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INTERACTIONS-BASED CLUSTERING TO ASSIST PROJECT RISK MANAGEMENT

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ABSTRACT

Projects are dealing with bigger stakes and facing an ever-growing complexity. Project risks have then increased in number and criticality. Lists of identified project risks thus need to be decomposed, for smaller clusters are more manageable. Existing techniques are mainly mono-criteria, based on a parameter such as nature or criticality. Limits have appeared since project risk interactions are not properly considered. Project interdependent risks are indeed often managed as if they were independent. We thus propose an interactions-based clustering method with associated tools and algorithms. Our objective is to group risks, so that the interaction rate is maximal inside clusters and minimal outside. The final objective is to facilitate the coordination of complex projects by reducing interfaces when dealing with risks. We first model project risk interactions through matrix representation. A linear programming algorithm, two approximate iterative ones and possible refinement are then presented. A case study in the entertainment industry is finally presented, providing us information and points of comparison for global recommendations, conclusions and perspectives.

Keywords: Project management, Risk, Complexity, Interactions, Clustering.

1 INTRODUCTION

A project is a temporary and unique endeavor undertaken to deliver a result, which generally corresponds to the creation of a unique product or service which brings about beneficial change or added value [1]. A new organization within the firm is then needed to perform a project: new processes which must answer project finalities and objectives in terms of values creation must be set up. These new processes are performed thanks to resources (notably project actors) which belong to the created project organizational system.

A project is in essence unique, which means that the project organizational system is to be conceived for each project within a firm (as it is specific to a project). Project organizations are thus in essence temporary organizations. They coexist with permanent organizations which exist within the firm. This coexistence (involving interfaces and dependencies) makes project and project management all the more complex. Moreover, the conception of the project organizational system follows the steps of project phases' identification and analysis, planning and monitoring. As a consequence when thinking at projects in terms of systems following several phases, many dependencies and interdependencies between phases, sub-systems and other entities can be identified

Project systems are indeed in essence complex, be it only through the fact they are performed by project actors, i.e. people [2]. Focusing on the management aspect, it must be kept in mind that management is indeed composed of decisions and activities made by people, those decisions being made at a given instant to reach an objective in the future. Once made, a decision changes the states of the elements it impacts and thus the state of the project itself, targeting a final state for the project (composed of the objectives of the project). The difference between the targeted state and the reached state basically accounts for the project performance. Moreover, every management decision is relative to a context which is the known present situation (resulting from the past decisions). Finally, decisions at a time T help to reach the future objective, which is more or less correctly defined and more or less stable. This overall decisions chaining determines the trajectories of the evolution of the project system. This intrinsic complexity of project management makes it impossible to visualize and manage projects as a whole, notably because of the existence of project complexity induced risks.

In order to illustrate this issue of complexity driven risks, let us consider an example, the case of a project within the field of automotive industry. A change in the design of the windscreen (in terms of inclination of this windscreen) implied changes at the connection with the front structure of the car. This was due to the interdependence of the final product components and it provoked in the end several changes which were localized at an interface. But this change also implied rework and a global increase of the duration and cost of some tasks (change of various parameters). This means that the first change had spread throughout the entire system, making it impossible to foresee its evolution properly.

As a whole, project management appears to be a complex and risky activity, which underlines the need for efficient and effective project risk management. As a consequence, this paper proposes an innovative method and its associated tools to assist project risk management under complex contexts by focusing on project risk interdependencies. Our goal is to group risks into clusters in order to catch inside of them most of project interactions, which is notably to facilitate the coordination of the project risk management process.

2 TRADITIONAL PROJECT RISK MANAGEMENT METHODOLOGIES

2.1 Classifying project risks by nature and/or by value

Project risk management is classically decomposed into four successive major steps: risk identification, risk analysis, risk response planning and risk monitoring [1].

Risk identification is the process of determining events which, may they occur, could impact positively or negatively project objectives. Risk identification methods are classified according two different families: direct or indirect risk identification [3]. The number of risks in the generated list may vary from some decades to some hundreds of risks. It is then mandatory to decompose it into subgroups in order to have more manageable items. This list is a priori (included in the methodology) or a posteriori classified according to the nature of the risks (financial, human, technical, schedule, etc…). This process is called clustering by nature.

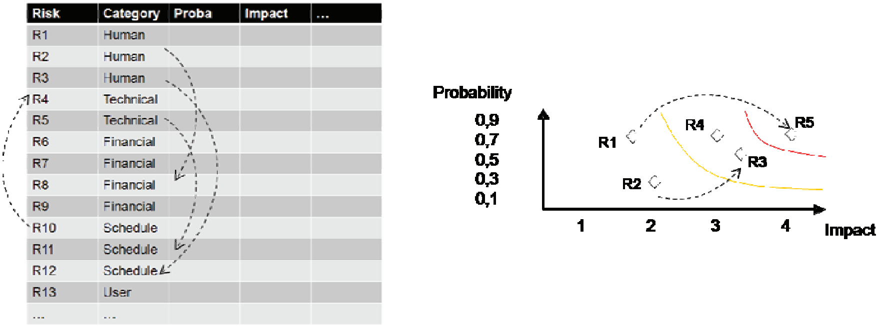
During risk analysis, risks are prioritized, essentially according to their probability and impact. Risk evaluation scales are often defined in terms of criticality, which is generally a function of probability and impact. The main output of risk analysis is a list or graph, which enables decision-makers to categorize risks as high, medium or low in terms of criticality. This is another kind of clustering, called by value (criticality value).

Next steps are risk response planning and monitoring. We argue that these steps should be performed after an innovative project risk analysis based on risk interactions since current methods have shown their limits.

2.2 Limits of traditional approaches

Indeed, the initial goal of clustering processes is to facilitate the coordination and management of risks. Fieldwork proves us this is not always the case with existing methods. Namely, project complexity, described notably in [4], [5], [6] involves issues in decision-making under complex situations [7], [8]. The complexity of a project makes it impossible to visualize simultaneously the complete project (global vision) and all the interactions in the project [9]. This can notably be underlined when looking at projects through systems thinking [10], [11]. Referring to complementary works [12], [13], many factors related to project interdependencies have been identified as drivers of project complexity, and thus of risks. But, there are still some phenomena which are not taken into account by classical project risk management methodologies, such as loops or non-linear couplings.

Actually, whatever the criteria 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. The problem with current methodologies is that project risk interactions are not clearly included, e.g. in Figure 1, where some links are existing, though not managed (dotted lines). Risks are indeed interrelated with complex links. A previous study we had conducted about 23 risk analysis methodologies enabled to identify complexity-related issues. 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.



Risk	Category	Proba	Impact	...
R1	Human			
R2	Human			
R3	Human			
R4	Technical			
R5	Technical			
R6	Financial			
R7	Financial			
R8	Financial			
R9	Financial			
R10	Schedule			
R11	Schedule			
R12	Schedule			
R13	User			
...	...			

Figure 1. Classification of projects risks by nature and/or by value

Project management current techniques include classical principles underpinning scientific management: the fragmentation of work and the maximization of visibility and accountability. We can argue that today projects are generally managed with single-link trees (WBS, pert, OBS, risk lists) and not as networks [14]. In the case of risk management, most of the methods use lists, screening or sorting risks, as seen before. Traditional methodologies are mainly single-risk oriented, analyzing their multiple causes and multiple consequences.

However, some works have been done to model interdependencies between risks. Bayesian networks for instance link several risks, from multiple inputs to multiple outputs, but they have specific validity conditions: links must be oriented, and there must not be any loop. That means that in some cases, they fail to reflect the real complexity of relationships between project risks.

There is thus crucial need for better awareness, consideration and management of project risks, knowing they are intertwined. We propose in this article such a methodology. Our ambition is not to give “exact” results: we want to assist day-do-day project risk management thanks to our method. This one is notably not based on the mathematics of probabilities. It can thus take into account easily the existence of loops and non-linear couplings for instance.

2.3 Overall problem setting and methodology

As shown by the former paragraphs, risks are managed thanks to the elaboration of smaller clusters. At this stage, a management issue arises, since decisions may be blocked, slowed down or ineffective if interactions are poorly taken into account. Our research problematic is thus to propose a new additional clustering methodology, which could take into account interactions between risks, in terms of existence and strength. First, we identify possible risk interactions. The whole is synthesized thanks to binary matrix representation. The matrix is then transformed to be a numerical one thanks to the use of the AHP principles. These numerical data permit us to develop a linear programming and two approximate iterative algorithms. We then express how these results can still be refined thanks to the introduction of a distance measure and similarity identification process. All the obtained results are then compared to classical decompositions, notably thanks to a case study in the entertainment industry. We then propose some conclusions and call for future perspectives of research around this issue, after studying the implications of our works on day-to-day management.

3 CATCHING PROJECT RISKS INTERACTIONS THROUGH MATRIX REPRESENTATION

3.1 Building up the Risk Structure Matrix (RSM)

The Design Structure Matrix (DSM) represents relations and dependencies among objects. The same objects are both in the rows and columns of the square matrix, which is square. The DSM was introduced by Steward [15] with tasks and was initially used basically for planning issues [16]. Since, it has been widely used with other objects, like product components, projects or people [17], [18], [19], [20]. As for us, we propose to use the concept of DSM for other conceptual objects, which are risks, in the context of project management. As tasks, projects and people, project risks are (or can at least be supposed as):

- in a finite number (since a project is in essence temporary, with finite resources, objectives, means, etc., i.e. a finite number of elements),
- managed during the project management process,
- interrelated, (notably because of project and project management complexity factors [21]) which justifies the use of a methodology for complex interactions management.

The reader may note that we define risk interaction in terms of the existence of a possible precedence relationship between two risks R_i and R_j. We then define the binary Risk Structure Matrix (RSM). It corresponds to the square matrix with $RSM_{ij}=1$ (else 0) when there is an interaction from R_j.to R_i. The main advantage of this approach is to overcome the display issue of complex network and to permit easier calculations which are inherent to the matrix format (eigenvalues, matrices product, matrix transposition, etc…).

In order to build the RSM, we have to identify the interactions which exist between project risks. The iterative procedure we use is notably addressed in ongoing publications. Classically, the DSM is re-ordered in a way which permits to show first-level blocks, thanks to the well-established partitioning process [16]. This one applied to the RSM gives three types of information:

- the dependent risks: they are engaged in a potential precedence relationship,
- the interdependent risks: they are engaged in mutually dependent relation, directly or with a bigger loop,
- the independent risks: the risks are basically non-related.

The aim of this process is basically to obtain a lower block-triangular matrix. Partitioning enables to isolate interdependent risks, but our purpose is different. We aim at grouping risks in clusters with maximal internal interactions and minimal inter-clusters interactions.

In order to do so, we firstly use an AHP-based evaluation to transform the RSM into a numerical matrix which is to catch the strength of local interactions. Indeed, fieldwork proves us that such assessment of interactions is hard to do directly. On the contrary, it can be observed that people find it easier to say that a cause C_1 is more likely to produce an effect E (first level neighbor) than another cause C_2, or similarly, that an effect E_1 is more likely to be the consequence of a cause C than another effect E_2. That is why we claim for the use of the AHP-based principle of pairwise comparisons (Analytic Hierarchy Process [22], [23]) to assess project risk interactions (as we define them in this article).

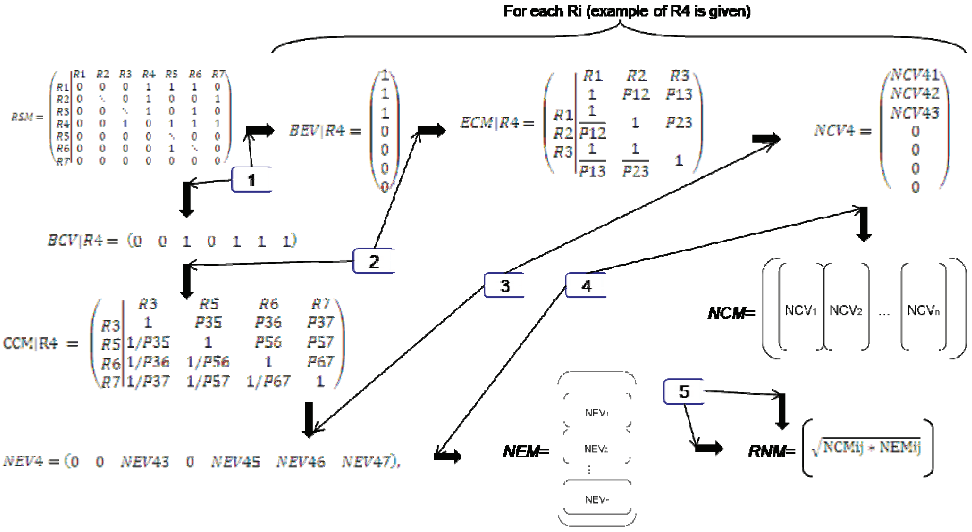


Figure 2. How to build the Risk Numerical Matrix (RNM)

3.2 Methodology

In this study, we do not use the complete process of the AHP but only some of its principles and techniques to fulfil our needs. Several steps are necessary to carry out our research (see Figure 2):

- Step 1: For each R_i, isolating (from the RSM) the risks which are related with R_i in column (possible effects of R_i) and in row (possible causes of R_i). They are called the Binary Cause or Effect Vectors and are relative to one risk R_i ($BCV|R_i$ and $BEV|R_i$). An example is given for risk R4.
- Step 2: Establishing pairwise comparison matrices regarding the risk R_i based on the two previously isolated sets of risks (in rows and in columns), which are to be the set of alternatives on which the calculations are done. They are called Cause or Effect Comparison Matrices and are also relative to one risk R_i ($CCM|R_i$ and $ECM|R_i$).
- Step 3: Consolidating the results thanks to a proper consistency index and finding the eigenvectors of the previously built pairwise comparison matrices: the Numerical Cause or Effect Vectors and are relative to one risk R_i.(NCV_i and NEV_i).
- Step 4: Aggregating the results obtained for each risk Ri into global Numerical Cause or Effect Matrices (NCM and NEM).
- Step 5: Compiling the Numerical Matrices into a Risk Numerical Matrix (RNM), the values of which assess the relative strength of local interactions.

The presence of a 1 in the binary RSM expresses the existence of a possible precedence relationship between risks R_i and R_j. $RSM_{ij}=1$ implies two possible ways to address the situation: this can be seen either as a possible risk input of R_i coming from R_j, either as a possible risk output from R_j reaching R_i. Similarly as in [24] for design tasks, we combine these visions.

Two stages must thus be performed. The first one consists in the ranking in rows for each project risk. Given the risk R_k, the set of alternatives are all the non-zero elements of risks other than the diagonal element in row k. The criterion on which the alternatives are evaluated is the contribution to R_k in terms of risk input: in other terms, for every pair of risks which are compared, R_i and R_j (thus following $RSM_{ki}=RSM_{kj}=1$), the user should assess which one is more important to risk Rk in terms of probability to be a risk input (i.e., a cause) for risk R_k. Numerical values express these assessments thanks to the use of the traditional AHP scales. Eigenvectors of each matrix $ECM|R_k$ and $CCM|R_k$ are now to be calculated. By combining the n eigenvectors NEV_k and NCV_k, we obtain two square matrices called NEM and NCM.The i-th row of NEM corresponds to the eigenvector of $CCM|R_i$, which is associated to its maximum eigenvalue. The j-th column of NCM corresponds to the eigenvector of $ECM|R_j$, which is associated to its maximum eigenvalue.

Let us now define the RNM by the geometrical weighting operation given by equation 1.

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

$$\forall (i,j), 0 \le RNM(i,j) \le 1$$

The RNM thus permits to synthesize the existence and strength of local interactions between risks inside a project (we insist here on the fact that in this article, we consider risk interaction as a possible precedence relationship).

4 PROPOSED CLUSTERING ALGORITHMS AND REFINEMENTS

4.1 Overall problem definition

We want to cluster risks in order to maximize intra-cluster interactions thanks to the use of the RNM. We do insist on the fact that the values of the RNM are local judgements, which implies that risk interactions assessments are in essence relative. However, we do argue that this first clustering is useful, since it permits to focus on the most significant local risk interactions.

Let us consider a set of project risks (R_1, R_2, …,R_N). This set of risks is in essence a complex one, since interactions do exist between risks. Let us suppose we know the RNM of this set of risks (the former steps to build the RNM should have been followed by the user). Let K be the number of clusters of the optimal clustering solution, which maximises intra-cluster global interactions value. INTRA value is defined by the sum of the values of all interactions between risks which belong to a same cluster. INTER (Inter-cluster global interactions) value is defined by the sum of the values of all interactions between risks which are not paired inside a same cluster. The sum of INTRA and INTER values corresponds to the sum of all risk interactions values, which is constant. As a consequence, maximizing INTRA is equivalent to minimizing INTER. The reader should note that we do not know K in advance. However, we know some constraints about it. Namely, the goal is to assign project members to clusters in order to manage more properly the risks which belong to a same cluster, i.e. which are strongly interdependent. It is known that people have a limited capacity to manage simultaneously numerous objects. We follow the hypothesis that in the end, the maximum size of a cluster should be 9. We choose to leave some margin compared to the classical empirical rule of 7 objects to be managed simultaneously. This permits us to know a lower bound of K, which is $K_{\min} = INT(\frac{N-1}{9}) + 1$, where INT is the integer part of a real number.

4.2 Developing a linear programming algorithm to answer this problem

Here is the corresponding integer programming problem formulation. This problem is to be solved for each value of K which is superior to $K_{\min}$. We first introduce the following decision variables: $\forall i, 1 \le i \le N, \forall k, 1 \le k \le K, x_{ik} = 1$ if risk R_i belongs to cluster C_k.

The objective function, which is to be maximized, is as following in equation 2

$$INTRA = \sum_{k=1}^{K} \sum_{i=1}^{N} \sum_{j=1}^{N} x_{ik} x_{jk} RNM(i,j) \tag{2}$$

Problem constraints are the following (equations 3 and 4).

$$\forall i, 1 \le i \le N, \sum_{k=1}^{K} x_{ik} = 1 \tag{3}$$

as we argue for clusters disjunction in order to permit easier management in practice.

$$\forall k, 1 \le k \le K, \sum_{i=1}^{N} x_{ik} \le 9 \tag{4}$$

since we want the maximum size of clusters to be 9 risks.

This problem is not linear but we can make it easily linear thanks to the introduction of new decision variables (equation 5) and new constraints (equation 6).

$$\forall i, 1 \le i \le N, \forall j, 1 \le i \le N, \forall k, 1 \le k \le K, y_{ijk} \text{ is a binary variable} \tag{5}$$

We define y_{ijk} by adding the constraints:

$$\forall i, 1 \le i \le N, \forall j, 1 \le i \le N, \forall k, 1 \le k \le K, y_{ijk} \le x_{ik} + x_{jk} - 1 \tag{6}$$

This equation forces y_{ijk} to be equal to 0 if x_{ik} and x_{jk} are not both equal to 1, i.e. if R_i and R_j do not belong to the same cluster. All other constraints are kept for problem formulation. The objective function can then be re-written thanks to these new decision variables, in equation 7.

$$INTRA = \sum_{k=1}^{K} \sum_{i=1}^{N} \sum_{j=1}^{N} y_{ijk} RNM(i,j) \tag{7}$$

We use OPL (Optimization Programming Language) to solve this problem. However, its complexity is high (2^{N-1}), and problems over 20-21 risks appear to be critical when testing them. We presently work on developing some heuristics to assist problem solving in the software and reduce processing time by avoiding trivial non-solutions. Meanwhile, we have developed some approximate iterative algorithms, which permit us to approximate the optimal solution of the problem.

4.3 Using approximate iterative algorithm to answer this problem

Both of these approximate algorithms are iterative, but they use two different values for clustering conditions, as described in equations 8 and 9. The first iterative algorithm IA_1 is based on the maximum value between two separate clusters. The second one IA_2 is based on global interactions value between two separate clusters. In the two cases, these values are to be maximized at each step.

$$Value_1(C_\alpha, C_\beta) = \max_{i \in C_\alpha, j \in C_\beta} RNM(i,j) \tag{8}$$

$$Value_2(C_\alpha, C_\beta) = \sum_{i \in C_\alpha, j \in C_\beta} RNM(i,j) + RNM(j,i) \tag{9}$$

At the initial step, all risks are isolated: every initial cluster is a singleton. The maximum value is obtained for two isolated risks R_{i0} and R_{j0}, which are grouped into a first cluster C_1. At each following step, the previous value ($Value_1$ or $Value_2$) is maximized. This procedure is repeated iteratively until reaching a solution which respects all the constraints. In the case the maximum size of a cluster is reached before the end of this procedure, the second maximum value in the RNM is identified and the clustering operation is done on the corresponding interaction.

4.4 Developing performance indicators to compare solutions

In order to compare different possible clustering solutions, we introduce some numerical indicators. Given a problem with N risks, the first two indicators we introduce are:

- MPT = Mean Processing Time, which is the mean time to obtain the solution of the problem.
- $$\nabla INTRA(A,B) = \frac{INTRA(A) - INTRA(B)}{INTRA(A)} \tag{10}$$

where A and B are two solutions and INTRA is the value of the intra-cluster global interactions value.

Given a possible solution thanks to a clustering method, we can build a K × N matrix (M_{ki}), so that $M_{ki}=1$ if risk Ri belongs to cluster C_k in the final solution. If $T(M_{ki})$ is the transpose of this matrix, then:

- $H=(M_{ki}).^T(M_{ki})$ is a K × K matrix, the diagonal terms of which correspond to the number of risks which are clustered in cluster K. MCS = Mean Cluster Size is then the average of the diagonal values of this matrix.
- $L={}^T(M_{ki}).(M_{ki})$ is a N × N matrix, the i-j^th term of which is equal to 1 if R_i and R_j belong to a same cluster. As a consequence, the calculation of $\nabla M(A,B)$ which is the difference of the two matrices L(A) and L(B), obtained thanks to the clustering methods A and B, permits to identify the similarity between two clustering solutions. Let N_0 be the number of non-zero values in the $\nabla M(A,B)$ matrix. We build up the following indicator (Eq. 11) which is a dissimilarity measure when comparing solutions. Note that MCS is taken into account, since, if given a clustering solution, if one risk R_i is taken out of the cluster it belongs to, then MCS non-zero values are likely to appear (mean value) in the dissimilarity matrix for this risk R_i.

$$\nabla(A,B) = \frac{N_0}{N^2 \times (\frac{MCS(A) + MCS(B)}{2})} \tag{11}$$

4.5 Refinement of the obtained solutions

Our goal here is to refine our results by identifying within clusters similar situations in terms of causes and effects, i.e. the less distant risks. Many distances (i.e. similarity functions) can be proposed in order to assess the proximity of two risks. To define them, we build up a symmetrical matrix, the Risk Interaction Matrix (RIM), the i-j^th term of which is given by

$$RIM(i,j) = \frac{RNM(i,j) + RNM(j,i)}{2} \tag{12}$$

At this stage, note that any metric can be used in order to define this distance. Indeed, many have been used [25], [26], etc. As for us, we claim for the use of the Mahalanobis distance [27], which corresponds to a weighted Euclidian distance (the weights being determined by the covariance matrix). We then use a classical average-linkage clustering algorithm [28] to identify similar situations inside clusters. Such identifications of similar risks (in terms of interactions) within the clusters obtained in 4.2 and 4.3 permit to give information to the person in charge of the management of the cluster: indeed, two similar risks may be handled with similar managing techniques and/or even the same preventive/curative actions.

5 CASE STUDY

5.1 Introduction of the case study

In order to test the proposals and results of our theoretical study, we carried out a case study in the entertainment industry: the chosen project is the production of a family stage musical in Paris. The project notably encompasses stage, costume, lightning and sound design, casting management, rehearsal management, fund raising and overall project management support activities, etc…

Staging duration target is 9 months at least. Target audience is family members aged 5 years old and more. Project duration is 6 months before staging. Project team is made of 6 permanent employees. Creative team is made of 7 people (lyricist/librettist, composer, director and choreographer, stage designer, light designer, costume designer, sound engineer).

The show is performed by a cast of 18 people, on the principle of alternating roles (9 on stage simultaneously). Overall budget is around 60000€ without salaries, on a profit-share basis for cast and creatives. Two financial investors and one media partner assist the project. The case study we present here is based on fieldwork and discussions which were conducted with 1 cast member, 2 creatives, and 1 production team member.

5.2 Results of the case study

First step is project risk identification. In that case, 20 overall risks were identified (with their interactions). Note that this reduced list is all the more interesting since this is to perform all the algorithms in order to compare them. For instance, we identified low budget, low team communication, low creative team leadership, lack of production team organisation, etc.

Once identified, project risks can be evaluated in terms of probability and impact, as we mentioned before. Criticality defined as a function of probability and impact, enabled us to have a simple indicator in order to classify project risks by value (and build a classical Farmer diagram).

Then, the identification of project risks interactions permitted us to build the corresponding RSM, the partitioning of which was done. In that case, no advantage is taken from partitioning since we obtain one block of interdependent risks and some risks left alone. Indeed, the partitioning algorithm does not seem to give interesting results (as far as our research objective is concerned) when risks are very intertwined.

We can then build up the RNM and process the three interactions-based presented algorithms. Their results can be seen next page in Figure 3. They only represent two graphs, since the second iterative algorithm (IA2) gave the same result as the linear programming (LP) algorithm. In this figure, they are compared to the two classical clustering results.

The reader can also notably note that these results were refined. Indeed, the risks R11 and R12 were analysed as very similar thanks to the Mahalanobis distance-based clustering method we use. The person in charge of the corresponding cluster should then think of handling these two risks with similar approaches (or at least be aware of the similarity of these risks inside the cluster). Interesting similarities and differences must be noted. As shown afterwards in Figure 4 (synthetic indicators), it must be noted that interactions-based clustering give here much more efficient results in terms of interactions values within clusters, as expressed by the values of $\nabla INTRA$. The linear programming and iterative algorithms we developed give very interesting results and perspectives for project risk management since in all cases, more than 70% of the interactions values are kept inside the obtained risk clusters (nearly 5 times best than by nature, and 2 times best than by values). This appears all the more interesting than each cluster can then be dispatched to one project team member.

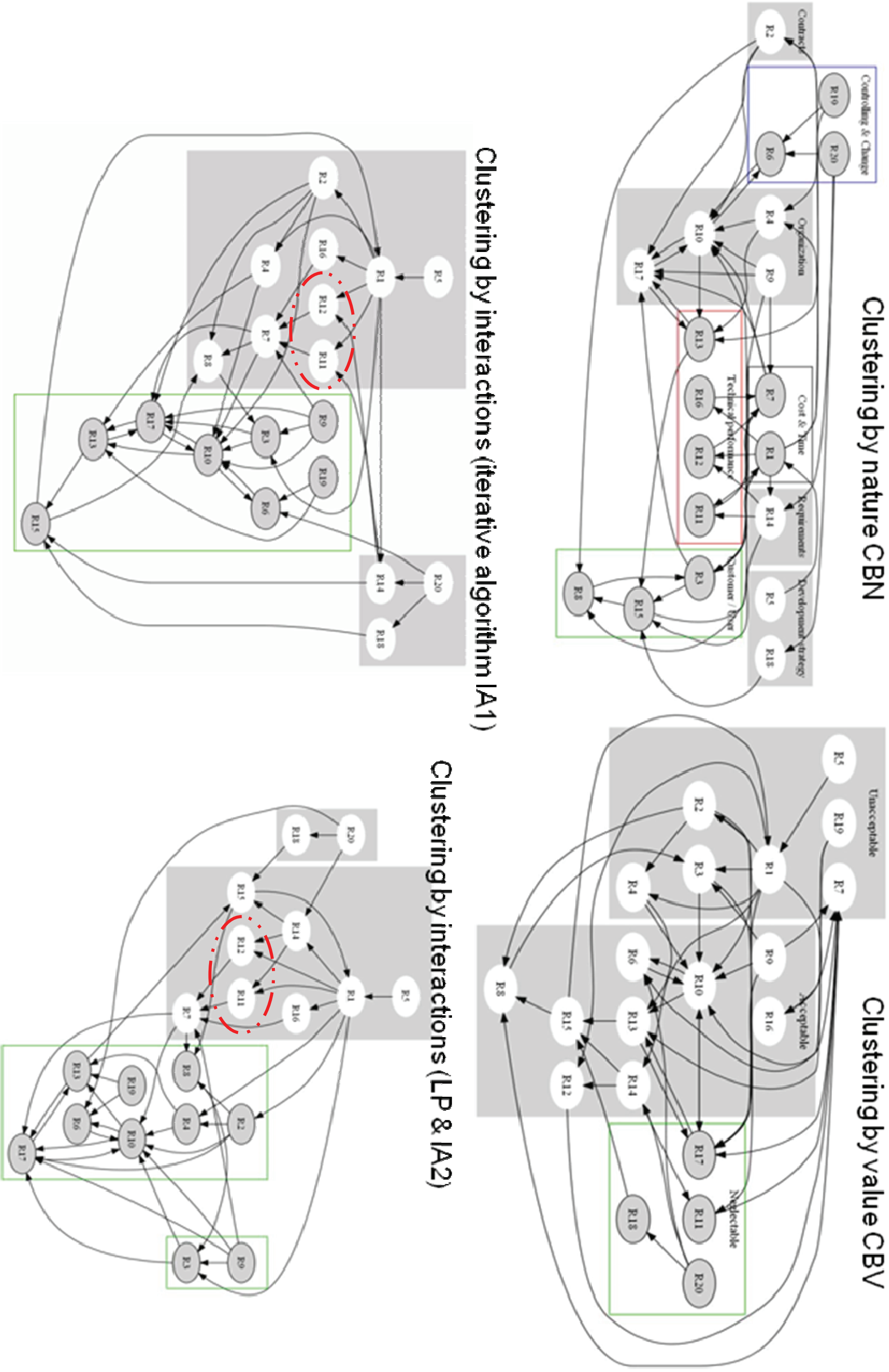
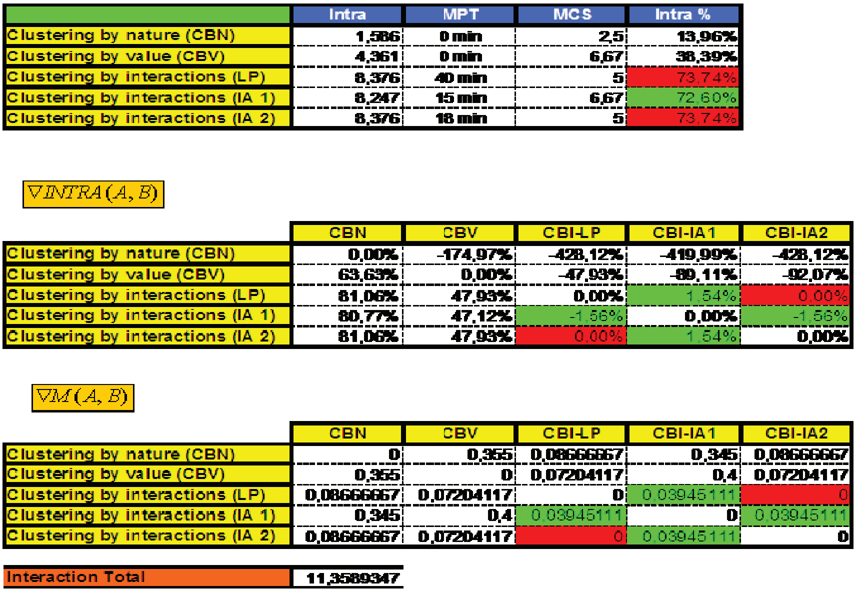


Figure 3. Results of the clustering algorithms

Moreover, in that case, the second iterative algorithm and the linear programming one give us exactly the same result. The reader should note that the first iterative algorithm gives us a slightly different result in terms of risks regrouping and intra-cluster interactions value. As a consequence, the issue of algorithm performance compared to MPT is to be addressed, since results do not differ much, whereas MPT can vary of around 275%. In order to answer it more properly and validate even more this overall approach, new tests are to be carried out on several projects (it is presently being tested with the data of a project of software development for anti-cancer drug anticipated production).



	Intra	MPT	MCS	Intra %
Clustering by nature (CBN)	1,586	0 min	2,5	13,96%
Clustering by value (CBV)	4,361	0 min	6,67	38,39%
Clustering by interactions (LP)	8,376	40 min	5	🟥 73,74%
Clustering by interactions (IA 1)	8,247	15 min	6,67	🟩 72,60%
Clustering by interactions (IA 2)	8,376	18 min	5	🟥 73,74%

$\nabla INTRA(A, B)$

	CBN	CBV	CBI-LP	CBI-IA1	CBI-IA2
Clustering by nature (CBN)	0,00%	-174,97%	-428,12%	-419,99%	-428,12%
Clustering by value (CBV)	63,63%	0,00%	-47,93%	-89,11%	-92,07%
Clustering by interactions (LP)	81,06%	47,93%	0,00%	🟩 1,54%	🟥 0,00%
Clustering by interactions (IA 1)	80,77%	47,12%	🟩 -1,56%	0,00%	🟩 -1,56%
Clustering by interactions (IA 2)	81,06%	47,93%	🟥 0,00%	🟩 1,54%	0,00%

$\nabla M(A, B)$

	CBN	CBV	CBI-LP	CBI-IA1	CBI-IA2
Clustering by nature (CBN)	0	0,355	0,08666667	0,345	0,08666667
Clustering by value (CBV)	0,355	0	0,07204117	0,4	0,07204117
Clustering by interactions (LP)	0,08666667	0,07204117	0	🟩 0,03945111	🟥 0
Clustering by interactions (IA 1)	0,345	0,4	🟩 0,03945111	0	🟩 0,03945111
Clustering by interactions (IA 2)	0,08666667	0,07204117	🟥 0	🟩 0,03945111	0

Interaction Total	11,3589347

Figure 4. Performance of the clustering methods – Case study

6 IMPLICATIONS ON PROJECT MANAGEMENT

Some other works in the literature show that, in the context of decision-making within some specific environments, project managers tend to deny, avoid, ignore and/or delay dealing with risks [29]. For all practical purposes, the gap between expected and real risk management implementation is significant. Our methodology permits greater communication on project risks and better confidence in risk management activities thanks to two aspects.

First, the evaluation of risk interactions which is performed when building up the RNM implies a two-step process (looking in terms of causes, and then of consequences). Information can thus be checked and refined since one interaction should be listed twice (from cause to effect, and from effect to cause): this checking process permits a better confidence in risk identification and risk interaction identification. Even if theory is sometimes difficult to implement in real projects, we argue that the theoretical background of our models can easily be implemented and understood at a reasonable level. The fact that it relies on expert judgements, mainly qualitative, makes it a user-friendly and easily computable tool. The case study indeed proved us that, even in project contexts which are not used to working with tools issued from design engineering and industrial engineering theories, the whole approach is globally understood.

Moreover, clustering risks in order to maximize intra-cluster global interactions value permits to facilitate the coordination of risk monitoring and controlling activities, as it underlines the need for cooperation and transversal communication within the project team. It permits greater communication between people, since it does not seek the identification 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, meaning we have less defensive phenomena.

However, this implies that a shift should be operated in the skills of project risk managers (or at least the team members who are in charge of the management of the obtained clusters). Such project team members should indeed be able to facilitate communication and to show great adaptability since they need to manage risks which are to be of different nature.

7 CONCLUSIONS AND PERSPECTIVES

In this study, we made a comparison between several possibilities for grouping risks in a project. Our aim is not to criticize the use of classical approaches: we refer to them as points of comparison. Our objective was 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 way than by nature or by values. In the end, regrouping risks in clusters which maximize the values of risk interactions inside them appears to be a promising approach to handle project risks. Indeed, such clusters are generally to be 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. Refining the clusters thanks to the Mahalanobis distance permits one to identify similar situation in terms of risk causes (generation) or effects (consequences). In the end, such refined clusters permit to group project risks in terms of interdependence and similarity. As a whole, this means that complexity-related possible effects can be caught more easily and as a consequence managed more effectively and efficiently. Project coordination is undoubtedly facilitated with this approach since interface problems are considerably reduced (for inter-clusters links global value is lowered). This new approach is thus a complementary one to traditional project risk management techniques.

Lots of aspects of this work and its results may however be discussed. We identify several of them hereinafter.

- Consolidating the constitution of the binary interaction matrix.
- Trying to integrate more project dynamics in this (quite static) methodology.
- Evaluating with more reliability the relative weights of risks.
- Exploring the sensitivity of this methodology and the use of fuzzy AHP to reduce the subjectivity of the users' judgements.

Future research works are thus to be carried out in order to explore these aspects and develop future implications for project complexity and risk management.

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