USING DSM APPROACH TO MANAGE INTERACTIONS BETWEEN PROJECT RISKS

Franck Marle
Ecole Centrale Paris, France

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1 INTRODUCTION

A project aims at satisfying all its stakeholders. That means lots of objectives which may be opposite, and lots of constraints and uncertainties. To take into account all the stakeholders with all their objectives, constraints and uncertainties makes a project complex (Baccarini 1996). As complexity of projects is continuously growing, project management concepts, methods and techniques must include this complexity and must help to manage it. The purpose of this paper is to introduce the Project Risk Interactions Management (PRIM) process and its associated tools and techniques. The aim is to assist project manager and project members to make decisions in a coordinated way by taking into account their direct and indirect interactions inside and outside the project. The problem with current methodologies is that there are some links which exist but are not managed. Risks are indeed interrelated with links which are more complex than what is actually modelled and then managed. We argue that projects are nowadays generally managed with single-link graphs (Work Breakdown Structure, PERT diagram, Organisational chart, risk lists) and not as complex networks (Marle 2002). In the case of risk management, most of the methods use lists, as if they were independent, in order to prioritise them, to assign them to risk owners and to group them into smaller clusters (Raz and Hillson 2005). Traditional tree-based methodologies are mainly single-risk oriented, even if they analyse multiple causes and consequences. Even the network-based methods, like Bayesian networks, do not allow a project manager or a risk manager for properly taking into account the real complexity of interactions between risks (Heal and Kunreuther 2007). This complexity involves many data of different natures, with the existence of long chains and/or of loops. These are not the optimal use conditions for existing methods, especially for big networks. Thus, we argue for the use of some methods which remain simple but permit to catch and to consider interactions better than today. DSM is one of these methods and is the pedestal of the proposed PRIM process.

2 WHY MANAGING INTERACTIONS BETWEEN PROJECT RISKS?

Classical project risk management identifies, analyses and treats risks. However, there are still some phenomena which are not enough taken into account by classical project risk management methodologies, such as loops, reaction chains or non-linear couplings. The consequences are detailed below in the case of a real industrial project.

2.1 Presentation of the industrial case

The industrial background of this study is a large infrastructure project, which consists in building the infrastructure and associated systems of the future tramway of a city with a population of 750 000. We shall designate the country as C; the lead company is French. This civil engineering project notably comprises:

- The construction of a depot to stock trains and execute their control and maintenance
- The installation of tracks throughout the city, over land with many steep slopes
- The construction of the corresponding trains
- The establishment of a traffic signalling operating system, which gives priority to the tramway in order to assure a performance level in terms of future travel time.

A project risk management process was implemented and led to the existence of 8 lists of risks which contributed to the successive risk reviews. Our focus here is on one particular product line known as

“System” which, as it integrates all the aspects of the project, is one of the most complex. The 42 risks indicated in the list are diverse and are classified according to six risk classes (risk nature), which are: contractual, financial, country, project management, technical and stakeholders. Risk ownership in terms of responsibility is shared by 12 actors in the project.

Currently, risk management presently receives moderate attention within the firm and the following issues are to be underlined. First, risk lists are elaborated since they must be done, but no real attention is paid to them and they are not used as they could be. According to the company, risk management is still too often considered as an academic work which is not necessary for day-to-day project management. According to the author, risk owners (in terms of responsibility) may sometimes be defined too quickly, since the examination of this list underlines that some ownerships should be rearranged. Indeed, risk owners belong to varied hierarchical levels in the firm structure, and some risk owners are responsible for one risk while other ones are responsible for more than ten. This involves some issues which are introduced in the next paragraph.

2.2 The need for anticipation and coordination in project risk management

In the first place, there are a great number of risks in a project. Then, lists of identified project risks need to be broken down into more manageable clusters. Existing techniques are mainly mono-criteria, since project risks are usually grouped by their nature (financial, technical, etc.), by their criticality value (low, high, etc.) or by their ownership. The risk owners are responsible for the occurrence and/or for the consequence of a risk within the project organisation. Whatever the criterion used for the decomposition of an initial risk list, and whatever the rigour and detail level used, there will always be interactions between risks which do not belong to the same cluster. At this stage, a management issue arises, since decisions may be blocked, slowed down or ineffective if inter-cluster interactions are poorly taken into account.

Secondly, it is difficult to anticipate potential consequences of a risk, especially if it is considered and documented as isolated. For instance, there may be propagation from one « upstream » risk to numerous « downstream » risks, the climax of this phenomenon being the famous dangers of the domino effect. Another example may be the existence of loops: amplifying loops are a great danger during projects and are all the more complicated to understand since the nature of the risks which exist within a loop is likely to be different. For instance, in a recent automotive development project, a technical issue in a specific component involved a delay, then an over cost for this component and for the associated task, because of additional workload. This over cost involved to do some savings in the rest of the car, which conducted to additional delays. The change in the component involved some changes in the safety components, because its mass had changed. This additional change involved again over cost and delay for the project. Finally, there was an amplifying propagation of overruns in terms of project (delay and budget) and in terms of product (component cost, component mass, component performance). After some propagation steps, the same element was impacted again, and was its own root cause. From what has been discussed above, we can conclude that project risks are interacted complexly in a network context. To manage projects with complexly interrelated risks, it is important to integrate the multiple dimensions of risks, including classical characteristics like probability, impact or nature, and also to bring risk interactions into project risk management. Risk interactions must be taken into account and well analyzed in order to make decisions more reliable. This is the object of the next section which introduces the PRIM process.

3 HOW TO MANAGE THESE INTERACTIONS USING THE PROJECT RISK INTERACTIONS MANAGEMENT (PRIM) PROCESS

We introduce the PRIM process, the structure of which is voluntary similar to the existing Project Risk Management (PRM) process. The steps are: Interactions Identification, Interactions Analysis, including Interactions assessment, Propagation analysis and Vulnerability Analysis, and finally Interactions Mitigation.

In this process, the interactions-based project risk network is built, first with binary data then with numerical data. Risk propagation behaviour is analysed to refine the results of classical methodologies. This may change risk prioritisation which is used for mitigation action planning. Then, mitigation actions are proposed, with some innovative actions like organisational clustering, or breaking propagation between two risks instead of trying to avoid a risk.

Innovative aspects of this approach can be summed up as:

- Putting interactions in terms of possible cause and effect relationships at the centre of this methodology permits to offer a complementary point of view regarding project risk management. The result is in itself an innovative way to rank or to prioritise project risks, or to group them together, or to assign them to risk owners.
- For all practical purposes, it also permits to facilitate the coordination of project risks between risk owners. Indeed, the identification of potential interactions and of potential propagation through these interactions may involve that risk owners will better communicate and coordinate their decisions. The second way to improve this coordination is through the clustering into the mitigation step which allows for grouping interdependent risks. Then, coordination through each cluster will permit to avoid the main reaction chains or loops.

4 THE IDENTIFICATION AND ANALYSIS OF RISK INTERACTIONS

4.1 Interactions identification

Identification of risk interactions is the first step to determine and establish the possible cause-effect relationship between risks. Design structure matrix (DSM) has proved to be a practical tool in project management for representing and visualizing relations and dependencies among system components. Thus we use DSM to assist in identifying risk interactions. The DSM was introduced by Steward with tasks (Steward 1981) and was initially used basically for planning issues (Eppinger et al. 1994). Since then, it has been widely used with other objects, like product components, projects or people (Eppinger and Salminen 2001; Sosa 2008). The main advantages of this approach are to overcome the problems associated with the visual display of complex networks, especially in the case of very complex structures, including lots of interactions and even loops. Thus, it permits easier calculations which are inherent to the matrix format (eigenvalues, matrix product, matrix transposition). An additional advantage is that it allows for systematic identification by considering each cell across the matrix. Marle and Vidal already presented a Risk Structure Matrix in Marle & Vidal (2008). There is an interaction between two risks if the occurrence of the upstream risk may trigger the occurrence of the downstream risk. For instance, a delay of a task may involve a delay for its successors, an over cost for the project, a motivation issue for the resources. These events are first identified as potential events and called risks. Risks may occur because of one or multiple causes; this is what we call Transition Probability (TP). They may also occur for other reasons, not included in our model; this is what we call Spontaneous Probability (SP). Classical models mainly focus on SP. In order to be more useful, this matrix needs to be transformed into a numerical one to catch the strength of risk interactions. That is why we introduce the following steps of interactions assessment and analysis.

4.2 Interactions assessment

Two approaches can be considered for assessment of risk interactions. The first one is to ask to experts to evaluate them directly on a 10 level Likert scale. The second possibility is to use pair wise comparisons, as the ones used in the Analytic Hierarchy Process (Saaty 1999). With the outcome of identification and evaluation, risk interactions can be represented in network structure. This network may be very complex, as each risk could cause multiple subsequent risks and can also be triggered by multiple risks. There exist different paths from one node to another, either direct paths or via multiple intermediary nodes. Assessment of individual interactions enables to analyse more global phenomena, like reaction chains or loops. This is the object of the next paragraph.

4.3 Analysis of potential propagation through the interrelated network

It is difficult to calculate the propagation behaviour in the risk network, especially with complex phenomena like loops. Furthermore, it is not similar to scientific research in some disciplines like chemistry or biology. In the context of project management, it is too difficult, costly and impractical to carry out physical studies on the project itself. Namely, continuously repeating projects as experiments in reality is basically unfeasible. Therefore, in our research on project risk management, we model and analyse risk network through discrete event simulation with the Arena software. The risk network model is introduced in the software to calculate propagation through 10000 simulated iterations. It enables to re-evaluate risks upon some of their characteristics, such as probability and criticality. The results can provide project managers with new insight on risks and their relations, and help to plan effective mitigation actions. Details are in (Fang et al. 2010), but in figure 1, we can see that some risks have a different place in the ranking, in terms of probability (left side) or criticality (right side). This is due to their position in the network, and not only to their individual assessment. For instance, risks R10 and R17 have a higher ranking after simulation. This is mainly because they have lots of causes, or an important part of the network which may trigger them. On the contrary, R05 and R09 were considered as important in the initial estimation, but not so much after simulation. In terms of criticality, the simulated value takes into account the global consequences of a risk, direct and indirect. This means that risks R01 and R05 have many consequences and have to be considered as more important than with the initial ranking. On the contrary, R03 has a more "local impact". All these information assist decision-makers to plan risk mitigation actions. As estimations and rankings change, the priority and then the mitigation actions will change.

Ranking	By Spontaneous Probability		By Simulated Frequency		By Evaluated Criticality		By Simulated Criticality	
	Risk ID	Value	Risk ID	Value	Risk ID	Value	Risk ID	Value
1	R01	0,500	R01	0,807	R03	4,50	R01	16,16
2	R03	0,500	R03	0,771	R01	3,50	R05	11,17
3	R02	0,360	R02	0,696	R05	2,16	R02	6,21
4	R05	0,360	R10	0,529	R02	1,80	R03	6,14
5	R14	0,360	R04	0,495	R04	1,13	R14	2,89
6	R04	0,126	R17	0,469	R07	1,01	R04	2,12
7	R07	0,126	R14	0,445	R14	0,72	R07	1,98
8	R09	0,050	R07	0,425	R09	0,30	R09	0,91
9	R16	0,050	R12	0,400	R16	0,25	R16	0,34
10	R06	0,011	R11	0,393	R19	0,11	R19	0,21
11	R08	0,011	R08	0,388	R06	0,09	R12	0,17
12	R10	0,011	R13	0,383	R12	0,09	R10	0,16
13	R12	0,011	R05	0,364	R08	0,08	R06	0,16
14	R13	0,011	R06	0,266	R13	0,08	R13	0,15
15	R19	0,011	R15	0,196	R10	0,07	R08	0,10
16	R11	0,001	R16	0,191	R15	0,01	R15	0,02
17	R15	0,001	R09	0,049	R11	0,01	R17	0,02
18	R17	0,001	R19	0,014	R18	0,01	R11	0,01
19	R18	0,001	R18	0,002	R17	0,00	R18	0,00
20	R20	0,001	R20	0,001	R20	0,00	R20	0,00

Figure 1. Comparison between risk ranking with and without considering interactions

As a conclusion of this section, it is to be noticed that the same complex risk network will not involve the same consequences depending on the maturity of the organisation and of its managers and experts. That means that complexity is not in itself a problem, and that we should more analyse the gap between the complexity level and the capacity of the project organization to deal with it, including anticipation and coordination. This gap may be defined as the vulnerability of the project organisation. This point is not developed here, but has been introduced in Vidal and Marle (2010).

5 THE MITIGATION ACTIONS IN ORDER TO REDUCE GLOBAL RISK

This section combines classical mitigation strategies with new ones which are specific to the issue of complexity. Classical mitigation actions are avoidance, reduction of probability and/or gravity, transfer and acceptance. Facing the complexity of risk interactions, two additional strategies may be adopted: changing the organisation to adapt it to the current complexity, or reducing the complexity to make the project able to cope it. The aim is to act also on links (the interactions between risks), instead of acting only on nodes (the risks).

5.1 First type of action: adapting the organisation to the existing complexity

The problem of reforming teams inside a project organisation can be formulated as a clustering problem applied on an interaction matrix. The clustering approach has already been introduced by

Marle and Vidal (2008); some refinements have been made for two years but the global structure is the same. Comparing to classical clustering techniques, like DSM partitioning, the goal is different since it does not aim to identify independent groups, but quasi-independent groups. The target of the optimisation problem is to maximise the quantity of interactions within the clusters. But, due to the complexity of the network, it is almost impossible to get several independent clusters. The partitioning algorithm gives one big block and several isolated risks. Clustering risks in order to maximise intra-cluster global interactions value allows for facilitating the coordination of risk monitoring and controlling activities, as it underlines the need for cooperation and transversal communication within the project team. An example is given in the case of the tramway project (figure 2). It shows that identified clusters are slightly different than the current structure in six classes. Namely, there are approximately 30 % of the risks which are grouped together in both structures. This means that interactions are mainly between risks of different natures. It enables better communication between people, since it does not seek the identification of ownership, responsibility and/or accountability, but the identification of risk interdependencies. After the clustering process, coordination is made by the person who is assigned to the cluster, but communication has been facilitated before.

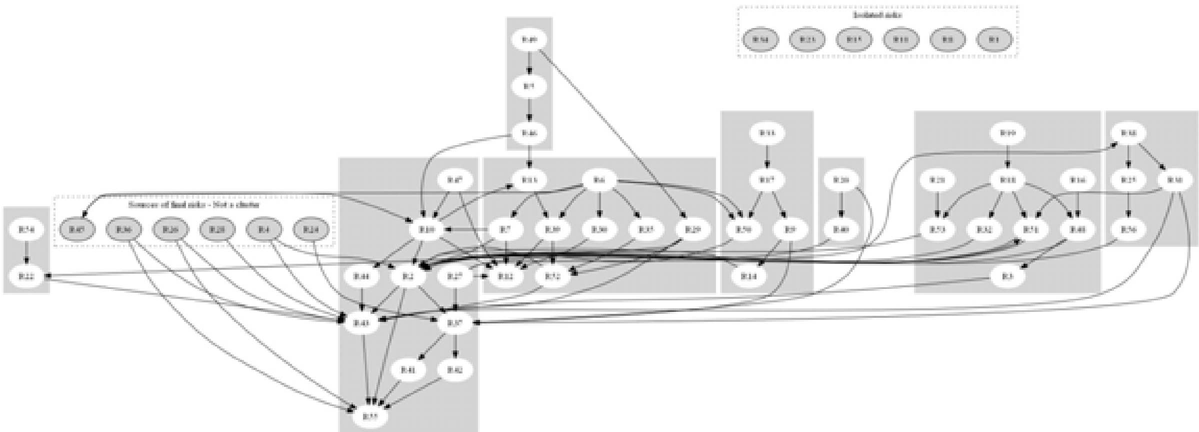

Figure 2. Description of proposed clusters, obtained to maximize interaction between risks

5.2 Second type of action: reducing the complexity

The main innovation is to act on interactions, not only on risks. The mitigation actions can be identified using the structure of the network and the results of the propagation analysis. When a risk appears after simulation to be a source of lots of dangers, it may be useful to avoid it or to break its consequences interactions. On the contrary, when a risk appears to be triggered by others more than occurring alone, then an action on the causes or on the upstream links of this risk is efficient. Breaking some links may be more effective than trying to avoid some risks. This is called confinement; the aim is not to avoid the occurrence of the risk itself, but its propagation. Another example of innovative mitigation action is to reassign risk owners. To assign the same owner to some strongly interrelated risks will enable this actor to “internally” manage the complexity. The mitigation actions can be tested with simulation, including both classical actions on risks and innovative actions on risk interactions. This permits to assess their potential global impact, and their possible secondary negative effects.

6 DISCUSSION

This proposal of a Project Risk Interactions Management process is complementary to the existing Project Risk Management process, not in replacement. It just introduces a change of paradigm, for instance to cluster risks according their interactions and not for their similarity-dissimilarity in terms of nature or criticality. It is also an extension of scope for cause-effect analysis, since long-term chains or loops are developed.

Through the simulation experiments, we can anticipate the potential consequences of risks, and get the refined evaluation of risk characteristics, such as simulated risk frequency and risk criticality. It is then possible to prioritise risks based on these refined characteristic values. By comparing with the results in classical methods, we find for some risks that the simulated values are higher than their initial values. Some risks are underestimated because classical methods do not properly take into account risk interactions and possible propagation phenomena. Simulated risk prioritisation results provide re-evaluation of risks and of their potential importance in the project.

Our objective is the improvement of coordination through the better recognition and handling of risks interactions. Our works and case study have shown possible significant improvements regarding this specific objective. They also underline the need for a shift in the way project risk management should be approached. We argue that, when facing complex situations, risks could be grouped in a different manner than by nature or by values. In the end, grouping risks in clusters which maximise the values of risk interactions within them appears to be a promising approach to handle project risks. Indeed, such clusters are generally assigned to project team members. Each person in charge of a cluster can thus manage risks which are closely related in terms of possible causes or consequences.

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Contact: F. Marle
Ecole Centrale Paris
Laboratoire Genie Industriel
Grande voie des vignes
92295 Chatenay-Malabry Cedex
France
franck.marle@ecp.fr

Using DSM Approach to Manage Interactions between Project Risks

Franck Marle

Laboratoire Genie Industriel,
Ecole Centrale Paris

Technische Universität München

UNIVERSITY OF CAMBRIDGE

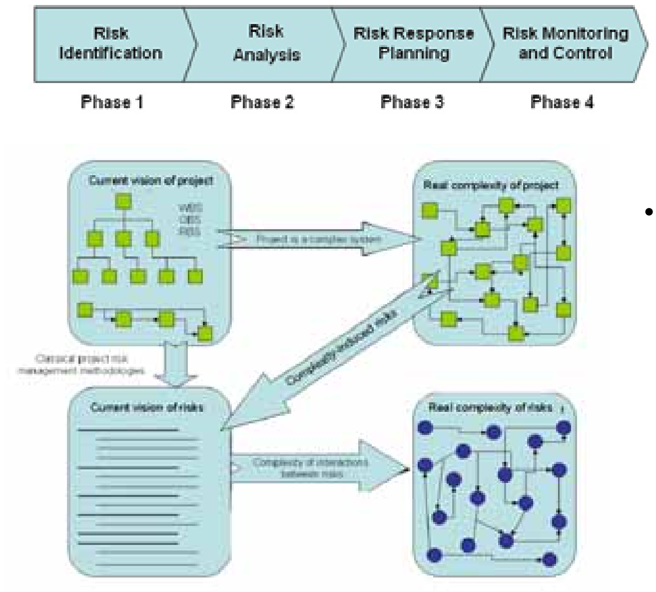
MANAGING COMPLEXITY
BY MODELLING DEPENDENCIES

Outline

- Complexity in project risk management
  - Limits of current process and methodologies
- Proposal of a Project Risk Interaction Management (PRIM) process
  - Complementary to the classical Project Risk Management (PRM) process
  - Application to the Tramway project case study
- Modelling of risk interactions and risk network
  - Risk Identification (PRM)
  - Risk interactions identification (PRIM)
  - Risk assessment (PRM)
  - Risk interactions assessment (PRIM)
- Analysis of the network and its vulnerability
  - Risk propagation anticipation (PRIM)
  - (Vulnerability to complex phenomena: chains, loops, nonlinear couplings) (PRIM)
- Determination of mitigation actions (PRM)
  - Adapting the organisation to the complexity (PRIM)
  - Reducing the complexity (PRIM)
- Conclusion and perspective

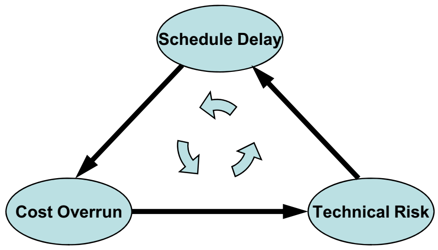
MANAGING COMPLEXITY
BY MODELLING DEPENDENCIES

Complexity in project risk management



The growing complexity of project leads to a risk network which is more complex than what is actually managed (lists, trees or acyclic networks)

- Chain reaction & loop



MANAGING COMPLEXITY
BY MODELLING DEPENDENCIES

The case: a tramway 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 exists but risks are managed as if they were independent
- Classified in six classes: technical, contractual, financial, PM, stakeholder management, country, with many interactions between groups
- Assigned to 12 different risk owners (RO) : some RO manage more than ten risks, some RO manage several but independent risks

Research question and proposal

- Theoretically:
  - To assist risk mitigation decisions in the context of complex projects
- Proposal of a process
  - Modelling (based on DSM)
  - Assessment
  - Propagation anticipation
  - (Vulnerability analysis)
  - Mitigation
    - Clustering
    - Complexity reduction

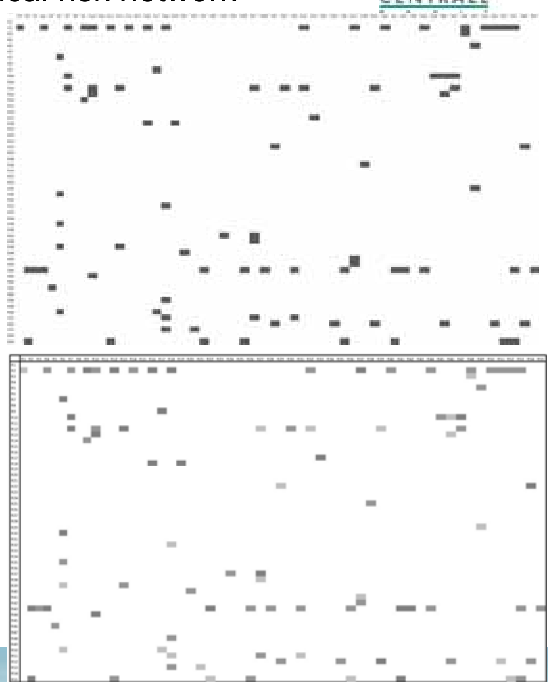
- Complementary to the current risk management process
- Focused on complexity, interactions and propagation

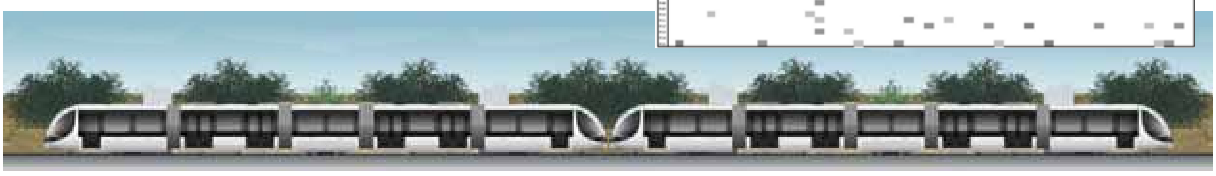
- Practically:
  - To identify new risks / vulnerabilities of the project
  - To assess them in order to update risk ranking and priorities for risk response planning
  - To know what could be worse / better because of phenomena which are not currently modelled
  - To identify innovative and complementary mitigation actions
    - Adapting the organisation to the complexity
    - Reducing the complexity

Modelling of numerical risk network

- Risk Structure Matrix (RSM)
  - Represents potential causality links between risks
  - DSM/DMM/MDM of project objects can facilitate
- From 42 initial risks to 55 with 13 additional risks
  - Existing risks, but not in this list
  - Intermediary risks between existing causes and effects (e.g. civil work delay)

- Risk Numerical Matrix (RNM)
- Methods of assessment by expert judgment:
  - Direct
  - Relative: AHP





Risk propagation model

- Concepts:
  - Transition Probability: evaluated cause-effect probability between risks in RNM
  - Spontaneous Probability: evaluated risk probability by classical methods

- Assumption for calculating propagation:
  - Independence of multiple causes / effects
  - A risk may occur more than one time during the project
  - The structure and values in RNM do not change

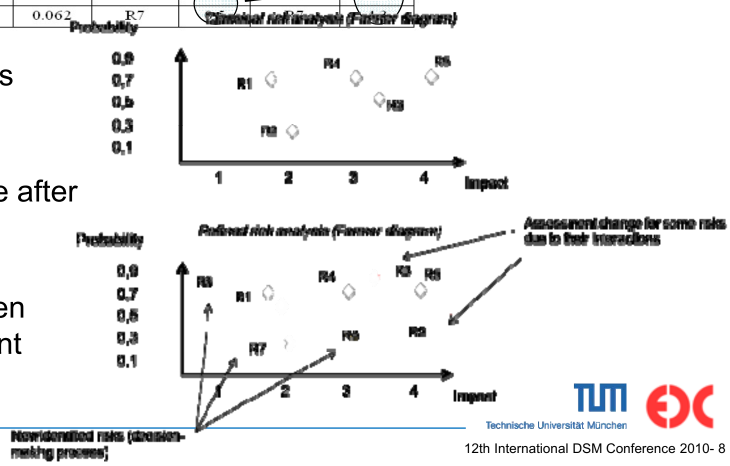
- Models for anticipation propagation phenomena:
  - Simulation (Fang et al. 2009)
  - Mathematical formulation (matrix) (Fang et al. 2010)
  - Bayesian Network
  - Boolean-Driven Markovian Process

Results Analysis

- 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	[illegible]	[illegible]	[illegible]

- Probability of some risks increase since they are triggered by other risks
- Ranking of risks change after taking into account risk interactions
- The relative gap between values becomes different



Results Analysis

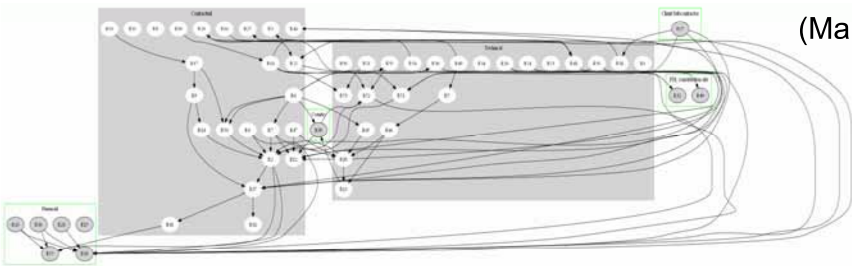
Risk ID	Risk Name	Numerical SP	Risk Frequency
1	Safety studies	0.001	0.001
2	Liquidated damages on intermadiate milestone and delay of Progress Payment Threshold	0.308	1.715
3	Vehicle storage in another city	0.381	0.381
4	Vandalism on site	0.001	0.001
5	Traction/braking function : behaviour in degraded 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

- It classifies risks into three categories:
  - Source risks are mainly local and technical
  - Intermediary risks are mainly technical and delay
  - Accumulation risks are contractual and financial risks
- But this analysis shows which of them are more contributive to final results
- Vulnerability analysis
  - Lack of consideration of impacts of local technical or delay problems of final contractual and financial performance
  - Because organisation has recently changed, it is not yet able to cope it

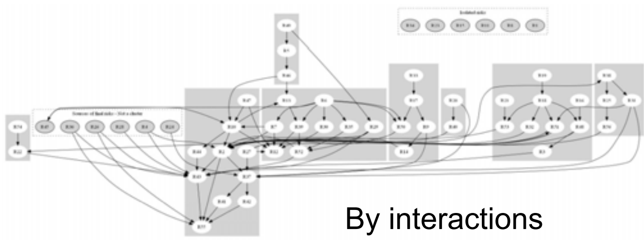
Mitigation actions (1/2)

- Adapting the organisation to the existing complexity

(Marle & Vidal, DSM 2008)



By nature

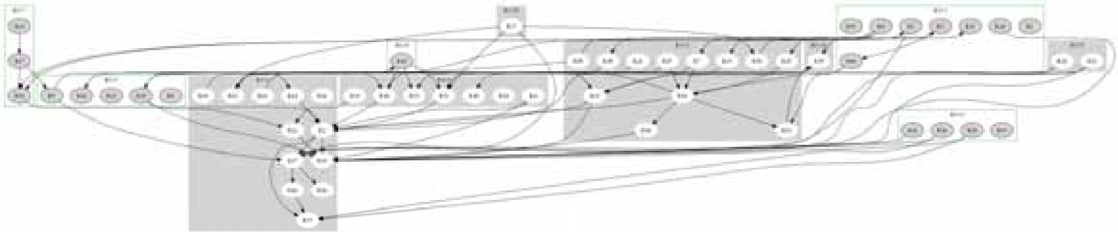


By interactions

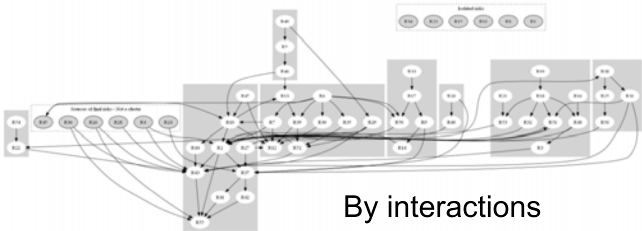
Mitigation actions (1/2)

- Adapting the organisation to the existing complexity

(Marle & Vidal, DSM 2008)



By risk owner



By interactions

Mitigation actions (2/2)

- Reducing the complexity of the network
  - Breaking links
    - Mitigation actions on edges instead of actions on nodes
    - Breaking long chains, loops, undesired amplification chains
    - Confining risks with many consequences, preventing risks with many causes. « Many » in the sense of the global upstream/downstream part of the network, not only on direct causes/effects.
  - Reassigning people
    - Assigning the same owner to several interrelated risks
    - Assigning a more experimented owner to very complex nodes/parts of the network, even if the risk itself is weak
  - Only theoretically, not implemented

Conclusion and perspectives

- Summary of study
  - Modeling of risk interactions thanks to techniques like DSM and AHP
  - Risk propagation model to re-evaluate risks and to identify new phenomena related to complexity
  - Mitigation of the vulnerability due to this complexity
    - Clustering of the organisation to maximise interactions within clusters
    - Reducing the complexity
  - 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
  - Propose (through tests and calculation) an optimised mitigation plan on risks and on interactions
  - Take into account quantitative and qualitative impacts of risks
  - Take into account the possible interdependence between common causes or common effects