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ASSISTING PROJECT RISK MANAGEMENT METHOD SELECTION

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Abstract

Projects have spread into companies and are more than ever exposed to risk, because of tight constraints, uncertainty, complexity and change. Risk management thus plays an important role in project management. Since there are more and more available methods in the literature, it has become increasingly difficult to choose the right one. Our objective in this paper is to introduce and analyze the main existing Project Risk Management (PRM) methods and to provide decision-makers with a model to assist them to select one of these methods for their projects. To do this, we first investigate the existing methods in the PRM field and the criteria that should be considered for the selection. Secondly, we propose a simple Multi Criteria Decision Making (MCDM) model which screens out inadequate methods and ranks remaining alternatives. An application for one example is presented and some conclusions and perspectives are drawn.

Keywords

Risk identification; risk analysis; multi-criteria decision-making; project management; fuzzy numbers; method choice

Biographical notes

Franck MARLE is assistant professor in project management at Ecole Centrale Paris for twelve years. He has a MSc of Ecole Centrale Lyon (1997) and he received his PhD from Ecole Centrale Paris in 2002 about interactions modeling in PSA Peugeot-Citroën internal projects. He is now conducting research works about risk modeling in projects, interactions modeling and assessment, and decision-making in complex and uncertain contexts. He is the author of several papers on project risk management and project complexity management.

Thierry GIDEL is an assistant professor in “Université de Technologie de Compiègne”. He received his PhD degree in industrial engineering from “Ecole Nationale Supérieure d’Arts et Metiers, Art&Metiers PARISTECH”. He is in charge of UTC Innovation Centre development. Before joining “Université de Technologie de Compiègne”, he had worked as a project manager in France, Asia and United Kingdom. His research interests include robust design, multi-project management and innovation process. Thierry Gidel is the author of several papers and books on project risk management and project management.

1. Introduction

Project Risk Management (PRM) has been established as having an important influence on project management, as well as on project success rate (Müller and Turner 2001; Cooke-Davies 2001; PMI 2008). In this paper, our goal is to provide project office managers, project managers or any decision-maker (like risk managers) with a framework and its associated tools to select a PRM method. Project management consists of the planning, organization, monitoring, control and reporting of all the aspects of a project, and in the motivation of all people involved in reaching the project objectives (ISO 2003; IPMA 2006; PMI 2008). Ulrich and Eppinger (1995) show that product development projects are rarely executed as planned. This is partly due to the existence of uncertainty and risk, mainly in the initial phases of the product design, which commonly involve vague, qualitative and insufficient information (Grubisic et al. 2007). The influence that project planning performance has on final project success or project outcome performance has been studied by Farooque and Farooque (2009). In this study, the correct execution of the risk management process is included in the measure of planning performance. Project risk is defined as “an uncertain event or condition that, if it occurs, has a positive or negative effect on at least one of the project objectives” (PMI 2008; AFNOR 2003). If these risks are not managed pro-actively using a structured approach, then they can result in serious consequences for the project, as outlined in ISO 10006 (2003). According to Raz and Hillson (2005), “the origins of operational risk management can be traced to the discipline of safety engineering”. Modern risk management has evolved from this issue of physical harm that may occur as a result of improper equipment or operator performance. Many risk management methodologies and associated tools, whether their approach be qualitative or quantitative, have often been developed based on the concepts of probability and impact (or gravity) of the risk.

However, when looking at company practices, it can be observed that PRM methods are not widely used (Coppendale 1995; Lyons and Skitmore 2004). When a method is implemented on a project, it is often either imposed by a corporate standard or chosen by the project leader, who has tested it before. On the other hand, leading companies and organizations are, of course, implementing various PRM methods. For instance, according to Tumer and co-workers (Tumer et al. 2005; Kurtoglu and Tumer 2007), NASA implements various PRM methods like Failure Modes and Effects Analysis, Fault Tree Analysis, Probabilistic Risk Analysis, which will be detailed in section 2. Typically, only experts in the field are able to take full advantage of a PRM method. The expertise required to choose a method may be extensive because of some advanced concepts employed, such as Markov chains, Monte-Carlo simulation or logical gates. The issue of PRM methods choice becomes even more important when it is applied on a decentralized way, sometimes with local or web-based software, without any technical support, from a project office for instance, or a risk manager or an expert.

The selection of one or several PRM method(s) is generally done without explicit process and according to a precedent that may have become obsolete. To address this issue, we define a Multi-Criteria Decision-Making (MCDM) process which will evaluate, eliminate and rank PRM methods alternatives. The purpose is to assist decision-makers to select one or several PRM methods.

The paper is organized as follows. A literature review of PRM methods (focused on risk identification and analysis) enables us to propose a typology of these methods (section 2) and a list of criteria to select them (section 3). The Section 4 details the characteristics of PRM methods. The decision-making process is introduced in Section 5. A test is introduced on an example (section 6) and some discussions and conclusions are drawn (sections 7 and 8).

2. Background on Project Risk Management (PRM) methods

The Project Management Institute presents project management in nine knowledge areas: integration, scope, time, cost, quality, human resources, communications, procurement and risk management. The PRM purpose is described as “the increase of probability and impact of positive events, and the decrease of probability and impact of negative events” (PMI 2008). Risk management consists of the treatment of project uncertainties through a structured, four-step generic approach:

1. Risk identification describes identifiable risks, that is to say the potential events that could occur and lead to negative or positive impact on the project.
2. Risk analysis analyzes causes and consequences of identified risks, in order to evaluate their criticality, mainly by assessing probability and impact.
3. Risk treatment or response planning makes decisions about tasks, budgets and responsibilities in order to avoid, mitigate or transfer the most critical risks. In some cases, it is also possible to conclude that the project should be cancelled or a new scenario should be proposed (Gidel and Zonghero 2006).
4. Risk monitoring and control regards the follow-up by the corresponding responsible people identified in the previous steps. This follow-up concerns the risks and the execution of planned actions, including the real impact of these actions on the criticality of the risks.

During our literature review, we found many different tools and approaches used for project risk management. What we call PRM method in this paper is a global approach, covering the four generic steps presented above. Numerous standards or specific methods have been introduced for managing project risks, some of which come from other fields such as systems analysis, design, insurance, food industries, information systems, chemical systems, and industrial safety (IEC 1995; AFNOR 2003; AFNOR 1999; Office of Government Commerce 1999; APM 2004; IEEE 2001; BSI 2002; Barlow 2004; IPMA 2006; PMI 2008; Chapman and Ward 2003).

There is sometimes a fine line between product, process and project risk management methods. These three levels of risk are often linked. New approaches tend to integrate technical and project risks (Gonzalez 2000). Though our primary focus in this paper is on project risk management, we also consider product and process risk management methods when they were applicable to project risk management, especially when they allow consideration for cost and time related risks. The main differences between the methods are in the identification and/or analysis steps. Each applies similar principles for establishing, implementing, and following treatment decisions as well as monitoring the evolution of the risks. We make a distinction between Risk Identification Methods (RIM) and Risk Analysis Methods (RAM). Occasionally, the same PRM method permits the execution of both steps (for instance, a cause-and-effect tree allows for both the identification and the analysis of the risks and their relationships), sometimes it is by using two separate RIM and RAM (for instance, a check-list for identification, then a brainstorming for analysis).

We propose a presentation of the methods according to a typology based on the level of experience (Table 1): analogical (high level of experience), heuristic (mix of experience and creativity) and analytical (low level of experience). It must be noted that even if one method is introduced in only one paragraph for convenience of reading, it may be applied in other contexts. For instance, a method introduced in the analytical subsection may be used with experience, like an analogical method. If it can be applied without experience, it is still better to apply it with experience. The distinction is between capitalized experience for the company and non-formalized experience of an expert.

Some methods use both types of experience at the same time (experts using check-lists), but in certain cases we may have found young engineers using check-lists without deep expertise, or we may have found experts working on a completely new situation with an innovative context not allowing the reuse a previous similar experience.

Table 1: classification of PRM methods according to their approach to risk identification

We introduce in the following paragraphs the classical PRM methods according to their type (analogical, heuristic, and analytical).

2.1. The analogical methods

The analogous comparison consists in investigating what happened in previous similar projects in order to identify possible risks in the current project. To do this, records of changes and problems in past projects can be useful. Analogical methods are presented below according to their degree of generality.

First, there are generic methods, such as checklists and Bayesian networks, usually created in the context of other domains. Checklists may be based on previous projects with items indicating potential risks to be validated or screened out (Riek 2001; Smith and Merritt 2002). Checklists can also be seen as a method of risk categorization. They provide a structure that guarantees systematic risk identification for each category, e.g. business, external, technical and legal. A Bayesian network or Bayesian belief network is a probabilistic graphical model that represents a set of variables and their conditional dependences via a directed acyclic graph. Nodes represent variables in the Bayesian sense and edges represent conditional dependencies. It is then possible to infer the probability of a potential consequence, a risk, knowing the conditional probabilities of the causes. A risk assessment can be done using Bayesian network (Fenton and Neil 2004; Neil et al. 2005; Grubisic and Ogliari 2009), particularly in the project management field (Lee et al. 2008; Fang and Yu 2004). As with every probabilistic assessment method, Bayesian networks are more efficient if previous experiences are available to give information about some data, whether it be about the nodes or about the edges. But, algorithms exist that perform inference and learning in order to build or to update networks using posterior data (Pearl 1988).

Second, there are several methods which are focused on more specific design-related aspects, like the product, the manufacturing process or the design process. Tumer and Stone (2001) have presented a mathematical mapping that links a product's functional model to potential failures, the function-failure design method (FFDM). According to them, "a product functional modeling is a key step in the product design process. Functional modeling begins by formulating the overall product function. By breaking the overall function of the device into small, easily solved sub-functions, the form of the device follows from the assembly of all sub-function solutions." A product functional model is the result of this process. Tumer and Stone propose a method to help product design projects based on product risk analysis (Stone et al. 2004). In this method, possible failures of a component or a task are supposed to be known *a priori*. Risk identification consists of identifying the link between an already known failure and a function using the component or a task of the project.

As this method is using an existing failure corpus, it is not applicable in the case of new product development within a new domain. On their side, Grubisic et al. (2007; 2009) propose a risk base with typical technical risks related to the main product design activities. Finally, Monte Carlo methods are useful for modeling phenomena with significant uncertainty in inputs, such as the calculation of duration or cost of the process (project schedule). They rely on repeated random sampling to compute their results, which means they must have access to experience for the possible values of the inputs (Metropolis and Ulam 1949).

These methods are based on past experience. Therefore, their applicability could be limited in case of radical innovation projects.

2.2. The methods based on heuristics

These methods mainly use expert creativity, sometimes with a mix of experience and expertise. Experts may have experience with an aspect of the project, and they have to mix data which come from previous experience and data which are completely new. Heuristic-based methods are presented in the following paragraphs according to the way they are carried out. The expert judgment may be asked individually or in group. Interviews and meetings may be structured, semi-structured or completely based on creativity.

First, Delphi is perhaps the best-known method of using group evaluations in forecasting. This is a method for the systematic collection and collation of evaluations from isolated anonymous respondents on a particular topic, through a set of carefully designed sequential questionnaires. The participants are asked individually, usually in the form of mailed questionnaires, about the risks associated with a particular project. These are then collated and summarized in such a way as to conceal the origin of the individual's opinion. The results are then circulated and the participants are asked if they wish to revise their earlier forecasts. These rounds can continue until the estimates stabilize (Kerzner 1998; Chapman 2001).

Second, additional methods for risk categorization include the breakdown of risks into sub-categories, called Risk Breakdown Structure (RBS) by the PMI, the semi-structured interview technique and the Risk Analytical Structure (RAS) (Kerzner 1998). The semi-structured one-to-one interview is an interactive dialogue aid for eliciting risks directly from the interviewee (Chapman 2001). The questionnaire used as a support deals with traditional risk areas in a project, such as, project team, customers, and technology. The RAS and RBS list the categories and subcategories in which the risks can appear in a typical project. Keizer and co-workers developed the Risk Diagnosing Methodology (RDM) since 1991 (Keizer, et al. 2002). This method allows for risk identification and management in innovative projects in various domains. It is based on semi-structured interviews and questionnaires together with a global approach for the implementation of the method and the follow-up of risks.

Third, brainstorming and working group methods lead by a moderator, such as KJ (developed by Kawakita Jiro), also known as Affinity Diagram, are also well known techniques based on group creativity (Kawakita 1991; Shiba 1991). The affinity diagram facilitates organizing ideas and data coming from a group of people using a method based on post-it notes. In the context of risk identification, it allows large numbers of risks stemming from brainstorming to be sorted into groups for review and analysis.

Whatever the approach, in heuristic based methods, the implication of the core design team and the contributions of the moderator are key factors for an effective risk identification (Chapman 2001).

2.3. The analytical methods

These methods are mainly based on systematic analysis of the project activities. By analyzing potential failures on project tasks, project resources or project results, it is possible to identify numerous risks. These methods are presented in the following paragraphs using their level of cause-effect identification (direct impact only or identification of several levels of propagation) and the point they focus on, which may be related to the project objectives (cost, time, etc.) or to the project results (the product itself and how the project failure could impact the product failure in the next steps of its lifecycle). Recall that there is a fine line between product, process and project risk management in new product development. First, most of the project risk management methods are based on product or process risk management approaches, especially the analytical ones. Second, studies show that about 80% of companies use a combination of product, process and project risk management methods (Verdoux 2006). Our position is that product and process risk are one type of project risk that needs to be tackled by project manager. Although we recognize that there are important risks related to other factors, based on our experience and on the project manager interviews, we would argue that in new product design, risks also do come from the product itself.

First, one of the most frequently employed methods in the industry nowadays is FMEA, or FMECA which means Failure Modes, Effects and Criticality Analysis (MIL-STD-1629 1998). The classical version of this tool consists for looking for eventual failure modes for each function of a product. It has been adapted to process failure analysis and then again to project failure analysis. Its goal is to evaluate the criticality of failures by providing a classification of risks. To identify product-related risks, the FMEA methods suggests to first identify the function and then study the potential failure of the function (Bowles 1998; Kmenta et al. 1999; Teoh and Case 2004). Designers can start at the component, system or product level. Similarly, to identify project-related risks, the project FMEA identifies the objectives and their potential failures, starting at the task, phase or project level. Shimizu and co-workers developed the Design Review Based on Failure Mode (DRBFM), an improvement of the FMEA which focuses on best practices to be used when modifications are done to an existing product (Shimizu and Noguchi 2005). One of the main points of the DRBFM is the (function x change point) matrix. It permits the identification of which function is impacted when modifications are done on a product. Gautier presents the Project Information Failure Analysis (PIFA) method (Gautier et al. 1997). The method applies FMECA on the activity of product design. The project is modeled using information processors (information input, treatment and transmission), which enables a risk failure analysis of these processors.

Second, the Probabilistic Risk Analysis (PRA) is a systematic and comprehensive method (Henley and Kumamoto 1992; Kumamoto and Henley 1996; Stamatelatos 2004; Shimizu and Noguchi 2005; Lee et al. 2007). It consists of measuring the variations of performance levels with respect to the uncertainties that the product suffered. Stamatelatos (2004) presents the use of the techniques of PRA at NASA in the design process (risk of not reaching the desired levels of performance), in upgrading and decommissioning operations. In PRA, the main risks are when the mission is lost, failed, crashed, etc. To link the top level (mission objectives) and the components, the PRA proposes to use the Master Logic Diagram (MLD). MLD is a hierarchical model which identifies the links from top system objectives to functions and components. In this method, risk identification is mainly based on creativity techniques. In some cases, it could be based on functional requirements. In any case, it does not take into account the interdependence between risks. These methods are based on knowledge about product and usage scenarios (of the technological solutions) to identify potential failures.

Third, another example is the Fault Tree Analysis (FTA) which focuses on a root failure and identifies the combination of reasons that caused this failure. It uses deductive reasoning (or backward logic) to find the causes. Pahl and Beitz (2007) present a “fault tree analysis” based on Boolean algebra (function AND, function OR) which includes causes and effects to estimate failures. The method proposes a negative formulation of the product function. It is an original approach for risk identification because of the fact that the negative function should be unfulfilled. In the same spirit, the Anticipatory Failure Determination (AFD) based on TRIZ begins with an observed failure (as in FTA) and tries to find another solution by changing the point of view (Kaplan et al. 1999; Haimes et al. 2002). It starts from the question “what can go wrong” to “how to make it happen”. The Event Tree Analysis (ETA) starts from the undesired event and tries to find all possible scenarios which could happen after the event.

Fourth, Klein and Cork (1998) presented a Technical Risk Assessment Methodology (TRAM), based on product decomposition. The method is dedicated to complex technical systems such as aircraft or computer. It enables the deduction of project risks from possible product failures, including local or more complex failures. The Functional Failure Identification and Propagation (FFIP) “estimates potential faults and their propagation under critical event scenarios using behavioral simulation” (Kurtoglu and Tumer 2007). This approach consists of a functional decomposition of the overall system into several sub-functions, which can then be decomposed again. According to the author, this method helps in to choose the functional concept in the early phases of a project, at conceptual design stage.

Finally, the methods based on an analytical approach, mainly decomposition, are adapted to risk assessment of complex system development projects. They require specific skills and a computer implementation in order to manipulate a great deal of data of different nature.

3. Building a list of selection criteria

As there are numerous PRM methods, it is hard for a decision-maker who is involved at the project level or at the multi-project level to select the most suitable one for his particular context. Two main reasons explain this difficulty: the difficulty to catch the context and the difficulty to have a deep enough expertise in all the methods. We propose twelve criteria that could be used to choose a PRM method: 4 of them are related to the organization and the 8 remaining criteria are related to the methods (Table 2).

Since the first four criteria are related to the organization, this means that the organization has to meet certain minimum levels on these criteria. Otherwise, it would be risky for the company to implement such a method if it is not mature enough. These criteria are specifically measured for each organization (or part of the organization if several parts run different types of projects or with different standards) and are compared to a type of method (analogical, heuristics, analytic). Organizational maturity is based on self evaluation. Details in Table 2 show that the maturity levels depend on availability of formalized processes, performance indicators, etc.

The eight last criteria are about several characteristics of the methods. For instance, the *specificity* of the method, i.e. its capacity to be implemented in domains other than the one where it had been developed, has been initially removed by several interviewees.

But after discussion about the differences between risk identification and risk analysis, they decided to keep it as a selection criterion for analysis and not for identification. On the contrary, the *number of characteristics* was initially proposed for both and was removed for analysis.

These criteria have been deducted from a literature review. We proposed the levels in terms of definition and number. In most cases, three levels were enough to clearly discriminate where a method is located on the scale. In two cases only, five levels were defined, since it was possible to be more precise, and then to distinguish more precisely where an organization is and where it should be at least to use such method (the minimum maturity threshold associated to each method). Also, the classical maturity models are all defined with five levels, and we preferred to remain consistent with that.

Then, the list has been validated through experts' interviews, following the process of a classical Delphi study. Though the principles were identical, the panel of experts did not follow exactly the recommendations of a Delphi study. This process of adaptation of the list to the specific requirements and context of the organization enables the removal, the renaming or the addition of some of the criteria. Four experts have given assistance to the validation of our model (including the lists of methods, of criteria and the definition of their levels). Experts were mostly people involved in the risk management area, like risk manager, knowledge manager or technical expert (closer from product-related risks). Finally, the criteria which are considered here in PRM selection are listed below in table 2, with details about their assessment scales.

Table 2: list of selection criteria

3.1. The organization-related family

Some organizations may be very mature from a technical point of view but underdeveloped from a project management point of view. This will result in poor project performances because even though the final product will be good, the project will experience problems with cost and time parameters. Reciprocally, a company which is mature in how it runs projects but not mature in its product development processes, typically caused by the use of a new technology, a new process, or new partners, may have wastes and failures in its projects independent of its maturity in project management. The two are interdependent and should not be separated. Four criteria are identified: product development maturity, project management maturity, risk management maturity and product innovation level. Two are related to the nature of the project, and two are generic. These criteria will be used as a filter to screen out methods which are not adequate to organization's maturity. This is mandatory, since it would be counterproductive to implement a method in an organization which is not able to receive it. That means that the organization will have to meet certain minimum levels on these four criteria.

Skelton and Thamhain (2003) made a two-year field study into technology-based product developments in order to examine risk management approaches. They pointed out that "managers must foster a work environment where people can deal with the uncertainties, ambiguities, and organizational imperfections". He also pointed out that "to be effective as risk managers, project team leaders must be capable of more than understanding the tools and techniques of enterprise risk management. They must also understand the infrastructure of their organization and deal with the complex social, technical and economic issues that determine the culture and value system of the

enterprise.” The work of Ward suggests that the successful implementation of risk management is higher when the method is adapted to the structural and cultural characteristics of the company (Ward et al. 1991). It is to be noted that, with regards to risk management methods, there is a strong link between some methods and particular industries. For instance, HAZOP is mainly used in chemical industries. This method is therefore suited to safety critical industries, which already have awareness and expertise available in risk management. Uher and Toakley (1999), presenting the results of a study on the use of project risk management in construction industry, stated that “individuals in the surveyed organizations were more willing to embrace change than their organizations. The main barrier to change appears to be a low knowledge and skill base, caused by a lack of commitment to training (...)”. Andersen and Jessen (2003), following Hofstede (1982), state that attitude towards risk and uncertainty avoidance is one of the main cultural dimensions: “positive attitudes towards risk and uncertainty [...] are taken as indications of mental willingness to undertake project work”. For instance, even when a project applies recognized risk management processes and seems to be managing its risks well, research demonstrates that internally generated risks are managed on a different matter altogether (Barber 2005). The perception of risks, and then their consideration and their treatment actions, is dependent of who analyses it and of who it may impact. Two risks with the same parameters of probability and gravity will not be considered as identical if one is internal and the other one is external. The capacity to influence or to keep under control a risk because it is in our influence sphere is a parameter that changes the perception of a risk.

In order to evaluate the context, maturity models are increasingly used (Fraser et al. 2002). It is a quite flexible tool as maturity assessments can be performed by self-assessment or by an external audit. Based on the literature review, project management and product development maturity level seem to be a relevant criterion for the choice of PRM methods. Not only because it helps to evaluate the attitude towards risk, but also because the maturity level takes into account the available tools, databases and competences in the company. All of these characteristics involve some differences between theoretical recommendations and reality of use and practice (Elkington and Smallman 2002; Lyons and Skitmore 2004):

- Risk identification and risk assessment are the most often used risk management processes,
- Qualitative methods of risk assessment are used most frequently,
- Risk reduction is the most frequently used response strategy,
- Project teams are the most frequent groups used for risk analysis, ahead of in-house specialists and consultants.

Other results show that because of environment-related and decision maker-related conditions, some project managers may tend to deny, avoid, ignore and delay dealing with risk (Kutsch and Hall 2005). The gap between expected and real risk management implementation is significant, and is related to be difficult to implement theory into practice as related to negative perception of risk management, independently of the pertinence or difficulties of the theory. This justifies the work done for proposing to users a more adequate PRM method, in hoping that it will be used and correctly used.

3.2. The method-related family

Eight criteria are identified about methods: Simplicity of use, Interactions considerations, Completeness, Number of risk characteristics, Types of data, Graphical display, Specificity and Notoriety of the method.

Cooper states that “a key challenge faced by new product development projects is how to acquire knowledge and manage sources of uncertainty in order to reduce the risk of failure of either the project or the resulting product. Under ideal conditions, the project would be able to identify all unknowns and to implement a risk management program to systematically address them.” (Cooper 2003). This highlights the question of the *completeness* of the identification. Cooper stresses the fact that methods and tools used to tackle these problems should not generate more risks than they solve. He points three aspects that should be taken into account when introducing a new tool:

- tools should not interrupt the natural flow of activities,
- tools should not substantially change the roles of team members,
- tools should take into account the context.

PRM methods focus on different kinds of risks (Conroy and Soltan 1998; Browning et al. 2002; Deyst 2002; Pahl et al. 2007; Lough et al. 2009) and different kinds of projects (Coppendale 1995; Bearden 2003; Lyons and Skitmore 2004; Esterman and Ishii 2005). Therefore, some PRM methods are applicable to a particular type of project (innovation or construction projects for instance), or to a particular type of risk (investment decision, planning uncertainty, cost risk, schedule risk, quality risk,...). These parameters are summarized in a criterion called *specificity*. That means that the method can only be applied in particular contexts.

Due to the complexity of the project, related to several factors, such as size, diversity, context and presence of interdependencies between its components, many potential interactions exist between risks. For instance, there might be propagation from one “upstream” technical risk to numerous “downstream” non-technical risks; on the other side, a “downstream” cost risk may arise from the occurrence of several “upstream” risks which may belong to different categories. The extreme case of this propagation behavior is the chain reaction phenomenon or the “domino effect”. Another phenomenon is the loop, which is a causal path that leads from the initial occurrence of an event to the triggering of subsequent consequences until the initial event occurs once more. These interactions can have influence on the behavior and so the performance of the project, including its outcomes, and should then be considered when making decisions. Even if some works have been done in order to model interdependencies between risks (Heal and Kunreuther 2007; Marle and Vidal 2009; Marle and Vidal 2010), there is still a gap between what results from methods and what is the real complexity of risk interactions. The risks are mainly analyzed and managed as if they were independent. Methods that do not permit the management of risk interactions have clearly an impact on the reliability of final decisions, i.e., risk response plan. This justifies the introduction of a criterion related to the *consideration of interactions* between risks by the considered methods.

The nature and the number of data are also key parameters of the project risks description: are they quantitative, mainly based on experience, qualitative or even fuzzy? Is there only the classical information about probability and gravity which are included, or is there some complementary information? Some data are not managed in every project (for instance detection ability, influence capacity), so the *number of risk characteristics* used in each method is also a criterion. In the same project, it is often a mix between different types of data. So, if a method does not permit the management of these *types of data*, then it has an influence on the final decisions. For instance, the concept of probability is subject to some requirements that the project does not fulfill (Pender 2001), such as the knowledge of future potential states, the rationality, randomness and repetitiveness of phenomena. It is then often difficult to estimate reliable probabilities, and it is necessary to give estimates on a qualitative scale. Even the impact is difficult to assess, because multiple domains are

considered, with often non comparable scales. For some scales, like human aspects or quality, the impact is not easily measurable (Cox et al. 2005).

Depending on the skills and experience of people in risk management, the decision-maker may want to implement a very simple method. On the contrary, he may also prefer a more sophisticated method, even if it has some theoretical pre-requisites. We introduce thus the *simplicity* criterion. When two methods have similar characteristics, the method which is best known can be better accepted and implemented. This criterion of *notoriety* is mainly subjective, but it has to be taken into account for real-life implementation. Finally, some methods do have a *graphical display* which enables easier reporting and decision-making, like all cause-effect trees, Bayesian Networks (Fan and Yu 2004; Lee et al. 2008) or vulnerability graphs (Holmgren 2006). It may also be a preference for the decision-maker to choose a method which includes easy-to-do and easy-to-understand graphs.

4. Evaluation of the methods on the criteria

We propose hereafter the lists of RIM and RAM that will be potential alternatives for the final choice with their evaluations (Tables 3a and 3b). The columns concerning the type (analogical, heuristic and analytic) are binary and a method may be used in one or more contexts. The columns about the criteria are assessments of the methods using the three level scales described in table 2.

Table 3a: list of Risk Identification Methods (RIM)

For instance, the RIM 3 “Scenario analysis” may be used in different contexts, with the inclusion or exclusion of previous experiences or the inclusion or exclusion of creativity, which enables a mix of strategies to fill a single document. Moreover, it is evaluated among criteria relevant for identification, namely C_5 to C_8 . It is noticeable that RIM3 has average evaluations on all criteria. That will mean that it has less chance of being screened out, but less chance of being ranked first. In contrast, the RIM 12 “Master Logic Block Diagram” is specifically designed for analytical identification, and has extreme values (whether minimum 1 or maximum 3). This means that it has a greater chance of being screened out, and if it survives, perhaps more chances to be well ranked.

Table 3b: list of Risk Analysis Methods (RAM)

The same type of information is available in Table 3b, except that the criteria are not the same. Criteria C_5 and C_6 are common with identification (Table 3a), criteria C_9 to C_{12} are specific to risk analysis. It is the objective of the next part to study which multi-criteria decision-making process will be used with these criteria and these PRM methods.

5. Development of a multi-criteria decision-making process for Project Risk Management method choice

Classical MCDM (Multi Criteria Decision Making) methods suggest conducting an evaluation of some alternatives regarding some criteria, by using qualitative or quantitative scales, crisp or fuzzy values, and direct or comparison-based evaluations. Our objective in this paper is to propose one or

more adequate PRM methods to the decision-maker, which is contingent upon the combination of screening and ranking. The different PRM methods introduced in previous section are potential candidates for the organization. Some evaluations are based on facts and are quantitative, and some are based on human judgment and are qualitative or even fuzzy. We decide to use in our approach a combination of screening and ranking, and a combination of qualitative and fuzzy evaluations. Indeed, preferences are often uncertain and expressed by linguistic terms, such as “good”, “very much”, “I prefer”, which may require the use of fuzzy set theory.

The selection process is in three steps, which consists of gathering and treating data about methods, criteria and organization (see figure 1):

- Step 1: A selection of the RIM/RAM which correspond to organization-related criteria.
- Step 2: A selection and ranking of the RIM/RAM which correspond to method-related criteria,
- Step 3: The final selection, which is a combination of a RIM and a RAM which are compatible and consistent.

The output of these three steps is the selection decision, followed by the implementation (figure 1).

Decision-makers may be involved in the project management area, like project manager or project director or project office manager. They use the model previously validated by experts (not the same persons). The challenge is that they need to have enough high-level management roles in order to be able to give a global opinion about the organization. They only express preferences about the criteria of the second type, method-related criteria. Namely, they do not express preferences for the first family, organization-related criteria, since this is the assessment of the organization which automatically implies to screen out or not some methods.

Figure 1: description of the decision-making process by screening and ranking

5.1. Step 1 : first selection of RIM/RAM regarding organizational maturity

This step is detailed for RIM; the same principles are applied for RAM. Only the terms and the values change. It can be expressed as step 1a and step 1b, where step 1a is detailed below for RIM and step 1b is identical for RAM.

The four criteria related to organizational maturity are used in this step (C1 to C4). For each of these criteria, it asks the decision-maker to assess her company, in order to get evaluations called OM_j for Organization Maturity for the j^{th} criteria.

As seen in part 2, three types of RIM do exist: analogical, heuristic and analytic. They are called T_k , $k=1$ to 3. For each type T_k , a minimal maturity is mandatory in order to be able to correctly implement a method of this type. A threshold is defined for each type T_k and each criterion C_j , called MT_{jk} (for Maturity Threshold). We proposed these thresholds according to our expertise and experience. We have the following constraint:

For each $k \in [1..3]$, if there is $j \in [1..4]$ such as $OM_j < MT_{jk}$, then the type T_k is not adequate for the company and is screened out.

Then, we evaluate whether the RIM_i belong or not to each type T_k . This binary matrix presented in part 2 allows us to know whether each RIM_i can be applied or not regarding company maturity. There are two possibilities:

- RIM_i belongs to only one T_k : if T_k is screened out, then RIM_i is screened out
- RIM_i belongs to more than one T_k (2 or 3) : if one T_k is not screened out, then RIM_i is not screened out. That means, that even if RIM_i cannot be applied in a certain way (analytic for instance), it can be applied in another way (analogical for instance).

From the initial list of RIM , this step gives a shorter list of potential candidates for next step.

5.2. Step 2 : selection and ranking of RIM/RAM regarding method-related criteria

This step is detailed for RIM ; the same principles are applied for RAM . Only the terms and the values change. It can be expressed as step 2a and step 2b, where step 2a is detailed below for RIM and step 2b is identical for RAM .

The goal of this step 2a is to study the fitness of the remaining RIM alternatives to method-related criteria. These criteria are expressed with a weight and a minimal threshold, respectively referred to as RIw_j and $RImt_j$. The decision-makers propose these weights and minimum thresholds on method-related criteria. We then have to evaluate each RIM_i among each C_j , known as E_{ij} , and give a global evaluation E_i :

$$E_i = E(RIM_i) = \prod_j E_{ij}^{RIw_j}$$

With the constraint: RIM_i is screened out ($RIM_i=0$) iff there exists j such as $E_{ij} < RImt_j$

We reformulate the constraint as following:

$$E_{ij} \in [1..5] \text{ except if } E_{ij} < RImt_j \text{ where } E_{ij}=0$$

The specificity of this evaluation is the use of fuzzy weights. They are expressed on a fuzzy scale which transforms linguistic preference judgments into numerical intervals on a scale [1..10]. Six levels are introduced in a linguistic scale: “Negligible”, “Very Low”, “Low”, “Average”, “High” and “Very High”. Each level represents the importance of the criterion and is expressed with a fuzzy number. A defuzzification formula is applied in order to obtain a final global score for each method, using the center of gravity approach. Methods are then ranked according to their global score. This step allows for screening out methods which do not correspond to requirements, and then the remaining methods are ranked in order to make the final choice.

6. Application on an example

An application of the selection process was carried out within a company which delivers tramway system and infrastructure for cities. The company has historically focused on product development and has recently extended its scope by delivering both the product and its environment to a city, that is to say the civil engineering, the signaling material, the maintenance and storage depots, etc. As this type of project was new for the company, the question of Project Risk Management method selection was

considered appropriate, as risk management for product development project is not the same for other areas such as civil work. The company had not been able to capture lessons learned from its past projects, whether relative to construction management practices or to technical and design-related construction practices, which is a key issue in risk management, in order to avoid the same mistakes (Arditi et al. 2010). Moreover, the contract with the city included financial incentives. They may have different roles which are sources of extrinsic motivation, symbols of trust and efficiency and generators of communication processes, as shown by (Kadefors and Badenfelt 2009). In this case, the context is very limiting, with a tight schedule and high penalties in case of delays; these are a source of negative risks and additional pressure.

The first action consisted of interviewing a person accountable for PRM method choice. The decision-maker was involved in several running projects. It was not a decision-maker from a project office. There was in this application no question about standardization of the method to all projects of this type. The goal was only to test which risk identification and analysis methods could best fit to these five specific projects. The smallest project had a 5 year timescale and a budget of 200 M€. This interview gave us information about the maturity and the preferences of the company, respectively OM_j , RIW_j , RI_{mt_j} , RAW_j and RA_{mt_j} . We obtained the following results.

6.1. Step 1 : first selection of RIM/RAM regarding the organization's maturity

Due to the team maturity level in risk management and due to the innovative level of the product, it was difficult for the company to implement analytic methods (see Table 4).

Table 4: adequacy of each type of PRM method to the company's maturity

The column Organizational Maturity has to be compared to each minimum maturity threshold for the three types of methods, for each criterion. For instance, the organization has a maturity of 2 in Team maturity. Since analytic type requires 3, the organization is not mature enough for this kind of methods. It is suitable to use heuristics or even more comfortable to use analogical methods. This criterion makes a difference and some methods are filtered. On the opposite, the criterion Product design maturity is very high in the organization (4), and thus does not permit to screen out some methods.

RIM and RAM which were only analytic were therefore screened out : RIM 4 to RIM 8, RIM 10, RIM 12 to RIM 19, RIM 21 and RIM 22, RAM 1, RAM 4 to RAM 6, RAM 10, RAM 17. 15 RIM remain on the 32 initial ones and 13 RAM remain on the 19 initial ones. The selection ratio of step 1 is far different between RIM (47%) and RAM (68%).

6.2. Step 2 : selection and ranking of RIM/RAM regarding method-related criteria

The decision-maker expressed preferences in terms of weights with the fuzzy scale described in section 5.2. He also expressed minimum thresholds, the value 1 meaning that there was no minimum threshold. The Table 5 below shows the preferences expressed by the decision-maker.

Table 5: synthesis of preferences of the decision-maker

Each method was compared to the minimum threshold required for each criterion. The methods assessed with a strictly lower value in table 3a (for RIM) or 3b (for RAM) have been screened out. Depending on the ambition of the decision-maker and of the combination of requirements, more or less methods will be filtered. It may even be possible to screen out all the methods at this step, but then the weights can be used to relax a constraint on the less important criterion, until the feasibility space becomes non null.

This step enabled the decision maker to screen out many methods: RIM 1, RIM 2, RIM 9, RIM 11, RIM 23, RIM 24, RIM 26, RIM 28, RIM 30 to 32, RAM 2, RAM 11, RAM 13, RAM 14, RAM 16 and RAM 19. For the final ranking, only 5 RIM and 7 RAM were still candidates.

6.3. Step 3 : the final choice of a combination of a RIM and RAM

The final ranking in this case is given below in table 6. A score is calculated for the 11 remaining methods (5 RIM and 6 RAM) and they are sorted according to decreasing value.

Table 6: synthesis of the results in terms of scores and rankings

In the first place, the results show that the *cause and effect modeling* is an important parameter of the choice, since it explicitly appears in 2 RIM (RIM 20 and RIM 3) and in 5 RAM (RAM 3, RAM 12, RAM 7, RAM 8 and RAM 15). Secondly, the use of *previous experience* is recommended, since RIM 29, RAM 9 and RAM 18 (which are strongly related since RAM 18 is a refinement of RAM 9) use historical data. The difference in Monte-Carlo simulation is to model uncertainty by including different possible data, but it can also be based on previous projects, namely to get an optimistic, pessimistic and realistic values.

The final choice was to combine the *interactions* aspect and the *experience* aspect by using:

1- Ishikawa for risk identification, based on previous experience to build some parts of the diagram, and then to complete it mainly by creativity.

2- Fault tree analysis, which is also based on cause and effect modeling. It allows the inclusion qualitative or quantitative data, depending on the level of confidence, which is related to the level of experience.

Both methods are very compatible and do not require many theoretical pre-requisites or specific computational skills, which would not have been the same for Bayesian Network or Monte-Carlo

implementation. The choice was also to keep it simple and to begin to implement in the culture of the organization the notion of cause and effect interaction.

6.4. Managerial insights

The growing complexity of projects involves a huge number of cause-effect relationships between parameters, resources and events. These relationships can cause unwanted surprises like chain reactions or loops, which are quite impossible to detect in the current situation. The current PRM method implemented in the organization was a simple list of risks with probability and gravity assessment (combination of RIM 8 and RAM 2). It is mainly based on independent analysis and treatment of risks. The decision-maker noticed the gap between his preferences, which involve the choice of interactions-based methods, and the current implemented method. He was truly confident that the proposed ranking corresponds to his inputs and to the organizational needs (for this type of project). In particular, the fact that the current methods are eliminated in our approach was initially a surprise, but it was accepted because accompanying explanations were clear. He was also surprised by the number of methods which were eliminated by his requirements of minimum thresholds.

Even if the decision-maker agreed with the methodological recommendation, he predicted a tough change from the current situation to the desired one. Namely, the methods in themselves are not difficult to implement, but the team maturity in risk management is very low. Difficulties in understanding the benefit of including cause-effect relationships between risks inside the global process can ensue.

The decision-making process took 1 hour to introduce the approach and the criteria, and to assess company's maturity and preferences. Then, the scoring of the methods is done instantaneously and the results can be analyzed immediately.

7. Discussion

The list of methods is quite representative of what exists in literature and what is really applied in companies. It should be noted here that several methods can exist with different names but similar principles. We have always kept the name of the most known and widespread version.

The pertinence of the criteria list has been tested by studying and analyzing the characteristics of the methods in the literature and by validating it with local experts of the considered organization. When authors presented a new PRM method, they usually did not clearly specify the application domain of their methods. So when it was not explicitly specified by the author(s), we identified the criteria based on the case study presented.

Finally, the implementation effort (time and resources dedicated to PRM, including cultural and organizational changes) is an important parameter of the decision. Tight schedules and limited budgets are unavoidable constraints in a project. This fact has to be taken into account when choosing the right method. Generally speaking, as stated by Coppendale, "successful risk management technique must be simple to understand and apply" (Coppendale 1995). Many authors justify the introduction of new methods because they are cost effective and practical (Bearden 2003; Lee et al. 2007). Under constrained budgets and rigid schedules, efficient risk management methods are therefore a way to improve design efficiency, and this parameter could be included in the multicriteria evaluation.

Nevertheless, it requires additional information not only on the method, but on the couple (method, organization) which is not immediately available.

8. Conclusion

This study points out that there are many methods for risk identification and risk analysis. In this paper, we propose an approach to help selecting the right project risk management method(s) considering twelve criteria. The proposal is a three-step decision-making process, where the first step screens out methods which are too ambitious compared to the organizational maturity, the second one screens out and ranks remaining methods according to decision-makers' preferences, and the third one refines this choice in order to propose a consistent combination of one RIM and one RAM.

We argue that this decision-making process has an added value for the Project Risk Management process of the company, as well as for the global project management process. Namely, a more suitable RIM/RAM will enable a reduction of the impact of risks and of the probability of these risks occurring. So, both the success rate and performance level of projects could be improved.

The requirements of implementation of this model are quite reasonable, since only several man-hours are required. In terms of competence, the use of the model is quite intuitive, since the data are always expressed with qualitative, linguistic variables. The treatment of the data and the use of fuzzy numbers or a weighted geometric average score is transparent (invisible for the user). This is more complicated for experts who validate and eventually customize the model to their organization.

One further development could be to use this decision-making process as a functional requirement definition of a good RIM/RAM, and then to develop a specific and more suitable method. This method could be built by compilation of existing methods (the most frequent) or by specific development. Finally, we think that this study will increase managerial awareness of all available PRM methods, and that it will lead them to consider their selection as a strategic decision that could have an impact on the project success.

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Table 1: classification of PRM methods according their approach to risk identification.

Type	Description	Example
Analogical approach	The analogous comparison consists in investigating what happened in similar previous projects in order to identify possible risks in the current project. For this, information regarding registered changes and problems which occurred in passed projects, along with customer satisfaction information, can be useful.	Checklists of risks originating from previous projects are emblematic of this category.
Heuristic approach	The methods based on heuristics mainly use expert creativity, sometimes with a mix of experience and expertise. Experts may have experience with a part of the project, and they have to mix in not only their risk identification and risk analysis data which come from previous experience but also data that are completely new.	Brainstorming techniques help to obtain a wide list of the project risks.
Analytical approach	The analytic methods are mainly based on systematic analysis of the project activities. By analyzing potential failures on project tasks or project resources or project results, it is possible to identify a great number of risks.	In FMEA (Failure Modes and Effects Analysis) techniques, tasks or phases are systematically analyzed.

Table 2: list of selection criteria

#	Criterion	Family	Type of PRM method	Level 1	Level 2	Level 3	Level 4	Level 5
C1	Product design maturity	Organization's maturity	RIM and RAM	Definition of requirements in a non systematic way, definition of a product sketch, structures and drawings. Use of CAD, product requirements, analysis of life cycle analysis, process macro planning, talks with suppliers. Adoption of simple approval of phases (gates).	Use of functional modeling, definition of solution principle, DFX, alternative conceptions, application of QFD. Application of FMEA, CAE, integration supply chain and specification of the production process and assembly, use of CAPP and PDM.	There are performance indicators of all activities.	Control of all activities with a base in the indicators and actions are integrated into the processes of the changes management and incremental improvement.	Transformation cycle of the PD process integrated into the cycle of incremental improvement, the change management and the project planning.
		Organization's maturity	RIM and RAM	No PM processes or practices are consistently available. No PM data are consistently collected or analyzed. Functionally isolated. Lack of senior management support. Project success depends on individual efforts.	Individual project planning. Informal PM processes are defined. Informal PM problems are identified. Informal PM data are collected. Organizations possess strengths in doing similar work.	Systematic and structured project planning and control for individual projects. Informal training of PM skills and practices.	Strong teamwork. Formal PM training for project team. Planning and controlling multiple projects in a professional matter. Integrated PM processes. Data are quantitatively analyzed, measured and stored.	Project-driven organization. Dynamic, energetic, and fluid organization. Continuous improvement of PM.
C3	Risk management maturity	Organization's maturity	RIM and RAM	Level 1 Low maturity team without expertise or experience in project management.	Level 2 whether no expertise and experienced team with project risk management.	Level 3 Mature and experimented team with expertise and experience on project risk management.	Level 4 Very mature team, with adaptability and resilience to unknown situations.	Level 5 Very mature team, with adaptability and resilience to unknown situations.
C4	Product innovation level	Organization's maturity	RIM and RAM	Alternative	Adaptive	Innovative		
C5	Simplicity of use	Decision-makers' preferences	RIM and RAM	The method is not easy to understand, even for specialists of risk management, and takes a long time to be appropriated, especially for users (non specialists).	The method requires some time and explanations to be understood and appropriated, but remains easy to use.		The method is easy and fast to understand. No pre-requisite. The appropriation time is low.	
C6	Interactions consideration	Decision-makers'	RIM and RAM	Risks are considered and managed independently	Risks are interrelated with simple cause-effect links or trees		Risks are interrelated with complex cause-effect links, including reciprocal links and	

		preferences				loops
#	Criterion	Family	Type of PRM method	Level 1	Level 2	Level 3
C7	Completeness	Decision-makers' preferences	RIM	The method enables the identification of some specific risks and does not cover the whole areas of project risks.	The method intends to cover the different areas, but without a certainty about the completeness (in the defined scope).	The method enables the obtainment of a decent completeness, in the considered scope.
C8	Number of characteristics	Decision-makers' preferences	RIM	Only basic information, like name, nature, probability (or likelihood) and impact (or gravity) are managed.	Some intermediary concepts are manipulated, like direct causes and effects, mode of failure.	Some advanced concepts are manipulated, like detectability, vulnerability or level of influence.
C9	Types of data	Decision-makers' preferences	RAM	Manipulation on qualitative and subjective data only.	Manipulation on both qualitative and quantitative data. Qualitative data can even be fuzzy. Even qualitative data may be based on experience.	Manipulation on quantitative and reliable data issued from previous experience, potentially with statistical analysis.
C10	Graphical display	Decision-makers' preferences	RAM	No graphs, only lists or tables	Basic graphs, like Farmer diagram, Kiviati diagram or color tables (for criticality areas for instance)	Advanced graphs, like cause-effect trees or networks, with or without logical gates and with or without loops.
C11	Specificity	Decision-makers' preferences	RAM	The method is valid only in the context where it has been created.	The method is valid only in some contexts, like a type of project or an industrial sector.	The method is quite generic and applicable to every project.
C12	Notoriety	Decision-makers' preferences	RAM	The method is unknown, except where it is used and where it has been developed.	The method is known by some specialists, experts and companies.	The method is well-known by almost every person involved in project risk management.

Table 3a: list of Risk Identification Methods (RIM)

Code	Complete Name	Description	Analog.	Heur.	Analyt.	C5	C6	C7	C8
RIM1	Preliminary Risk (or Hazard) Analysis (PRA or PHA)	Identifies the potential dangerous elements, dangerous situations and hazards. Then, identifies and evaluates situations which could become dangers (with probability) and their consequences (with gravity).	1	1	1	1	2	3	2
RIM2	Strengths, Weaknesses, Opportunities & Threats (SWOT)	Strategic planning tool based on information gathering and structuring, mainly used in early phases.	1	1	0	2	1	2	1
RIM3	Scenario analysis	Process of analyzing possible future events by considering alternative possible outcomes (scenarios).	1	1	1	2	2	2	2
RIM4	Who What When Where How Why	Information structuring tool used to gather information and risks on a project	0	0	1	3	1	1	1
RIM5	Probabilistic Risk Analysis (PRA)	Systematic and comprehensive method combining ESD, MLD, FTA, etc.	0	0	1	2	2	3	3
RIM6	Failure Mode, Effects (and Criticality) Analysis (FMEA or FMECA)	Consists of a qualitative analysis of dysfunctions modes followed by a quantitative analysis of their effects, with probability and gravity.	0	0	1	2	2	3	3
RIM7	Project Information Failure Analysis (PIFA)	Uses FMECA applied to the project modeled as an information process (information input, treatment and transmission).	0	0	1	2	1	3	3
RIM8	Risk Breakdown Structure (RBS)	The RBS is a "a hierarchically organized depiction of the identified project risks arranged by risk category"	0	0	1	3	1	3	1
RIM9	Design Review Based on Failure Mode (DRBFM)	An improvement of the FMEA which focuses on best practices to be used when modifications are done to an existing product	1	0	1	2	1	3	3
RIM10	Function-Failure Design Method (FFDM)	Mathematical mapping linking a product's functional model to potential failures known a priori.	0	0	1	1	2	2	2
RIM11	Reliability Block Diagrams (RBD)	Block diagrams (like fault trees) provide a graphical means of evaluating the relationships between different parts of the system. Incorporate predictions taken from historical data.	1	0	1	1	3	2	2
RIM12	Master Logic Block Diagram (MLD)	A hierarchical model which identifies the links from system top objectives to functions and components	0	0	1	1	3	3	3
RIM13	Anticipatory Failure Determination (AFD)	Based on TRIZ starts from the observed failure (as in FTA) and tries to correct the solution by changing the point of view	0	0	1	1	2	3	3
RIM14	Technical Risk Assessment Methodology (TRAM)	Dedicated to complex technical systems such as aircraft or computer, based on product decomposition	0	0	1	1	2	3	3
RIM15	Functional Failure Identification and Propagation (FFIP)	Estimates potential faults and their propagation under critical event scenarios using behavioral simulation	0	0	1	1	3	3	3
RIM16	Hazard Operability	Identifies the consequences of variance in components parameters. Variances	0	0	1	1	2	2	1

(HAZOP)		are expressed by No, More, Less, Before, After.				C5	C6	C7	C8
Code	Complete Name	Description	Analog.	Heur.	Analyt.				
RIM17	Root causes analysis	Root cause analysis (RCA) is predicated on the belief that problems are best solved by attempting to correct or eliminate root causes, as opposed to merely addressing the immediately obvious symptoms.	0	0	1	3	2	2	1
RIM18	Fault Tree Analysis (Failure tree or Dysfunction tree) or Cause Tree	Determines the conditions which conduct to an event (deductive reasoning). Uses logical connectors' combination. The cause tree is similar to the failure tree, except that it analyses the event a posteriori.	0	0	1	2	2	2	1
RIM19	Event Tree Analysis (ETA)	Establishes the consequences of an event, which allows for linking this event with another one.	0	0	1	2	2	2	1
RIM20	Ishikawa, fish bone diagram	Causal analysis using heuristic technique, sometimes based on categories (e.g. 5M)	0	1	1	3	2	3	1
RIM21	Event Sequence Diagrams (ESD)	Kind of ETA / Ishikawa allowing mapping loops between events	0	0	1	1	3	3	3
RIM22	Defect Detection and Prevention Process (DDP)	The application of the DDP process involves four steps: 1) Develop the Requirements Matrix, 2) Develop the Effectiveness Matrix, 3) Optimize the Residual Risk and 4) Iterate with the Project Life Cycle.	0	0	1	1	2	3	3
RIM23	Affinity diagram (KJ)	The affinity diagram (or KJ for Kawakita Jiro) consists in recording each idea, then looking for relations between ideas and finally sorting them into prioritized groups.	0	1	0	1	2	3	3
RIM24	Peer interviews	Contrary to expert judgment, interviewees are not necessary experts of the field. They may be users, or decision-makers, or experts in the project area.	0	1	0	3	1	2	2
RIM25	Expert judgment, Delphi method	Semi-structured interview based on questionnaires and allowing mixing individual and group judgment.	0	1	0	2	2	3	3
RIM26	Risk Diagnosing Methodology (RDM)	Risk identification and management in innovative projects based on semi-structured interviews and questionnaires	0	1	0	2	1	2	1
RIM27	Brainstorming	Organized creativity based on a initial question	0	1	0	3	2	2	2
RIM28	Diagramming techniques	A diagram is a two-dimensional geometric symbolic representation of information according to some visualization technique. In project risk management, the symbolic is often related to cause-effect relationship.	1	1	1	1	3	3	1
RIM29	Check-lists	List of risk presented in categories. Some time associated with causes, effects and criticality.	1	0	0	3	2	3	2
RIM30	Pareto analysis	Pareto analysis is a statistical technique in decision making that is used for selection of a limited number of tasks that produce significant overall effect. It uses the Pareto principle: a large majority of problems (80%) are produced by a few key causes (20%).	1	0	0	3	1	2	1
RIM31	Data analysis	Data analysis is a process of gathering, modeling, and transforming data with the goal of highlighting useful information, suggesting conclusions, and supporting decision making: Examples are correlation method, variance analysis or data mining.	1	0	0	1	1	3	3
RIM32	Risk Analytical Structure (RAS)	List of categories and subcategories in which the risks can appear in a typical project	1	0	0	3	1	3	1

Table 3b: list of Risk Analysis Methods (RAM)

Code	Complete Name	Description	Analog	Heuris	Analyt	C5	C6	C9	C10	C11	C12
RAM1	Failure Mode, Effects (and Criticality) Analysis (FMEA or FMECA)	Consists of assessment of dysfunctions modes, effects and their criticality (probability and gravity).	0	0	1	3	2	1	1	3	3
RAM2	Preliminary Risk Analysis (or Hazard)	Assesses potential dangerous elements, dangerous situations, hazards and then dangers (with probability) and their consequences (with gravity).	1	0	1	2	2	1	1	3	3
RAM3	Fault Tree Analysis (Failure tree or Dysfunction tree) or Cause Tree	Evaluates the conditions and their probability which lead to an event.	1	1	1	2	2	3	3	3	3
RAM4	Information System Risk Analysis and Management Methodology (ISRAMM)	Focused on risks linked with information and information systems in the project.	0	0	1	3	1	1	1	1	2
RAM5	Event tree	Evaluates the consequences of an event.	0	0	1	3	2	3	3	3	3
RAM6	Hazard Operability (HAZOP)	Identifies the consequences of variance in components parameters. Variances are expressed by No, More, Less, Before, After.	0	0	1	2	2	2	1	2	2
RAM7	Bow tie or Cause-Consequence Diagram	Consists of focusing on a single risk and analyzing both its causes and its consequences.	1	1	1	2	2	3	3	2	3
RAM8	Markov chain state graph	Identification of the whole possible states of the project system, including normal and altered states. Focused on transitions from a state to another, and consequences for the rest of the project.	1	0	0	1	3	3	2	2	2
RAM9	Monte-Carlo simulation	Includes different durations (or costs) for each task and simulates the possible scenarii. Delivers a probability distribution (cumulative or not) for project global duration (or cost).	1	1	0	2	2	3	3	2	2
RAM10	Analysis of Dysfunctions of Information in a Project (ADIP)	Method focused on information aspect of project. Based on a PRA followed by a Project FMECA limited to information risks.	0	0	1	1	2	1	1	1	1
RAM11	Contingency Assessment	Method based on return of experience which consists of using previous project data in order to assess current project risks. Consequence is assessment of mandatory contingency reserves.	1	0	0	1	1	1	1	1	1
RAM12	Bayesian Network	BN or BBN (Bayesian belief network) is a probabilistic model that represents a set of random variables and their conditional dependences via a directed acyclic graph.	1	1	0	1	2	3	3	2	3
RAM13	Scoring Methodology	Evaluates risk exposure of product development projects, through assessment of market attractiveness, product competitiveness, technological feasibility and development costs.	0	1	0	2	1	3	3	1	1

Code	Complete Name	Description	Analog	Heuris	Analyt	C5	C6	C9	C10	C11	C12
RAM14	Hazard analysis Critical Control Points (HACCP)	Identifies Critical Control Points in the production phase. Hazards are identified and assessed at each phase of the process.	0	1	0	1	1	3	1	2	2
RAM15	System Dysfunctions Analysis Methodology (SDAM)	Analyses dangers and chain relations between these dangers. Consists of a probabilistic approach which enables to identify a danger's occurrence probability, and of a deterministic approach which enables to assess the effectiveness of the barriers if danger occurs.	0	1	0	1	2	3	2	1	3
RAM16	Analysis of Program Risk (APR)	Identifies and analyses cause-consequence couples, where causes are project activities which may cause risks and consequences are categorized (delay, cost, technical, juridical, ...)	0	1	0	3	2	1	1	1	3
RAM17	Analysis of Dysfunctions and Risks in Operations (ADR)	Risk categorization method among two aspects: effect gravity and residual effect	0	0	1	2	1	1	2	1	2
RAM18	Estimation Risk Analysis (ERA)	Cost probability distribution calculation. Based on Monte-Carlo analysis. Takes into account uncertainty in cost variance and dependence between costs. Uses triangle distribution.	1	0	0	1	2	3	2	1	2
RAM19	Design Risk Analysis (DRA)	Analysis of product normal use and altered use for risk identification. Focused on product risks, but allows to generate associated project risks (delays, cost overruns, technical non-acceptance)	1	1	1	2	2	1	1	1	2

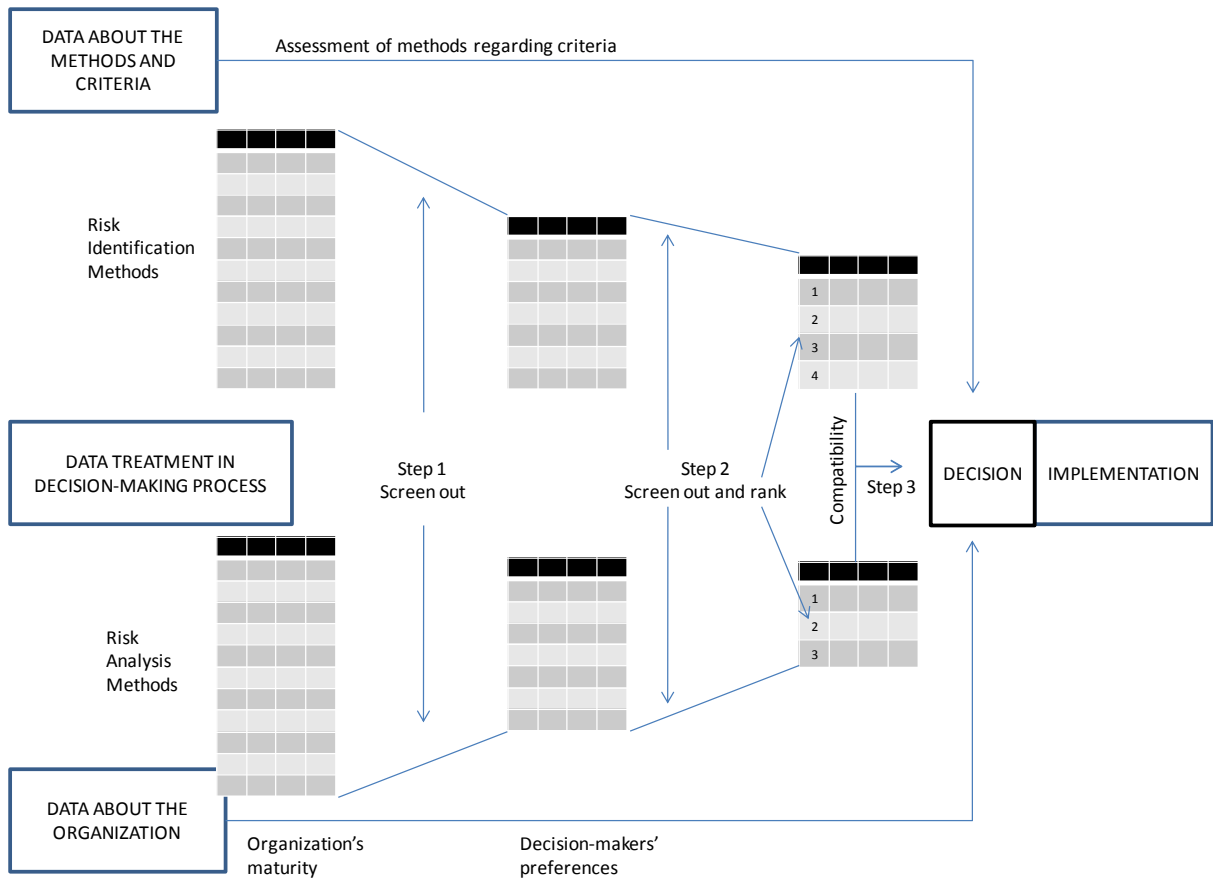


Figure 1: description of the decision-making process by screening and ranking

Table 4: adequacy of each type of PRM method to the organization's maturity

Organizational Maturity (OMC _i)	Criteria	Scale	Alternative Types (T _k)			Organization's Maturity evaluation (OM _j)	Score S(T _{jk}) = 1 iff OM _j ≥ MT _{jk}		
			Analogic	Heuristic	Analytic		Analogic	Heuristic	Analytic
			Minimum Maturity Threshold (MT _{jk})						
Product maturity	design	[1,5]	3	1	3	4	1	1	1
Project maturity	management	[1,5]	3	1	3	4	1	1	1
Product level	innovation	[1,3]	1	2	3	2	1	1	0
Team maturity (in risk management)		[1,3]	1	2	3	2	1	1	0
						S(T _k) = min S(T _{jk})	1	1	0

Table 5: synthesis of preferences of the decision-maker on method-related criteria

Criteria for RIM	Scale	DM's preferences		Criteria for RAM	Scale	DM's preferences	
		Minimum threshold	Fuzzy Weight			Minimum threshold	Fuzzy Weight
Simplicity of use	[1,3]	2	VH	Simplicity of use	[1,3]	2	VH
Interactions consideration	[1,3]	2	A	Interactions consideration	[1,3]	2	A
Completeness	[1,3]	1	VL	Types of data	[1,3]	2	VL
Number of risk characteristics	[1,3]	2	VL	Graphical display	[1,3]	2	H
				Specificity	[1,3]	2	VL
				Notoriety	[1,3]	2	A

Table 6 : synthesis of the results in terms of scores and rankings

Rank	Code	Name	Score	Rank	Code	Name	Score
1	RIM 29	Check-lists	8.13	1	RAM 3	Fault tree (Failure tree or Dysfunction tree) or Cause Tree	12.8
2	RIM 27	Brainstorming	7.61	2	RAM 12	Bayesian Network	9.57
3	RIM 20	Ishikawa, fish bone diagram	7.23	3	RAM 7	Bow tie or Cause-Consequence Diagram	9.21
4	RIM 25	Expert judgement, Delphi method	7.08	4	RAM 9	Monte-Carlo simulation	8.68
5	RIM 3	Scenario analysis	6.02	5	RAM 8	Markov chain state graph	8.33
				6	RAM 15	System Dysfunctions Analysis Methodology	6.48
				7	RAM 18	Estimation Risk Analysis	5.95