currently working on a simulation-based method in order to model more complex situations.

REFERENCES

Biedermann, W. & Lindemann, U. (2008). Cycles in the multiple-domain matrix - Interpretation and applications. Paper presented at the 10th International DSM Conference, DSM'08, Stockholm, Sweden.

Browning, T. (2001). Applying the design structure matrix to system decomposition and integration problems: a review and new directions. *IEEE Transactions in Engineering Management, 48*(3), 292-306.

Carr, V. & Tah, J. H. M. (2001). A fuzzy approach to construction project risk assessment and analysis: Construction project risk management system. *Advances in Engineering Software, 32*(10-11), 847-857.

Chapman, C. B. & Ward, S. C. C. (2003). *Project Risk Management – Processes, Techniques and Insights*. Chichester: John Wiley & Sons.

Fan, C. & Yu, Y. (2004). BBN-based software project risk management. *Journal of Systems and Software, 73*(2), 193-203.

Heal, G. & Kunreuther, H. (2007). Modeling interdependent risks. *Risk Analysis, 27*(3), 621-634.

Ledet, W. & Himmelblau, D. (1970). Decomposition procedures for the solving of large scale systems. *Advances in Chemical Engineering, 8*, 185-254.

Lee, E., Park, Y., & Shin, J. (2008). Large engineering project risk management using a Bayesian Belief Network. *Expert Systems with Applications, 36*(3), 5880-5887.

Marle, F. & Vidal, L. (2008). Potential applications of DSM principles in project risk management.

Paper presented at the 10th International Design Structure Matrix Conference, DSM'08, Stockholm, Sweden.
PMI, S. C. (2004). *A Guide to the Project Management Body of Knowledge (PMBOK)* (2004 ed.). Newton Square, PA, USA. : Project Management Institute.
Saaty, T. (2003). Decision-making with the AHP: Why is the principal eigenvector necessary. *European Journal of Operational Research, 145*(1), 85-91.
Smith, R. & Eppinger, S. (1997). Identifying controlling features of engineering design iteration. *Management Science, 43*(3), 276-293.

Contact: Chao Fang
Ecole Centrale Paris
Laboratoire Genie Industriel
Grande Voie des Vignes
92290, Chatenay-Malabry
France
+33 1 41 13 18 02
chao.fang@ecp.fr

Modelling Risk Interactions to Re-Evaluate Risks in Project Management

Chao Fang
Franck Marle
Ludovic-Alexandre Vidal

Laboratoire Genie Industriel
Ecole Centrale Paris

Technische Universität München

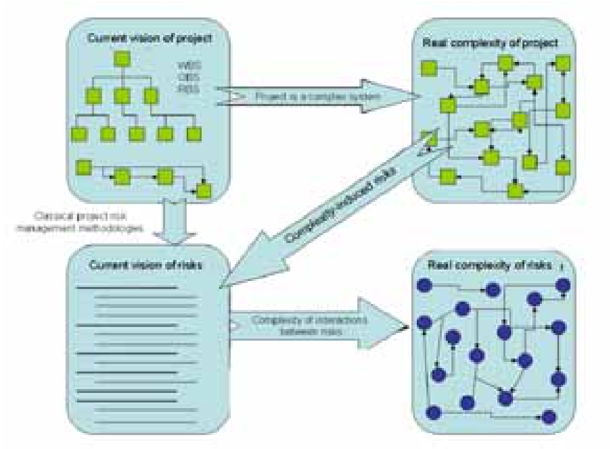
UNIVERSITY OF CAMBRIDGE

MANAGING COMPLEXITY
BY MODELLING DEPENDENCIES

Outline

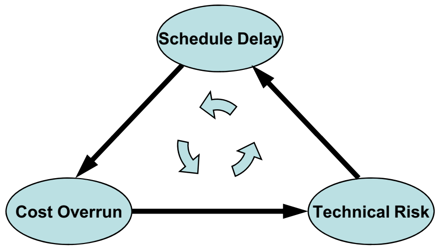
- Complexity in project risk management
- Investigation of current methodologies
- Modelling of risk interactions
- Risk propagation model
- A simple example for illustration
- Application on a tramway infrastructure project
- Conclusion and perspective

Complexity in project risk management



Classical steps of PRM:
- Risk identification
- Risk analysis
- Risk response planning
- Risk monitoring and control

- The growing complexity of project leads to the complex risk network
- Chain reaction & loop

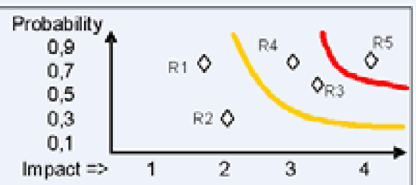


MANAGING COMPLEXITY
BY MODELLING DEPENDENCIES

Investigation of current methodologies

- Classical assessment of risks:
  - Probability & Impact (or Gravity)
  - Criticality = Probability * Gravity

Probability	Threats				Opportunities			
0,9	R6			R1				
0,7						O1		O2
0,5			R3	R2				
0,3		R4						
0,1	R5						O3	
Impact =>	1	2	3	4	1	2	3	4



- Current methods fail to represent real complexity of project risks
  - Classical methods independently analyse and rank individual risks
  - Tree structure methods with cause-effect links are still focused on single risk
  - Network model like Bayesian Belief Network (BBN) is acyclic, thus could not model loop phenomenon

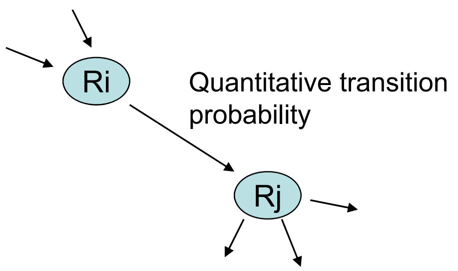
Identification of risk interactions

	R1	R2	R3	R4	R5	R6	R7
R1							
R2						1	
R3					1		1
R4			1				
R5	1			1			1
R6	1	1			1		
R7				1			

- DSM of project objects may facilitate the identification of risk correlations
- Risk Structure Matrix (RSM) represents potential causality links between risks
- RSM is the DSM with risks as system elements
- RSM can be regarded as a MDM (risks are from different domains)

- Classical DSM analysis on RSM:
  - Partitioning or sequencing – categorise risks: source, transition, accumulated risks
  - Power of RSM – identify propagation loops in risk network
  - Clustering by interactions – provide interfaces for decoupling subsystems and assign risk owners (Marle & Vidal, DSM 2008)

Evaluation of risk interactions



- From existence to numerical value
- From RSM (Risk Structure Matrix) to RNM (Risk Numerical Matrix)

- Methods of evaluation
  - Directly evaluate by experts
  - Relatively evaluate: AHP (Analytic Hierarchy Process) assessment based on pair-wise comparison (Marle & Vidal, DSM 2008)

- An example of RNM

	R1	R2	R3	R4	R5	R6	R7
R1							
R2						0.08	
R3					0.15		0.125
R4			0.25				
R5	0.32			0.28			0.09
R6	0.42	0.39			0.22		
R7				0.22			

Risk propagation model

- Concepts:
  - Transition Probability: evaluated cause-effect probability between risks, numerical values in RNM
  - Spontaneous Probability: evaluated risk probability by classical methods
- Assumption for calculating propagation:
  - Propagation can be analysed according to divided stages
  - A risk may occur more than one time during the project
  - The structure and values in RNM do not change

- Definition of mathematical symbols:
  - *A* – matrix of transition probability
  - *P(R)* -- vector of risk probability
  - *s* – vector of risk spontaneous probability
  - *G* – vector of risk gravity
  - *C* – vector of risk criticality
  - *I* – Identity matrix

Risk propagation model (continue)

- The risk probability vector equals $A^i \cdot s$ after *i* stages propagated from initial states .
- If we only consider first *m* steps of propagation:

$$P(R) = s + \sum_{i=1}^{m} A^i \cdot s = (I + \sum_{i=1}^{m} A^i) \cdot s = (\sum_{i=0}^{m} A^i) \cdot s$$

- Otherwise, if not considering the limit of stages:

$$P(R) = \lim_{m \to \infty} (\sum_{i=0}^{m} A^i) \cdot s$$

- We multiply both sides by (*I* - *A*):

$$(I - A) \cdot P(R) = (I - A) \cdot (\sum_{i=0}^{m} A^i) \cdot s = (I - A^{m+1}) \cdot s$$

- Usually it satisfies:

$$\lim_{m \to \infty} A^{m+1} = 0$$

Risk propagation model (continue)

- The re-evaluation formula of risk probability:

$$P(R) = (I - A)^{-1} \cdot s$$

- Risk criticality is an important indicator for risk prioritisation
- It is possible to anticipate the consequences of one particular risk
- The re-evaluation formula of risk criticality incorporates consequences of the risk:

$$C(R_i) = \sum_{j=1}^{n} G(R_j) \cdot P_{R_i}(R_j)$$

$$C(R_i) = G^T \cdot (I - A)^{-1} \cdot (I^i \cdot P(R_i))$$

A simple example for illustration

- An illustrative example with 7 risks in the network

$$A = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.08 & 0 \\ 0 & 0 & 0 & 0 & 0.15 & 0 & 0.125 \\ 0 & 0 & 0.25 & 0 & 0 & 0 & 0 \\ 0.32 & 0 & 0 & 0.28 & 0 & 0 & 0.09 \\ 0.42 & 0.39 & 0 & 0 & 0.22 & 0 & 0 \\ 0 & 0 & 0 & 0.22 & 0 & 0 & 0 \end{bmatrix}$$

$$s = \begin{bmatrix} 0.350 & 0.220 & 0.220 & 0.170 & 0.080 & 0.010 & 0.010 \end{bmatrix}^T$$

$$G = \begin{bmatrix} 20.0 & 25.0 & 100.0 & 10.0 & 10.0 & 125.0 & 50.0 \end{bmatrix}^T$$

- Re-evaluation of risk probability:

$$P(R) = (I - A)^{-1} \cdot s = \begin{bmatrix} 0.350 & 0.245 & 0.267 & 0.237 & 0.264 & 0.311 & 0.062 \end{bmatrix}^T$$

MANAGING COMPLEXITY

BY MODELLING DEPENDENCIES

Results and analysis (case study)

- Risk re-evaluation and prioritisation results
- Comparison with classical methods

Ranking	By Spontaneous Probability		By Re-evaluated Probability		By Classical Criticality		By Re-evaluated Criticality	
	Risk ID	Value	Risk ID	Value	Risk ID	Value	Risk ID	Value
1	R1	0.350	R1	0.350	R3	22.0	R6	40.7
2	R2	0.220	R6	0.311	R1	7.0	R1	32.5
3	R3	0.220	R3	0.267	R2	5.5	R3	29.5
4	R4	0.170	R5	0.264	R4	1.7	R2	18.6
5	R5	0.080	R2	0.245	R6	1.3	R5	14.6
6	R6	0.010	R4	0.237	R5	0.8	R4	9.6
7	R7	0.010	R7	0.062	R7	0.5	R7	4.3

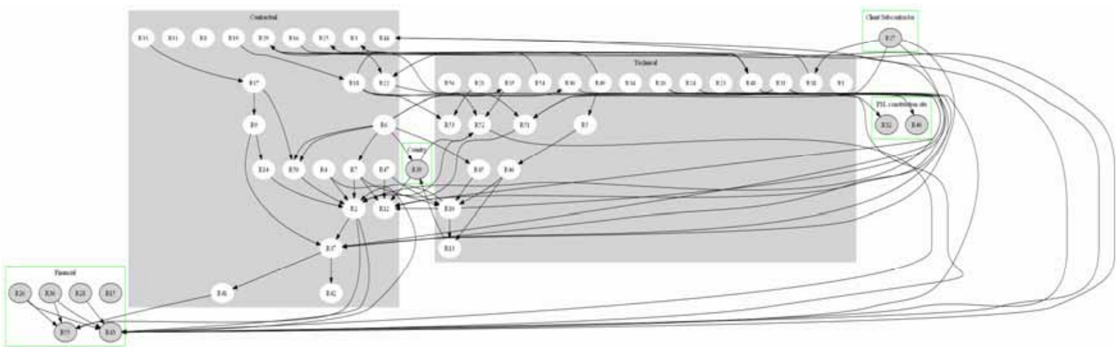
- Probability of some risks have increased due to causes from other risks
- Ranking of risks have changed after taking into account risk interactions
- The relative gap between values becomes different

MANAGING COMPLEXITY

BY MODELLING DEPENDENCIES

Application on a tramway infrastructure project

- Large infrastructure project: tramway, equipment, and civil work
- 10 years duration, hundreds of millions € budget,
- 55 risks at the main level (system product line)
- Risk network (clustered by risk nature: technical, contractual, financial, etc.)

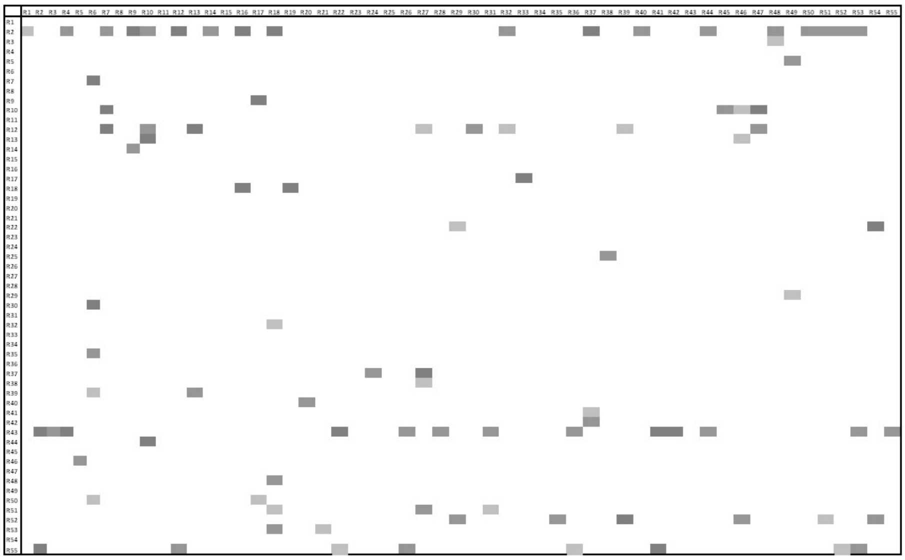


MANAGING COMPLEXITY

BY MODELLING DEPENDENCIES

Application on a tramway infrastructure project (continue)

- Risk numerical matrix of the project



MANAGING COMPLEXITY

BY MODELLING DEPENDENCIES

Application on a tramway infrastructure project (continue)

Risk ID	Risk Name	Numerical SP	Risk Frequency
1	Safety studies	0.001	0.001
2	Liquidated damages on intermadiate milestone and delay of Progress Payment Threshold	0.308	1.715
3	Vehicle storage in another city	0.381	0.381
4	Vandalism on site	0.001	0.001
5	Traction/braking function : behaviour in degraded mode on slope	0.086	0.086
...	...	...	...
42	Costs of modifications not covered by EOT agreement	0.001	0.037
43	Return profit decrease	0.381	1.412
44	Extra trains	0.001	0.074
45	Pedestrian zones	0.001	0.001
46	Train performance	0.086	0.104
47	Waiting time at stations	0.210	0.210
48	Depot delay	0.381	0.438
49	Error in the Survey (topography)	0.001	0.001
50	Ticketing design delays	0.308	0.308
51	Track installation delay	0.308	0.316
52	Reengineering / Redesign	0.381	0.506
53	Slabs pouring delay	0.210	0.267
54	Initial specifications of CW (Civil Work)	0.210	0.210
55	Available cash flow decrease	0.381	1.179

- Some results of risk re-evaluation
- Re-evaluated risk frequency might be larger than 1
- These risks are likely accumulated risks, such as financial risks

Conclusion and perspectives

- Summary of study
  - Modelling of risk interactions thanks to techniques like DSM and AHP
  - Risk propagation model to re-evaluate risks
  - Application of this method on case study of construction project
- Limitations of current matrix-based method
  - Independence assumption of risk interactions
- Perspectives of future work
  - Eigenstructure analysis of structure matrix to evaluate potential importance of risks (Smith & Eppinger, 1997)
  - Sensitivity analysis to enhance the robustness of model
  - Propose and test mitigation actions on risks and on interactions
  - Optimise portfolio of mitigation actions under constraints
  - Modelling in the simulation context, to include more parameters like resource, cost and risk lifecycle